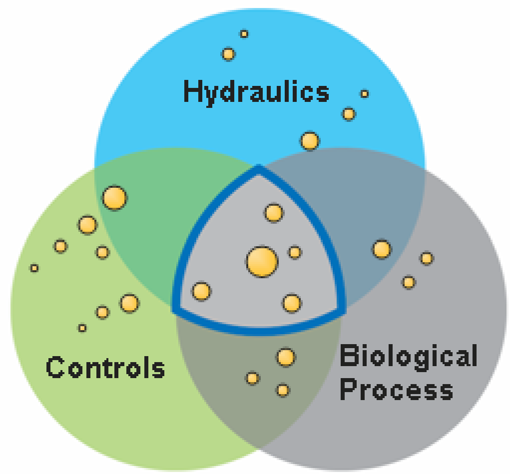
Understanding Membrane Performance in MBR Applications Through Biohydraulics

Dennis Livingston
Hiren Trivedi

Since the early 1990s, submerged membrane bioreactor (MBR) technologies have been reshaping wastewater treatment industries around the world and creating new reuse opportunities through decentralization and plant upgrades. In fact, in the US alone, there are now hundreds of operating MBR plants and by many accounts, more than 4,000 installations worldwide (Kennedy and Churchouse, 2005). With the maturation of MBR technology over the last decade, it has become increasingly apparent that an overall *system approach* is necessary to designing and operating a successful MBR plant. Assuming adequate pre-treatment, this type of approach accounts for the interdependency between control strategies, plant hydraulics and biological processes. This interdependency is referred to as *biohydraulics*. To understand the principles of biohydraulics, it is important to note that all submerged membranes have a *biofilm* that must be properly managed using a variety of design and operational techniques.



A biofilm creates a dense dynamic membrane that can allow for enhanced nutrient removal and degradation of refractory organics and more importantly, prevent *reversible* and *irreversible* fouling. Enviroquip has developed proactive design and operational strategies to prevent both types of fouling by managing biofilm properties. This approach deals with the causes of biofouling as opposed to the effects and gives operators better tools to run MBR systems.

Biofilm Components

Microorganisms

Extracellular Polymeric Substances (EPS)

Soluble Microbial Products (SMP)

Non-Biological Solids

Substrates

Metabolites

Interior Pores

Channels

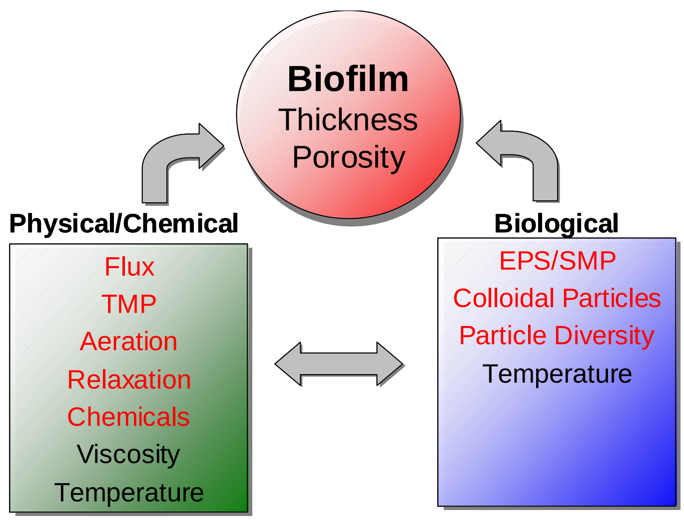
The importance of biofilm management can be demonstrated by looking at *Darcy's Law* relating flux to transmembrane pressure (TMP), water viscosity (μ) and the total resistance to water filtration R_T:

$$J = TMP / (\mu \times R_T) \qquad (1)$$

In Equation 1, flux is inversely proportional to flow resistance. In other words, assuming a constant TMP, less water is filtered with increasing resistance to flow. In simple terms, R_T is the combined resistance across a membrane and biofilm (or cake) and is given by Equation 2:

$$R_T = (R_M + R_F) + R_C \qquad (2)$$

Figure 1



R_M is the resistance of the membrane material itself, R_F is added resistance due to pore clogging or adsorption (irreversible fouling) and R_C is the resistance of the cake or biofilm (reversible fouling).

Research and field data indicate that R_c can, in some cases, account for roughly 90% of the total resistance to filtration for both hollow fiber (Chang, 1998) and flat plate membrane technologies and that it is primarily a function of interstitial void space (porosity) and thickness. Several factors affect these properties, most of which are shown in Figure 1.

Biofilm Management: Being Proactive vs. Reactive

Until recently, MBR suppliers focused on the effects of biofilm formation and not the causes. In other words, the question was, “How can operators react to changing biofilm conditions and eliminate it through physical/chemical methods such as backpulsing and chemical cleaning?” Enviroquip has always focused on changing the question to, “How do I manage fouling conditions to prevent irreversible fouling in the first place?” Aside from temperature, *EPS/SMP*, colloidal *particle size distribution* and *particle diversity* can all be addressed through design and operational choices.

It is widely believed that extracellular polymeric substances (EPS) and soluble microbial products (SMP) are the main culprits that cause reversible and irreversible biofouling. At a short SRT, polysaccharides, secreted by microbes, in an effort to stabilize their environment and to aid in flocculation, can combine to form colloidal material that subsequently block biofilm pores and increase filtration resistance. In fact, using hollow fiber membranes, researchers at the University of Berkeley observed that flux rates declined roughly 800% faster as F:M ratios were increased from roughly 0.5 day^{-1} to greater than

EPS
Complex mixture of polysaccharides, proteins, lipids and nucleic acids

Can create a highly hydrated gel or matrices, providing the dominant bridging mechanism between cells

SMP
Cellular components excreted through the cellular membrane due to metabolism during normal or stressed conditions

1.5 day^{-1} (Novak et al, 2004). These results are consistent with a 2004 UNESCO survey evaluating the cause of MBR system problems in North America for hollow fiber systems, which pointed out that an SRT of < 20 days may have accelerated biofouling. At the other end of the spectrum, microbes begin to lyse if the SRT is too high (50+ days) and generate SMP or protienaceous EPS that are also known foulants.

Although SMP concentrations increase at long SRT, there is evidence that average particle size also increases at higher MLSS and at long SRT (Huang et al., 2001). Particle size is important because it determines the rate at which particles migrate away from biofilm due to lift forces induced by air scouring. In other words, bigger (heavier) particles move faster back into bulk solution (mixed liquor) at a constant cross-flow velocity induced by air scour. Considering EPS/SMP data and similar information regarding particle size distribution as a function of SRT, it appears that the optimum SRT range is 12-50+ days.

SRT control through sludge management is the best way to keep EPS concentrations down and to maximize air-scouring efficiency. However, adding coagulants can also bind up free EPS and agglomerate colloidal material to increase average particle size. Novak and his colleagues noted that during a recent pilot study using a hollow-fiber MBR system, stable TMP values maintained for weeks with a 25-mg/l dose of aluminum sulfate (alum) increased within 48 hrs after alum dosing was terminated. Within 12 days, the average TMP increased by 61% (in spite of backpulsing and daily chemical cleans), and did not fully recover after resumption of alum dosing. It was speculated that, "colloidal polysaccharides, formed after alum dosing was terminated, may have caused irreversible fouling." (Novak et al., 2004)

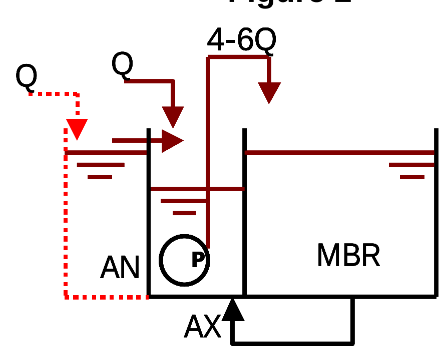
Enviroquip has been working with the Nalco Corporation for years to develop and integrate a specially formulated polymer, known as a flux enhancer, to sustain high fluxes at cold temperatures. MPE50™ is a long chain cationic polymer that bridges between negatively charged floc particles to reduce free EPS concentrations and decrease the number of small particles, *e.g.* colloids, that can clog biofilm and or membrane pores. The product is integrated into Enviroquip MBR systems to increase maximum monthly flows on the order of 30%-50% and can be used to decrease air scour requirements in certain cases.

Hydraulics

Topics seemingly unrelated to biohydraulics, such as *flow splitting*, *gate types* and *hydraulic profiles,* often determine the success of a MBR plant irrespective of the membrane technology selected.

Proper flow splitting is essential to the successful operation of any MBR system and

Figure 2



is dependent on the plant layout and flow control methods. Without proper flow splitting, there is a potential for preferential flow to one or more basins that can cause a significant imbalance in MLSS. Even with the proper plant layout, the type of gate used in between basins can be an issue. For example, using sluice gates instead of weir gates can trap nuisance organisms such as *Microthrix parvicella* in isolated areas and create foaming conditions at long SRT conditions common to MBR operation. Also, submerging return points can mask flow-splitting problems and uneven flow distribution.

Conventional wisdom says that internal recycle should be pumped back from MBRs to the head of the plant to reducing pumping costs. However, this strategy saves only a small amount of energy (<1%) at the expense of increased plant maintenance and operational complexity. Enviroquip standard MBR design practice (see Figure 2) reverses the typical hydraulic profile in order to gain precise control of the recycle rate and partially equalize flows upstream of the MBRs. Constant water level in the MBR generally improves overall performance.

Operational Controls

The key to successfully running any MBR system is to monitor and control biological conditions while sustaining high permeability, defined as flux over TMP (gpd/psi). Generally this is done by maintaining a target MLSS that corresponds to an approximate SRT, and in some cases (Enviroquip UNR™), using online biomonitoring. In order to optimize SRT, systems must be designed with the flexibility to operate over a range of MLSS concentrations. For example, Enviroquip generally allows for MLSS concentrations up to 18,000 mg/l without derating hydraulic capacity. Even with such flexibility, physical/chemical methods to address both reversible and irreversible fouling are necessary.

The relaxation and aeration strategies employed at a given plant can have a tremendous impact on operation. For example, Enviroquip has developed unique strategies, such as proportional aeration and enhanced relaxation, which can reduce energy costs by up to 30% while increasing sustainable fluxes. Whatever the strategy, it is evident that the industry trend is to move away from complicated and potentially counterproductive backpulsing, toward variations on relaxation.

Whatever the means of fouling control, it is generally a good idea to keep TMP as low as possible to avoid collapsing biofilm (increasing R_C) and to minimize the rate of irreversible fouling. Enviroquip generally employs permeability control automation and TMP interlocks to avoid high TMP operation and to reduce CIP requirements.

Conclusions

Understanding biohydraulics is the key to successfully designing and operating a MBR system. Moreover, taking a proactive approach to biofilm management, using the concepts grounded in biohydraulics, can significantly reduce MBR system costs and maintenance requirements.

Dennis Livingston is the MBR Product Manager and Hiren Trivedi is the Technical Manager at Enviroquip, Inc.

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