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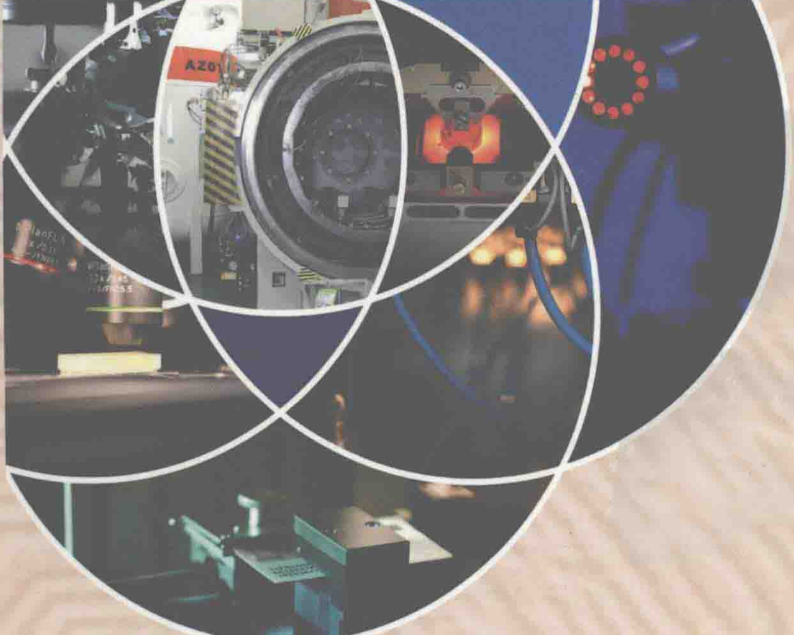

Edited by
Tomasz Giesko, Jerzy Smolik and Andrzej Zbrowski

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Advances in Manufacturing Engineering

Selected, peer reviewed papers from the
Conference on
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Advances in
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Preface

The volume contains selected, peer reviewed papers presented at the Conference on Future Engineering, held on 25-26 September 2014 in Korytnica, Poland. The papers are grouped into the following chapters: Chapter 1: Innovative Materials and Materials Processing Technologies in Mechanical Engineering; Chapter 2: Novel Engineering Solutions in Surface Engineering; Chapter 3: Innovative Technologies for Research and Design of Machines and Mechanisms; Chapter 4: Novel Methods for Measurement and Control in Technical Processes. The special volume covers the broad interdisciplinary domain of new research developments and practical applications of novel materials technologies including hybrid and multifunctional surfaces used in industry, prototype mechatronic and optomechatronic technologies and systems, advanced measurement techniques, optical inspection, and control systems.

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CHAPTER 1:

Innovative Materials and Materials Processing Technologies in Mechanical Engineering

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The concept of the system for parameterization of functionalized membranes

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Abstract.
Microbial biofilm formation on membrane surface layer (*biofouling*) impedes filtration processes through increased material- and energy consumption and causes the risk of contamination by microorganisms and their metabolites. Due to the constantly growing resistance of microorganisms to the commonly used methods of prevention, it is necessary to develop functionalised materials and coatings of stable, non-specific, and effective antimicrobial properties. The integral step in the process of the development of such materials and coatings is universal and reliable testing under process conditions.

The intensity of biological fouling is proportional to the microbial cell concentration in the system. Potentially present organisms are systematically varied and may include bacteria, fungi, and microscopic plants. The most convenient and universal method for microbial cell concentration assessment features the measurement of optical density of the liquid. Moreover, biofilm formation is dependent on the physiochemical factors, such as temperature, the chemical composition of feed liquid, membrane material, process flows, and pressures, etc. Additionally, process conditions may affect the activity of the functionalised material used for membrane formation. For this purpose, an integrated approach for multiparameteric assessment is needed, taking into account the measurements of the above listed parameters and allowing for comparisons.

The proposed modular test stand includes a number of actuators and measurement sensors, which enable the following control functions: the control over the process fluid flow, the control over the emission on the test object of electromagnetic radiation in the required spectrum, and implementation of the optical density measurements of the fluid. The whole installation test is placed in one closed cubature of controlled thermal conditions. The control system allows the recording and archiving of process data, which are collected (on-line) by a PLC and transferred to a PC via Ethernet interface. Dedicated software application on the PC provides a preliminary analysis and allows remote monitoring via a web browser. Remote access to measurement data can also be used for the creation of a network of series of such test stands, in which different aspects of the studied phenomenon are simultaneously analysed and controlled as the modules of a network control system (NCS).

The described system will allow the multiparameteric, universal and reliable assessment of antimicrobial properties of functionalised membranes under process conditions. The modular character of the proposed approach will be fully reconfigurable and adaptive for a wide range of membrane types. The results to be obtained will support the process of sustainable membrane development.

Introduction

Membrane filtration as a separation technique constitutes a crucial component of many large-scale industrial processes. Its advantages, such as versatility, effectiveness, simplicity, selectivity, flexibility, low energy demand, stability, and ease of control make membranes widely implemented in processes of separation, clarification, filtration, purifying, condensation, emulsification, crystallization, etc. [1]. Polymeric materials commonly used for membrane formation, e.g. polyethylene, polypropylene, polyamide, and polysulfone, are characterized by appropriate applicatory properties, ease of processing, and are relatively inexpensive [2]. However, the problem is in the lack of specific surface properties that are profitable in terms of resistance to biofilm formation. Moreover, the considerable porosity of these materials in addition to harsh working conditions promote biofouling. Since the essence of membrane technologies lies in selective concentration of compounds (including potentially present microorganisms) on one side of a membrane, favourable conditions for membrane biofouling occur due to the significance of the factor of microbial concentration [3]. Certain species-dependent concentrations of microbial cells cause changes in genome expression [4] and metabolism through, e.g., the loss of the ability to move or increase in the excretion of extracellular polymeric substances (EPS). These compounds, mainly polysaccharides, stabilize the biofilm structure and its adherence to the substrate. Moreover, EPS protects microbial cells from drying out and the diffusion of toxins from the environment [5]. The microstructure of biofilm consists of microcolonies that are of different sizes and metabolic activity, depending on access to nutrients and oxygen. This fact results in greater resistance to unfavourable environmental conditions and biocides, especially antibiotics. All these features result in microorganisms creating a simple but effective system to survive in the environment, which simultaneously generates serious problems in many industrial technologies.

Polymeric materials, commonly used for membrane production, are characterized by durability, ease of formation, and relatively low cost [1]. One of the major drawbacks is susceptibility to biofilm formation, especially in the case of liquid retention in the system. The techniques like cross-flow or back pulse are sometimes insufficient when it comes to maintaining optimum process performance [6]. Combining them with surface the modification and functionalization of a membrane providing reduction in microbial concentration is considered to be potentially the most reasonable approach. The addition of free-suspended biocide in some cases is impossible, economically unreasonable, or legally prohibited. The most rational option is the use of combined techniques involving immobilization of bioactive compounds and alteration of surface properties of materials. These attributes may be implemented during production or by physical and chemical processing of a "raw" membrane. A large number of products available on the market in combination with a wide range of possible modifications make this approach the most rational and economically reasonable [7]. The use of surface engineering becomes the second important part in the plastics industry. Commonly applied techniques of surface modification (separately or in combinations) are exposition to flame, various kinds of radiation, plasma treatment, chemical processing, and bombardment with ions, photons, and electrons [8]. These efforts are oriented to modify such parameters as hydrophilicity, crosslinking, the presence of highly reactive additional chemical groups, antimicrobial activity, and resistance to biofilm formation [9]. The alteration of surface properties may also improve general applicatory parameters like selectivity or flux. The modifications mentioned above may be implemented in almost all applications [7]. In order to reduce biofilm formation, the modifications intended to repel microbial cells away from the membrane surface may also be applied. It can be done by steric repulsion (e.g. grafting of polyelectrolytes), electrostatic repulsion, or low surface energy. Alternatively, the immobilization of biocides onto membrane surfaces is possible. The latter ones may act *per se* by direct contact, by diffusion, or by release of actual factor *in situ,* e.g. free radicals generated under external irradiation (photocatalytic reaction) - (Fig. 1) [10].

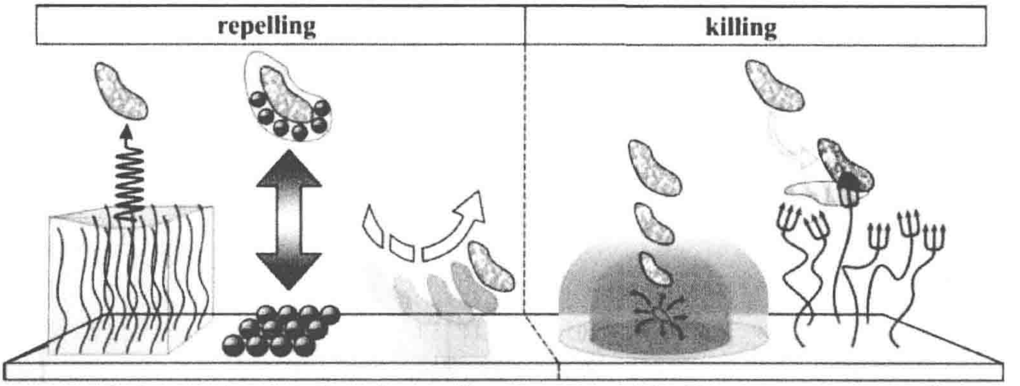

Figure 1. Types of antimicrobial activity of specialized materials [10]

Progressive biological fouling on the membrane and on the other parts of installation leads to deterioration of the process parameters. As a result of microbial cell subsidence, the pores of the membrane are plugged, causing a reduction in membrane flux, and an increase in the pressure and load of the installation. The fouled membrane module irretrievably loses its properties without the possibility of regeneration. The need of frequent replacement of the module in addition to increased energy demand makes the whole process less profitable [11]. Moreover, the presence of microflora and its metabolites changes the parameters of the process liquid, e.g., density, turbidity and optical density. The analysis of the parameters mentioned above provides the monitoring of the installation and proper reaction to emerging problems. This approach may be the foundation for a routine, multi-parametric evaluation of novel materials and functional coatings of antimicrobial and anti-biofouling properties.

The membranes may get in potential contact with microorganisms classified as bacteria, fungi, and microscopic plants. Their cells are characterized by considerable diversity of morphology, metabolism, environmental requirements, chemical composition, the presence of unique biochemical features, sensitivity to physiochemical factors, the ability of active movement, etc. [12]. The attributes mentioned above play an important role in contact with bioactive substances and thus their activity. In order to evaluate antimicrobial properties of given materials, the parameter of optical density (OD) of liquid may be used. The OD value (usually measured in the range of 550-600 nm) increases along with the number of cells present in the liquid (including inactive ones). Determination of the OD, its changeability within incubation period under the presence of antimicrobial substance and supplementary tests for CFU (*colony forming units*) may potentially provide data for further modelling [13]. The susceptibility to biofilm formation can also be determined with this method, through the analysis of a liquid used for biofilm removal.

The aim of this paper is to discuss the concept of the model test stand, providing multiparametrical analysis of the processed liquid during membrane filtration, combined with precise control of the process parameters. This equipment is intended for testing antimicrobial properties of a novel prototype functionalized membranes against the main representatives of different microorganisms. The conclusions drawn from the preliminary studies support the approach of the mentioned surface modification of membranes and the method for evaluating their activity. Figure 2 presents the changeability of the OD550 parameter of the culture medium induced by the presence of prototype membranes. Samples used in this test were previously examined and selected in plate assays (Fig. 3).

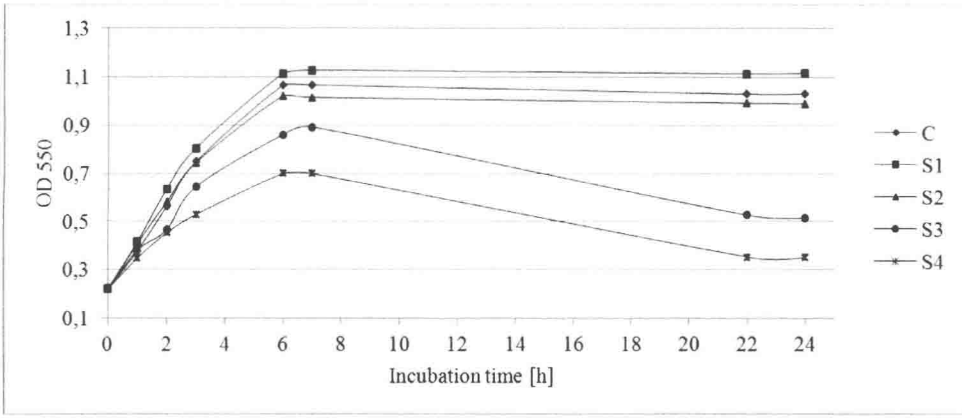

Figure 2. Changes in optical density of culture medium (E. coli) within a 24-hour incubation period induced by samples of different coatings.

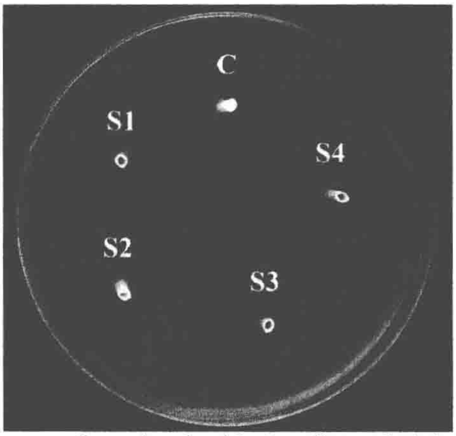

Figure 3. The results of plate assay (inoculated with *Bacillus subtilis*), performed for different modified materials

Differences in both effectiveness and the nature of observed changes in optical density will constitute the foundations for modelling interactions with microorganisms and should be thoroughly examined. The main objective is to increase the frequency of the measurements in order to perceive subtle, but relevant, alterations in the state of the system. The possibility of imitating working conditions, specific to the real membrane processes (e.g. temperature, pressure, access of the light, presence of cutting forces, chemical composition of feed liquid etc.) is also of great importance. All of this will constitute an important feedback in processes in which a high risk of biofilm formation occurs. The proposed concept of a test stand has a great applicatory potential in the process of design and manufacture of novel, functionalised materials.

Concept of the Test Stand

The task of the system for the parameterization of functionalized membranes (Fig. 4) is a model membrane process carried out, under controlled conditions, with a closed-loop circuit of the retentate and sterility of a circulating in the system liquid maintained. The concept of the test stand foresees two ways of liquid flow: with a separation and storage of the permeate in the permeate container and the return of the permeate into the feed container.