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Interfacing Bioreactors with Membrane Filtration Technologies for Closed Loop Water Recovery and Recycling

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Abstract

Membrane filtration processes can be used for down stream treatment of bioreactor effluents for water treatment and recovery for closed loop water recovery and recycling. Interfacing a membrane filtration process with a bioreactor system require both treatability and operational compatibility assessment to ensure that the final effluent meets the required water quality standards with minimum or no significant membrane fouling within the anticipated operating range. One of the main limitations of the technology interfacing membrane technologies is the high fouling potential of the bioreactor effluents. In this study, design and operational aspects of interfacing a membrane filtration system with an aerobic bioreactor was investigated. Microtopographical images of the membrane surfaces were captured by an atomic force microscope (AFM) to assess the rate of membrane fouling. Analyses of the microtopographical images indicate that contamination of the membrane surface begins immediately during the filtration process.

Introduction

One of the water recovery and recycling processes currently being evaluated for water recovery and recycling during space missions incorporates the aerobic rotational membrane system (ARMS) which is tested at the Kennedy Space Center, Florida. The ARMS is a novel compact membrane bioreactor which converts ammonia to nitrates. Oxygen is provided through the rotating hallow fiber membrane module to the biofilm on the membranes. The rotating hallow fiber membrane module provides mixing to maintain high mass transfer rates between the bulk liquid and the biofilm (Rector et al., 2004a and 2004b) resulting into high bioconversion rates which reduce the volume requirements of the system.

Membrane filtration can be used for down stream treatment of the effluents from biological treatment processes. However, the use of a membrane filtration process for bioreactor effluents requires both treatability and operational compatibility assessment to ensure that final effluent meets the required water quality standards with minimum or no significant fouling within the anticipated operational conditions. The previous experimental studies have shown that microfiltration did not provide significant quality improvement since the bioreactor effluent contained primarily dissolved salts (Tansel, et al., 2005). Therefore, to achieve any significant quality improvement of the bioreactor effluent, it is necessary to use nanofiltration (NF) or reverse osmosis (RO) systems.

The ability of RO membranes to reject inorganic species while passing relatively pure water has lead to the widespread use of membrane processes for drinking water purposes.
The mechanism of water and salt separation by reverse osmosis is not fully understood since both the porosity and diffusion processes play a role in the mass transport in RO processes (Ghiu et al., 2003). Transport may also occur by weak chemical bonding of the water to the membrane surface or by dissolution of the water within the membrane structure. The chemical and physical nature of the membrane determines its ability to transport solvent (water) over solute (salt ions).

Biofouling is caused by the accumulation of contaminants and bacteria on the membrane surfaces. Biofouling reduces the flux eventually leading to structural failure of the membrane integrity. The porous morphology of the membrane provides surfaces with suitable roughness for bacterial attachment and growth. Extracellular polymeric substances (EPS) are large molecular weight compounds that are excreted by bacteria. The term is used synonymous to exopolysaccharide, exocellular polymer, extracellular polymer, or exopolymer since the exact composition of EPS is difficult to determine. The EPS consists of high molecular weight bioactive compounds and consists of polysaccharides, proteins, lipopolysaccharides, lipoproteins or complex mixtures of these biopolymers.

EPS exhibit self-assembly characteristics, hence, they can initiate and develop a highly hydrated gel matrix where the microbial cells can attach and establish a stable synergistic consortium. The molecular masses of EPS range from a few thousands to several millions with a wide range of functional arrangements including carboxyl, amino and phosphate groups. EPS plays a significant role in bacterial adhesion and biofium formation on solid surfaces by altering the physicochemical characteristics of the surfaces such as charge, hydrophobicity, roughness and polymeric properties. EPS can effectively stick to wet surfaces which indicates that some of the water molecules within the EPS matrix can easily be replaced with the water molecules on the surface. The relative mobility of water molecules within the EPS matrix increases the flexibility of polymer and enable the EPS to adhere to surfaces in aquatic environments. Although the smooth surfaces may delay the initial attachment of bacteria, smoothness does not significantly affect the total amount of biofilm that will attach to a surface (Meltzer, 1993). Flow characteristics near the membrane surface affect the rate of biofouling as well as the biofilm thickness. High flow rates delay initial attachment period of the biofilms. However, once the biofilm is established, flow rate alone may not be sufficient to remove the biofilm.

The purpose of this study was to analyze the design and operational aspects of interfacing membrane filtration system with an aerobic membrane bioreactor was investigated. Although the membrane filtration system can significantly improve the water quality of the bioreactor effluent, the EPS may cause fouling. Microtopographical images of the membrane surfaces were captured by an atomic force microscope (AFM) to assess the rate of membrane fouling. Analyses of the microtopographical images indicate that contamination of the membrane surface begins immediately during the filtration process.

Process Integration

Interfacing a membrane filtration system with a bioreactor require both treatability and operational compatibility assessment to ensure that the final effluent meets the required water quality standards with minimum or no significant membrane fouling within the anticipated operating conditions. One of the main limitation of the technology interface is the high fouling potential of the bioreactor effluents. Biofouling is caused by the accumulation of contaminants and bacteria on the membrane surfaces. Biofouling reduces the flux eventually leading to structural failure of the membrane integrity. The porous morphology of the membrane provides surfaces with suitable roughness for bacterial attachment and growth. Extracellular polymeric substances (EPS) are large molecular weight compounds that are excreted by bacteria. The EPS consists of high molecular weight bioactive compounds and consists of polysaccharides, proteins, lipopolysaccharides, lipoproteins or complex mixtures of these biopolymers. Since EPS exhibit self-assembly characteristics, they can initiate and develop a highly hydrated gel matrix on surfaces where the microbial cells can attach and establish a stable consortium.

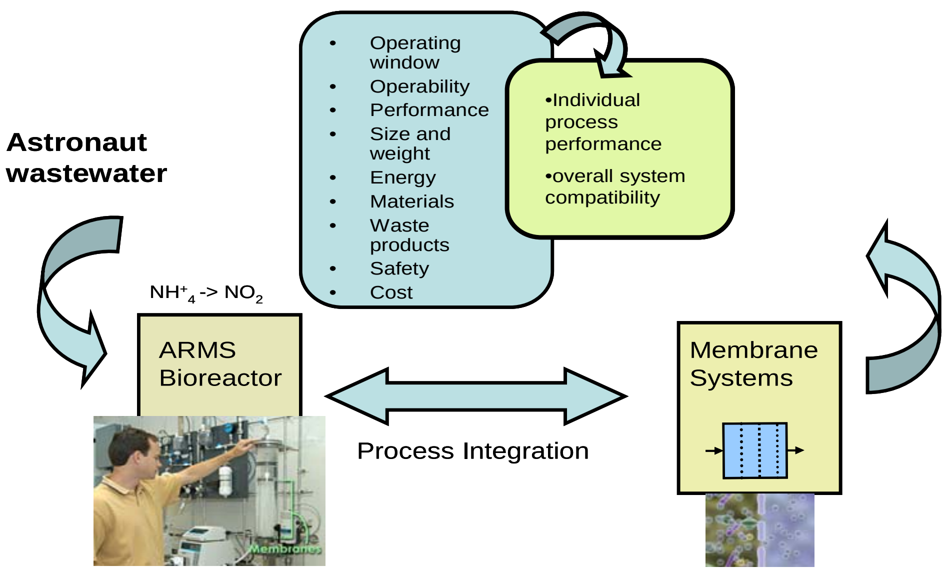

Figure 1. Integration of two membrane technologies for wastewater treatment.

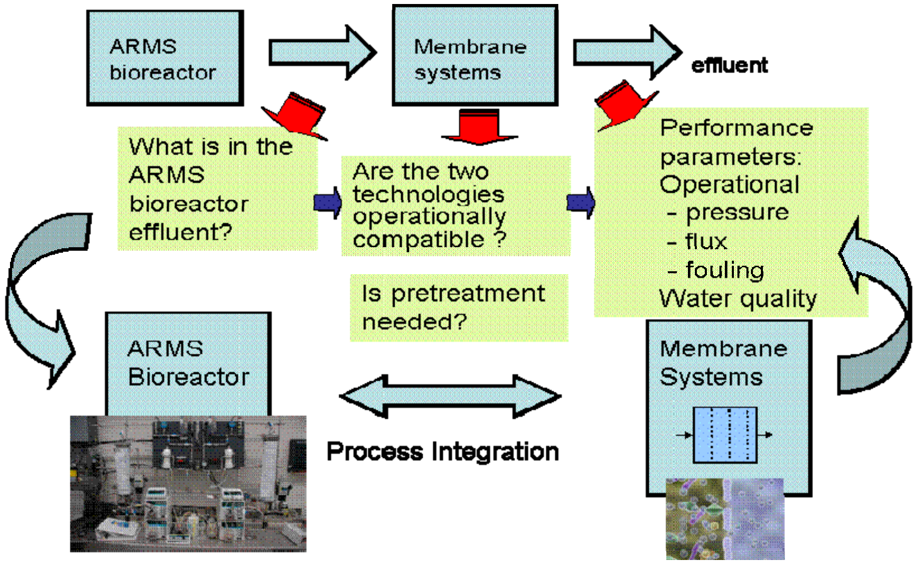

Figure 2. Technology integration considerations for closed loop water recovery and recycling.

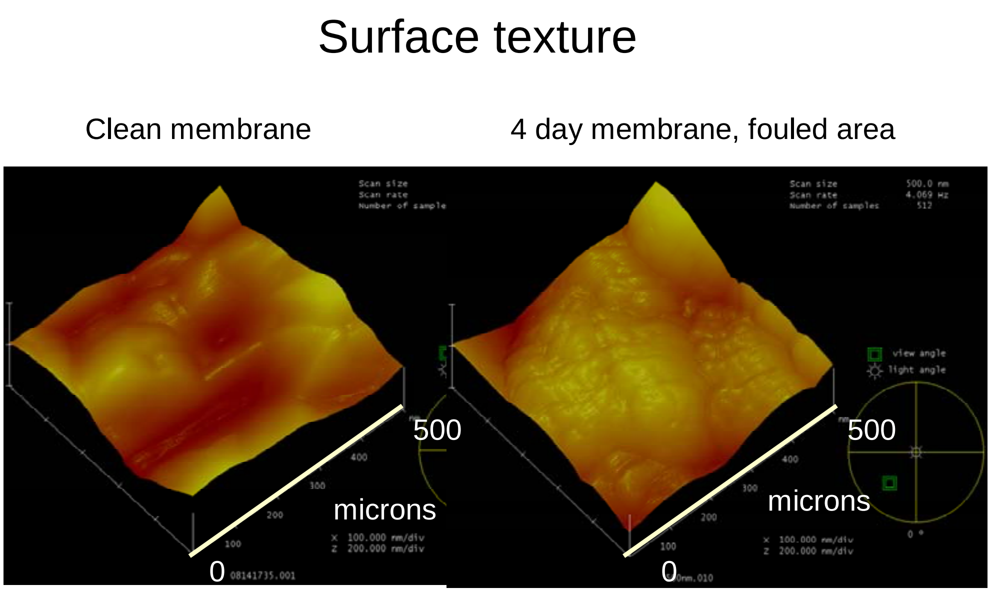

Figure 3. Comparison of microtopographical changes between clean and used membranes.

Conclusions

The interaction between an adhesive material and the substrate involves two main steps: a) wetting of the surface by the substrate, and b) cross linking of the substrate. Since EPS has bioadhesive characteristics, they exhibit both wetting and cross linking functions. How the EPS attach and start forming a gel matrix on a surface depends on a number of factors such as:

1. Adhesion characteristics between EPS and membrane;
2. Cohesion characteristics of EPS;
3. Flexibility and rearrangement characteristics of the EPS;
4. Morphology of the membrane surface;
5. Structure characteristics of EPS and membrane material;
6. Diffusion of EPS into the porous surface structure;
7. Dimensional factors such as surface roughness, pore size of membrane, and size of EPS molecules;
8. Near surface flow patterns.

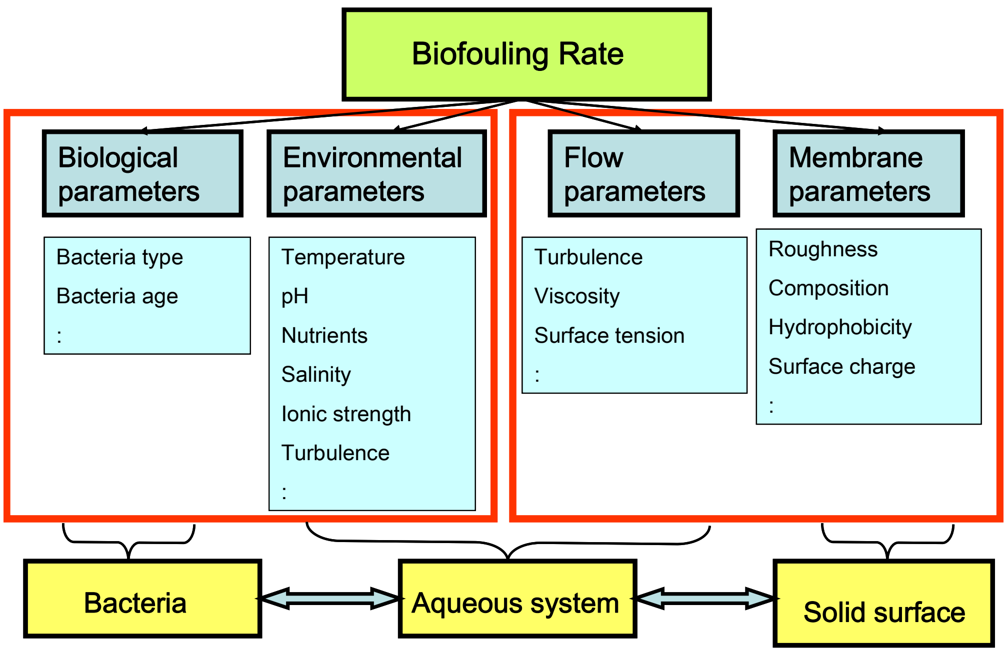

Figure 4. Design and operational parameters affecting biofouling rate.

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