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COMPARISON BIOFILM CHARACTERISTICS ON DIFFERENT TYPES OF CARRIERS FOR WASTEWATER TREATMENT

Larysa Sablii[1]✉, Veronika Zhukova[1], Maryna Kozar[1], Andrii Hrynevych[1], Katarzyna Jaromin-Gleń[2]

[1] *National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", 37, Beresteyskyi Ave., Kyiv, 03056, Ukraine*
[2] *Institute of Agrophysics, Polish Academy of Sciences, 4, Doświadczalna Str., Lublin, 20-290, Poland*
larisasabliy@ukr.net

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Abstract. Enhancing the operational efficiency of wastewater treatment plant can be achieved by increasing the biomass concentration within the reactor volume. For this purpose, the use of immobilized microorganisms on carriers has become progressively prevalent in wastewater biological treatment technologies, aiming to enhance the quality of treated water. The analysis of the characteristics biofilms on spherical, disc-shaped and wheel-shaped on carriers under the same conditions was carried out. All investigated carriers are classified as dispersed, distributed throughout the volume of the air tank. The following characteristics of four biofilm carrier samples were investigated: the concentration of biomass immobilized on the surface of the carrier and the specific biomass per unit area of surface for different types of loading for the treatment of domestic wastewater. It has been determined that the biomass concentration immobilized on the surfaces of four distinct carriers, varying in shape and size, spans from 5425 mg/dm^3 to 138 mg/dm^3. The study showed that the carriers with a diameter of Ø 9.95 mm had the highest biomass concentration immobilized on the surface, and such carrier can be effectively used in MMBR systems for wastewater treatment, as well as to improve the performance of aeration tanks by upgrading them. The choice of biofilm carrier is a critical factor as it influences the optimal thickness of the biofilm, biomass growth, and the efficiency of various natures pollutants biodegradation.

Keywords: biological wastewater treatment, biofilm, carriers, immobilization.

1. Introduction

One of the approaches to intensifying the operation of biological wastewater treatment plants is to increase the concentration of biomass, particularly wastewater treatment microorganisms, in the volume of the plant. For this purpose, the use of immobilized microorganisms on carriers is increase in biological wastewater treatment technologies as a means of enhancing the treatment properties of aeration tanks.

Immobilized microorganisms are those affixed to the surface or encapsulated within a carrier to stabilize their activity. These immobilized systems are utilized in wastewater treatment to improve biological processes, particularly in the treatment of complex or heavily polluted waters. The use of immobilized microorganisms enables a more effective degradation of organic pollutants, biogenic substances etc.

The advantages of applying immobilized microorganisms include:

– Higher efficiency: greater degree of decomposition of complex organic and toxic substances;
– Increasing the biomass of treatment microorganisms in the plant;

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- Reduced biomass growth: as immobilized microorganisms are more stable, their biomass growth is less compared to activated sludge;
- Compactness of treatment plant: reactors with immobilized microorganisms require less space:
- Reduced operational costs: Technologies employying immobilized microorganisms can lower operational expenses due to reduced energy and reagent consumption (Sabliy & Zhukova, 2022; Sabliy et al., 2019; An et al., 2018).

Today, there exists a vast array of carriers including plates, spatial grids, meshes with cells in the shapes of squares, rectangles, circles, ovals, triangles, hexagons, and octagons, bristles, cylindrical, cubic and helical polymer elements, fibers, fabrics made from natural and synthetic materials, granules of zeolites (clinoptilolite, mordenite, chabazite, phillipsite), volcanic slags, polyurethane foam, polymer fibers, threads, woven and non-woven materials from nylon – VIA, polyethylene, lavsan, polypropylene, polyamide fibers, fiberglass, cubes of expanded polyether, and others (Widjaya et al., 2023; Blyashyna et al., 2018; Wang et al., 2005).

When the carrier for immobilization of microorganisms is chosen wisely, taking into account the specific conditions of the microbial transformation of organic substances contained in wastewater, the carrier can actively influence the surrounding environment, stimulate microbial metabolism, protect cells from adverse factors, and promote the long-term preservation of their biochemical activity.

The choice of biofilm carrier is a critical factor, as the carrier influences the optimal thickness of the biofilm, biomass growth, and the effectiveness of biodegradation of pollutants of various natures. In IFAS and MBBR systems, two groups of carriers are used: dispersed, which are distributed throughout the volume of the aeration tank, and fixed (immobilized) carriers. Dispersed carriers have advantages in effective mixing and large surface area, they are self-cleaning, do not require backwashing, and systems with such carriers are economically advantageous and simple to operate. Fixed carriers can provide more effective nitrification in cold climates, and the biomass on them is more resistant to changes in hydraulic regime (Al-Amshawee et al., 2020; Zinatizadeh & Ghaytooli, 2015; Al-Zuhairy et al., 2015).

The nature of the microbial cells in activated sludge facilitates their attachment and aggregation on solid surfaces (Cresson et al., 2009). Moreover, the retention (maintenance on carriers) of slowly growing nitrifying colonies in the form of biofilm in a bioreactor enhances the wastewater treatment efficiency (for carbon, phosphorus compounds, ammonia, and ammonium salts) (Gieseke et al., 2001; Kermani et al., 2008).

A wide range of synthetic solid materials (such as polyurethane, polypropylene, polyethylene) and natural solid materials, such as plant parts and stones, have been investigated for the colonization of microorganisms without biomass processing to increase retention by solids and reduce the required contact area.

A biofilm is a biocenosis of microorganisms consisting of bacteria, protozoa, and fungi living together on a solid surface. These microorganisms produce extracellular polymeric substances (EPS), which stabilize the microbial community and also adsorb and accumulate organic and inorganic substances (such as pesticides, chlorophenols, polycyclic aromatic hydrocarbons, heavy metal ions). The main components of EPS, such as lipids, nucleic acids, proteins, and polysaccharides, determine the metabolic activity, elasticity, strength, diffusional capability, porosity, and density of the biofilm.

The aim of this study was to determine the technical and technological characteristics of different types of carriers for immobilization of microorganisms.

2. Materials and Methods

The study was conducted at the Department of Bioenergetics, Bioinformatics, and Ecobiotechnology of the Igor Sikorsky Kyiv Polytechnic Institute.

For the research, four samples of different types of carriers for the immobilization of microorganisms were used. The immobilization of microorganisms on these carriers was performed using activated sludge collected from the Bortnychi Aeration Station in Kyiv, where municipal wastewater from Kyiv and surrounding settlements is treated.

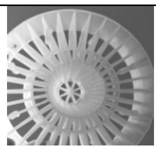
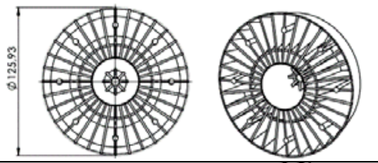
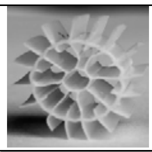
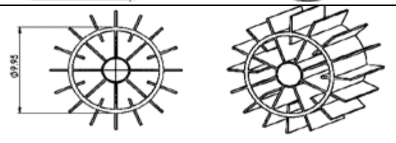
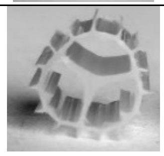
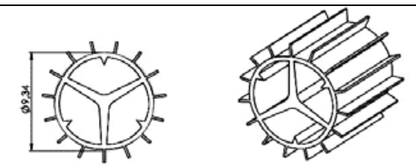
The analysis of the biofilm from the surface of the carriers and the activated sludge was conducted using standard methods and techniques.

Four bioreactors were used as the experimental setup, in which identical conditions for the process of biomass growth on the surface of the carriers were maintained. In each bioreactor, an aerator was placed at the bottom (center) and an additional flexible aerator around the perimeter of the base. Both provided fine bubble aeration using identical compressors. To maintain viability, 10 ml/day of a nutritive (model) solution was added to each bioreactor to supply the microorganisms with biogenic substances. The composition of this solution was based on a BOD: N: F ratio of 100:5:1 to sustain the activated sludge. The composition included glucose as a sugar source, organic matter, sources of biogenic elements, nitrogen (KNO_3), and phosphorus (K_2HPO_4). After hydraulic testing, activated sludge and a specific type of carrier were introduced into each bioreactor. The start-up period lasted 14 days, after which the growth of biofilms on the carriers was studied.

3. Results and Discussion

Biomass growth on the carriers was facilitated using microorganisms from activated sludge, with provisions for air (aeration system) and biogenic substances (model solution). An analysis of the characteristics of the biofilm on plastic elements of four different shapes and sizes was conducted: spherical with a diameter of 47.09 mm; disc-shaped – 125.93 mm; and wheel-shaped diameters of 9.95 mm and 9.34 mm under identical conditions is shown in the table. All the studied carriers are classified as dispersed, distributed throughout the volume of the aeration tank. They vary in size, structure, surface area, and the material from which they are made. To precisely determine the geometric parameters, 3D models of the four carriers were created and the surface areas calculated using the SolidWorks software environment.

Characteristics of the studied carriers for microorganism immobilization

No. of bioreactor	Carrier diameter, mm	Carrier photo	Surface area of one carrier element, cm^2	3D Models of studied carriers
1	47.09		153	
2	125.93		1266	
3	9.95		20.83	
4	9.34		13.15	

The following characteristics of four biofilm carrier samples were investigated: the concentration of biomass immobilized on the surface of the carrier and the specific biomass per unit area of surface for different types of loading for the treatment of domestic wastewater.

An important task of studying different carrier options is to determine and compare the biomass growth on carriers under experimental conditions created in bioreactors. Studies aimed at determining the amount of biomass growth on carriers placed in bioreactors were conducted in three replicates (3 series).

Fig. 1 presents photographs of clean carriers and carriers with dried with biofilm. All carriers differ externally in color, which may indicate variations in biomass quantity and biofilm layer thickness. The most significant color difference was observed for the carrier with a diameter of Ø 9.95 mm, position 3. Comparing it with the carrier of Ø 9.34 mm in diameter, a clear difference in the biofilm layer is evident, despite the external similarity of these carriers. In contrast, the smallest color difference is seen for the carrier with a diameter of Ø 125.93 mm.

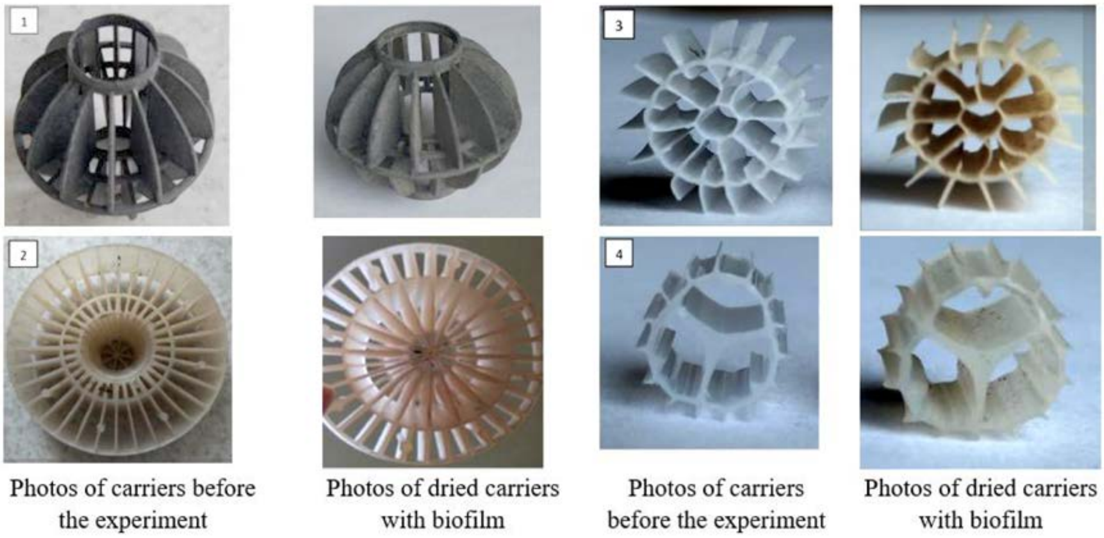


Fig. 1. Photos of carrier samples before the experiment (1–4) and dried with biofilm, respectively

According to the averaged results of three experimental series, the most biomass is immobilized on the carrier with a diameter of Ø 9.95 mm (Fig. 2). For the carrier Ø 9.95 mm, the average biomass concentration immobilized on the surface in setup 1 was 5425 mg/dm^3. For other types of carriers, lower average biomass concentrations were observed (in decreasing order): for carriers Ø 9.34 mm, Ø 47.09 mm, and Ø 125.93 mm, respectively, 2015, 869, and 138 mg/dm^3. The biomass concentration per unit surface area of the carrier was also highest for the Ø 9.95 mm carrier – 0.83 mg/cm^2, with carriers Ø 9.34 mm and Ø 47.09 mm showing close results of 0.48 a nd 0.28 mg/cm^2, while the carrier Ø 125.93 mm had the lowest value – 0.11 mg/cm^2.

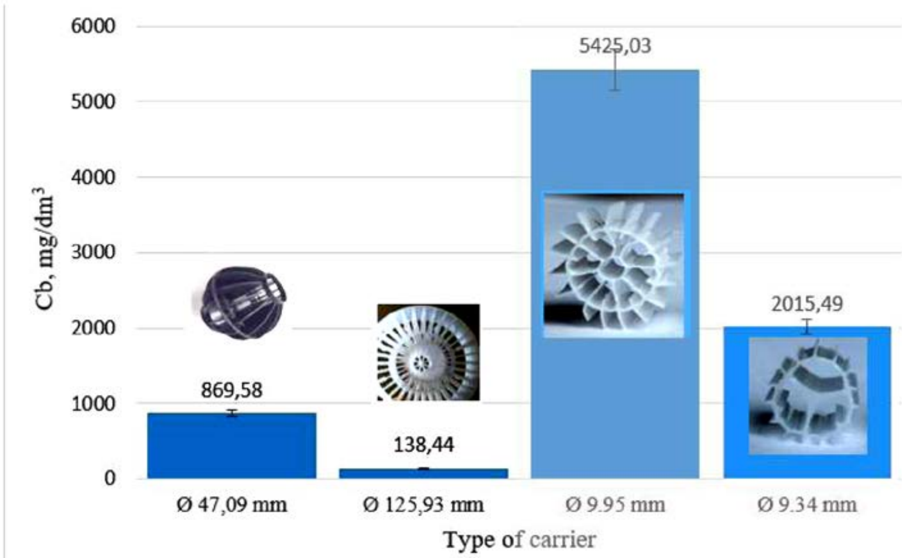


Fig. 2. Comparison of averaged biomass concentrations on different types of carriers across three experimental series

The highest biomass concentration on the plastic carrier can be explained by its highly developed external surface (the wheel-shaped carrier Ø 9.95 mm has the largest area – 20.83 cm^2), complex configuration of the carrier element (multiple partitions, ribbed surfaces), small dimensions, and a large number of elements in the volume of the bioreactor (350 pcs.). The advantage of the wheel-shaped carrier is also due to the intensive movement of individual carrier elements in the water column "from top to bottom" and vice versa under the action of air bubbles, which facilitates good washing by the activated sludge, promoting more intensive contact of the microorganisms in the activated sludge with the carrier surface and rapid formation and growth of the biofilm layer on the carrier.

The behavior of the carrier in the bioreactor plays an important role. Under the action of fine-dispersed air bubbles from the aeration system, individual elements of the carrier Ø 9.95 mm move in the water column "from top to bottom" and vice versa, are well washed by the activated sludge, which promotes more intensive contact of the microorganisms in the activated sludge with the carrier surface and rapid formation and growth of the biofilm layer on the carrier, as shown in Fig. 2.

Meanwhile, other carriers remained in a s tationary position in the reactor. Carriers Ø 9.34 mm and Ø 47.09 mm, due to the dispersion of air bubbles and the low density of the material, floated and constantly remained in the upper layer of the bioreactor. The carrier Ø 125.93 mm, due to its own size and weight, lay in the thickness of the water, resting against the walls and bottom of the reactor vessel. The mobility of the carrier Ø 9.95 mm can be explained by several factors – a higher density of the polymer material compared to the carrier Ø 9.34 mm; greater surface area and configuration.

4. Conclusions

The analysis of research results conducted by the department's scientists and contemporary publiccations in the field of wastewater treatment highlights the potential of using methods and technologies of biological purification involving microorganisms immobilized on c arriers. The advantages of such technologies are: high efficiency of removal of complex organic and toxic substances, nitrification and denitrification processes; increase in biomass of treatment microorganisms in the plant; reduction of biomass growth; compactness of treatment plants; reduction of operating costs due to lower energy and reagent consumption.

The method of biological wastewater treatment using immobilized microorganisms is innovative and highly effective, currently being researched and widely implemented in Ukraine and European countries in both traditional technologies (in existing aeration tanks at treatment plants) and in new technologies (in special bioreactors).

The choice of biofilm carrier is a critical factor as it in fluences the optimal thickness of the biofilm, biomass growth, and the efficiency of various natures pollutants biodegradation.

The study found that the carrier with a diameter of Ø 9.95 mm had the highest average biomass concentration immobilized on the surface – 5425 mg/dm^3, compared to others: Ø 9.34 mm, Ø 47.09 mm, and Ø 125.93 mm, which showed 2015, 869, and 138 mg/dm^3, respectively.

Thus, wheel-shaped carriers with a diameter of 9.95 mm can be effectively used in MMBR systems for wastewater treatment, and also for enhancing the operation of aeration tanks through their modernization– creating zones with carriers to increase the efficiency of wastewater purification from organic substances, nitrogen compounds, especially at the stage of nitrification, phosphorus compounds, and other pollutants.

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