THE USE OF MEMBRANE BIOREACTOR SYSTEMS TO CONSERVE WATER IN MANUFACTURING PLANTS

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Abstract—The use of membrane bioreactor systems (MBRs) in the manufacturing industry can reduce inefficient water consumption, increase the reusability of water within a factory, and contribute to efforts of widespread decontamination of water.

Not only is the purpose of MBRs to promote sustainability, but the reactor itself is designed to maximize water purity, produce a small environmental footprint, and have variability in design. These reasons make membrane bioreactors a beneficial water-cleaning alternative, as opposed to traditional biological separation processes. MBR technology combines wastewater treatment techniques with biological processes to filter water. The dirty water is streamed into the reactor where it undergoes a biological process that produces highly concentrated biomass solids. After the biological process, the membrane can reject the biomass material and only allow the clean water to pass through. There are three major components to this technology: the water, the biological process, and the membrane itself. Each are critical because this technology runs as a system, and its effectiveness is dependent on each of its variables.

Key Words—Industrial wastewater, membrane bioreactors (MBRs), reverse osmosis, water conservation, water reclamation

THE URGENT NEED FOR PERMANENT WATER SOLUTIONS

There are numerous contributing factors causing a world water crisis. According to the United States Environmental Protection Agency (US EPA), less than one percent of all of the water on Earth can be used by people [1]. Since water is a resource that is required for life, providing sufficient amounts of safe water to society is critical; therefore, the issue of water scarcity is dire. California environmental researchers William Jury and Henry Vaux state that, “As of today, some 1.1 billion planetary inhabitants do not have access to clean drinking water, and 2.6 billion do not have sanitation services,” [2] while the United Nations (UN) reports that “approximately one-fifth of the world’s population lives in water-scarce areas” [3]. These statistics reveal that water is a precious resource and not readily available, as many human beings think. This has led to chaos when incidents such as water contamination, water pollution, and droughts have occurred. Dangerous levels of contaminants in water, transmission of fatal diseases, and the increased possibility of wildfires are just some of the consequences of a decreasing water supply, not to mention dehydration and lack of resources for commercial and household reasons. Not only is the decreasing presence of water itself an issue, but how water is currently being used. While it is important to reduce water intake, consciously managing water consumption is also necessary. This can be done through understanding sustainability and how it relates to water management. Water management can contribute to a future of sustainability through conserving the natural resource of water, driving technological advancement towards more efficient water treatment processes, and hopefully decreasing future costs of both energy and water utilities.

While factors to the water crisis continue to grow, there are new developing technologies, for example membrane bioreactor technology (MBR), that can ease the effects of the water crisis, encourage sustainable practices, and conserve water in unconventional manners. Many conservation methods emphasize decreasing water intake, for example, turning off the faucet when brushing one’s teeth or fixing leaky pipes [1]; however, membrane bioreactor technology focuses on the idea of water reclamation and reusing water specifically in the manufacturing industry.

HOW DO MEMBRANE BIOREACTORS CONTRIBUTE?

Instead of simply reducing water usage in manufacturing plants, properly managing water usage would have a substantial effect on society. The high-water usage in manufacturing plants comes with high energy usage; therefore, decreasing water intake is preferable because energy would also be conserved, leading to a decrease in utility costs for companies. However, this is not necessarily needed if water intake can be managed and reused.

Membrane bioreactors (MBRs) have been successfully used in manufacturing environments because of their defining, sustainable characteristics of purity maximization, reduced environmental footprint, and
variability in design. In the basic process of MBR technology water flows through a reactor, undergoes a biological filtration and then passes through a membrane. The membrane utilized in the bioreactor has a small pore size, meaning that pathogens pass through; hence, the pathogen concentration of the water is reduced, and water purity is increased. The solids produced by the biological process are retained in the bioreactor, which controls the growth of the biomass solids. This waste produced is both smaller in volume and higher in biomass concentration, leading to a smaller environmental footprint left by the manufacturer. When excess waste, or sludge, must be removed, it undergoes a process known as activated sludge, which treats the sludge through aeration or other biological processes. [4]. Finally, the membrane bioreactors can be smaller for companies on a budget and larger for industrial waste companies. This design allows for the reactor to be placed in areas of limited space, yet continue to be productive if biodegradable organic content is available. [3]

While the overall process is simple, there are many elements within each component that contribute to the effectiveness of membrane bioreactor technology.

THE COMPONENTS OF MEMBRANE BIOREACTOR TECHNOLOGY

The Importance of Characterizing Water

Using wastewater containing contaminants not suited for the MBR technology will produce unsatisfactory results; therefore, it is important to note these situations.

There are several different types of wastewater and a plethora of contaminants found within water. Investigations on surface waters have found that a wide range of trace contaminants such as pharmaceuticals, industrial chemicals, personal care products, and metabolites of detergents, are all present in industrial wastewaters [5]. For this reason, a study was conducted by S. Baumgarten et al. in order to investigate the performance of membrane bioreactors for the treatment of industrial water affected by these wastes. Since industrial wastewater contaminants can differ from facility to facility and segment to segment within a system, the treatment of wastewater can be quite a challenge because different types of waste must be disposed of in different ways [5]. MBR technology is a viable solution to these problems.

The Aachen University Institute of Environmental Engineering (ISA) conducted a study specifically on industrial wastewaters with high concentrations of organic pollutants, or POPs. According to the EPA, “persistent organic pollutants (POPs) are toxic chemicals that adversely affect human health and the environment around the world,”[6]. Because these pollutants are a threat to human health, the ISA tested decontamination processes with MBR technology. The purification efficiency and operating behavior of the MBR was studied in order to determine the technical and economic viability of the process when the factor of water was varied [5].

Overall, nine different types of wastewater were studied, with different industrial origins and chemical features included for each type. For example, wastewater from the textile industry was tested. This water came from wool and cotton finishing processes and contained contaminants from dyeing fabric, bleaching and washing processes, and high concentrations of surface-active substances [5]. The study concluded that the degree to which the membrane bioreactor could eliminate organic compounds depended completely on the origin and contaminants within the wastewater, and varied greatly between the different types. They determined that the membrane performance was similar to conventional methods in water with identified compounds such as pharmaceuticals, stearic acid, alkyl ethoxylates, polyethylene glycol, tributyl phosphate, polypropylene glycol and its derivatives, and others as well. Identified compounds that reduced the performance of the membrane were observed as “non-degradable long-chain compounds,” [5]. Their poor performance stemmed from the reactor producing more retentate rather than permeate causing the membrane to filter less material.

It is evident not all types of water can enter the membrane bioreactor; hence, it is important to start wastewater treatment processes by identifying the waste that must be disposed of and taking a route of action based upon that. However, as the study above concluded, MBR is viable in many types of waste treatment, expanding opportunities to introduce sustainable practices in a greater number of industrial applications.

The Biological Processes

Membrane bioreactor technology has combined, yet enhanced traditional biological wastewater treatment processes. Biological degradation and an improved activated sludge process system are the aerobic biological treatment technologies that occur within the membrane bioreactor.

To understand these biological processes, it is important to first understand what an aerobic biological process is. An aerobic treatment uses “free oxygen to assimilate organic impurities, converting them into carbon dioxide, water, and biomass” [7]. This is essentially the degradation of waste. It uses bacteria as the primary agent to break down the waste into biomass, the living content from the total process [7]. The bacteria (aerobes) take in the organic contaminants, oxygen, and surrounding nutrients to produce the water, carbon dioxide, and excess matter (resulting biomass).

The activated sludge process uses this process of aerating waste by starting with two tanks. Activated sludge is “the suspension of microorganisms, both living and dead, in wastewater,” [7]. The first tank is the aeration tank, and in
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the case of MBR technology, it is the bioreactor. This is where the required concentrations of biomass are kept to ensure the steady growth of the bacteria that enables the biological process to continue. Then, oxygen is transferred to the reactor. Microorganisms, aerobic bacteria, are metabolized by mixing with oxygen and waste, thus enabling the new products to form [7]. The oxygen that is forced through the reactor separates the biomass from the filtered water [8].

MBR systems utilize this process by infusing membrane technology. The conventional activated sludge process uses gravity to separate the biomass from the filtered water, while MBRs use the specially designed membrane discussed in the section. The needed biomass is returned to the bioreactor through the RAS pump (return activated sludge). This will supply the microorganisms the energy they need to grow [7]. The resulting waste, or “sludge”, is separated to be disposed of properly. [8].

Combining the conventional activated sludge process with membrane technology has many benefits. By using a membrane instead of gravity, less biomass is able to pass through with the clean water, enhancing the purity of the effluent. This also results in more concentrated biomass because the biomass is more compact in volume. Finally, the bioreactor can be much smaller than conventional activated sludge aeration tanks because the membrane does not require as much space as gravity settlers do when separating the biomass. [8].

The Membrane Itself

The effectiveness of membrane bioreactor technology is due to the dependence on numerous components. The ability to individually manipulate these components per an application’s needs allows the MBR to be transformed for each task needed. However, without one component, there is no system; therefore, the membrane, just like all other components is critical to the MBR system, however it is the defining component that separates it from conventional wastewater treatments.

According to the MBR Book, a membrane is “a material that allows some physical or chemical compounds to pass more readily through it than others” [9]. Utilizing a membrane in water filtration is clever because one can selectively determine what will pass through the membrane and what will not. The substances that pass through the membrane are termed the permeate, while the substances that are rejected by the membrane are called the retentate. We can determine what will pass through the membrane through the membrane’s physical and chemical properties. Ideally, everything we want to pass through the membrane will. Everything that we do not want to pass through will not, but nothing is ideal.

Membranes have a degree of permeability [9]. This means there are factors that influence the effectiveness of the membrane, such as the material of the membrane. The material of the membrane surface is crucial to MBR being successful because MBR technology is effective primarily due to the surface of the membrane [10]. As previously stated, a membrane allows material to pass through, but when paired with the biological processes of MBR technology, the membrane “promotes microbial degradation and physical retention of all molecules larger than the molecular weight of the membrane,” [10]. This special technique allows the retentate (waste and bacteria) to be held on to. This creates dense, biodegradable biomass, which can be disposed of alternatively.

There are three basic rules to follow when it comes to creating a membrane. First, it must have a narrow pore size. Second, it must be structurally strong. Finally, it also must be resistant to both chemical and thermal attacks. [9].

A narrow pore size increases the selectivity of the membrane. Higher selectivity means that the membrane is pickier when it comes to letting materials pass through it, increasing the quality of purity of the permeate. A narrow pore size can vary dependent upon the duty the membrane is to perform; however, they can range from 10\(^{-5}\) to 10\(^{-10}\) m [9]. Many commercial membranes are made from polymers. A polymer is a compound made up of long chains of molecules. They have unique properties and can be chemically manipulated to complete certain tasks; hence the reason to use them in MBR technology [11]. There are many different types of polymers that can make up the membrane, from fully hydrophilic polymers, meaning being able to be dissolved in water, to hydrophobic polymers, polymers that resist mixing with water [9]. There are also in between polymers that fall in the “polysulfone family” [9]. They are polymers that can be modified by adding different chemicals to it. This is ingenious because it contributes to the great variability of the membrane. Simply changing the surface layer of the membrane can change its chemical properties, thus rapidly changing the material which can pass through it. However, this can become very expensive and the case-studies discussed further on focus on large-scale operations. For this reason, the membrane must be cost effective. The membrane is constantly at risk of being manipulated by the material moving through it and the material that is accumulating outside of it, so it must be strong; therefore, membranes are made with thick, spongy support inside to increase mechanical stability. Finally, not only is the material moving through it a threat to the inherent structure of the membrane, but the membrane’s surrounding environment as well. Changes in heat or chemical compounds are common occurrences in an industrial setting; hence, the membrane must be resistant to these changes. An example of both physical stress and chemical changes that a membrane may face is basic cleaning. A membrane can be physically cleaned by reversing the flow of water, which removes some of the waste that accumulates outside the membrane [9]. This can be forceful, so the inner structure must withstand this. It can also be cleaned with solutions with higher chlorine concentrations; demanding the
membrane to be chemically flexible over a wide range of pH levels [9]. Not only must it be chemically resistant for cleaning reasons, but logically thinking, the membrane must be structured to resist chemical breakdown because of its constant encounter with bacteria.

While the previous characteristics were chemical manipulations of the membrane, there are also mechanical ways to affect the operation of a membrane. The resistance, flux, and pressure can affect how the membrane operates. Membrane resistance is “the ratio of the pressure difference to the flux and viscosity” [9]. If the permeability of the membrane is increased, the resistance is decreased. If the chemical structure of the membrane allows more material to pass through, there is less mechanical resistance experienced. This is affected by the composition of the membrane, the fouling layer (the waste accumulated on top of the membrane), and the resistance of the solution that passes through the membrane. The flux is the physical amount of material that passes through the membrane. Normally, the membrane is operated at fluxes between 10 and 150 liters per meters squared per hour. The pressure is what pushes the solution forward and through the membrane. This is connected to the flux. With an increased pressure, there is an increased amount of flux because more solution is being pushed through over a duration of time. The pressure in a membrane is referred to “transmembrane pressure (TMP)” [9]. For a successfully operating membrane, it is desirable to have characteristics tailored to the needs of the specific task.

After careful construction of a membrane, the wastewater flows through the membrane. Bacteria, waste, and other materials resistant to the membrane will not be able to pass through and will be biologically broken down as explained in the previous section. The clean permeate will exit the membrane and can be used for the needs of the industry or, in some cases as explained later, go through a secondary treatment to increase the purity of the water. Researchers studied just how effective the combination of this membrane technology was when combined with biological processes. By examining the removal efficiency of different types of emerging contaminants (ECs) in wastewater, they proved that while MBRs did not sufficiently remove pesticides, they were roughly 95% effective in removing endocrine disruption chemicals (EDCs), 100% effective in removing personal care products (PCPs), such as propyl parabene and salicylic acid, yet they were comparable in removing pharmaceutical contaminants to other water filtration systems. However, when the MBR system was manipulated to utilize slow degradable biological processes, it was more effective [10].

The word hybrid implies a mix, a combination of two, to make something new and unique. Hybrid systems in water filtration are combinations of ordinary wastewater treatment options to enhance effectiveness through economical and environmentally reasonable methods. These systems began to be implemented because conventional methods were not as effective at removing new contaminants that were being found in waste [10].

Membrane bioreactor technology can already be considered a type of hybrid system because it is combining biological and chemical treatment into one process, but when MBR is combined with a process, such as reverse osmosis it better removes ECs “up to 99%” [10]. The two processes work very well together because they increase the efficiency of the other. Because the membrane produces “low suspended solids”, reverse osmosis is more effective, while the biological process in MBRs eliminates the need for clarifiers that are used in the reverse osmosis process [12]. This ultimately reduces the total environmental footprint of the system and is more cost friendly. The MBR system itself can also be very expensive, but when paired with reverse osmosis it can clean more types of ECs. Increasing its effectiveness over a wider range of emerging contaminants makes the MBR-reverse osmosis system more cost effective [10].

Though reverse osmosis is being used to increase the quality of the reusable water that is produced from the MBR system, it can remove the impurities of large volumes of water on its own. In the reverse osmosis process, dissolved inorganic solids that passed through the membrane in MBRs, such as pesticides, are removed from the solution. According to ESP Water Products, there are generally four stages in the reverse osmosis process: the sediment filter, the carbon filter, the reverse osmosis membrane, and the polishing filter. The sediment filter screens for substances like salts and dirt, while the carbon filter is designed to remove chemical contaminants, like emerging contaminants (ECs). The reverse osmosis membrane is like the membrane of MBRs in its selectivity, and the final, polishing stage is one last filter to ensure quality. [13].

Incorporating these hybrid systems enables industry to further customize their wastewater treatment. While there are numerous ways to combine ordinary and conventional wastewater cleaning methods, there are common characteristics: reliability, quality permeate, and low life cycles [12]. The following example illustrates how the water may flow through a MBR-reverse osmosis system. The MBR and reverse osmosis systems are highlighted to illustrate that while the systems are combined, they are two
independent systems. The surroundings are holding tanks for the water before they proceed to the next step and chemical holding tanks that store and send the chemicals as needed to the processes.

**FIGURE 1 [12]**

Chemical Cleaning Process

The benefits of MBR-reverse osmosis system are that it is variable and easy to operate. This is integral because wastewater treatment is not the main priority of the industries that employ them; instead, they are a “needed evil” [12]. No longer can water be used unnecessarily without a real purpose, instead all decisions regarding large-scale water consumption must be methodical.

**TURNING DISADVANTAGES INTO ADVANTAGES**

**MBRs and the Environment**

Despite all of the positive aspects to the membrane bioreactor, it does have disadvantages associated with it. The impact of the membrane bioreactor on the environment was studied by L. Ioannou-Ttofa et al. through life cycle analysis. The main purpose of this study was to examine the overall environmental sustainability of several different parts of the membrane bioreactor processes and technology in order to determine its true overall efficiency.

**FIGURE 2 [14]**

MBR Pilot unit

An IPCC 2013 impact assessment method was used to determine the amount of CO2-eq emissions from the MBR pilot unit. This assessment concluded, “the majority of the CO2-eq emissions is traced back to the energy used by the lift pump and the air blower in the pre-aeration stage and the air feeding and the permeate pump in the MBR stage” [14]. While there are negative emissions associated with the MBR process, they are restricted to the mechanical stages as opposed to the water treatment itself.

The construction phase of the MBR unit has a minimal environmental impact due to the fact that the materials used are not associated with high environmental impacts and they have an overall high life span. Comparing the treatment of the wastewater effluent per capita in a Cyprus unit and MBR unit, it is obvious that its emissions would contribute less than 1.2% of the mean daily CO2-eq emissions per capita. This low contribution illustrates the sustainability of the MBR technology for treating urban wastewater effluents” [14].

Another method used to study the environmental footprint of the MBR system and the midpoint and endpoint impact categories affected by MBR operation was the ReCiPe impact assessment method. From this assessment, it was concluded that the midpoint impact categories were mainly affected by indirect emissions from oil extraction and electricity production and do not directly come from the MBR system itself. The main energy source for the bioreactor in this experiment was the combustion of oil, thus many negative results were found based on the use of fossil fuels and the release of toxic materials [14].

When it comes to the total environmental footprint of the MBR pilot unit, it was found to yield low, but still important negative environmental impacts. For this reason, L. Ioannou-Ttofa et al. also studied alternative scenarios to improve the sustainability of the bioreactor. One of these is using solar energy, since many fossil fuels are consumed and airborne emissions are released during manufacturing. Another alternative measure is using a more environmentally friendly membrane material. “If the membrane material is to be substituted by ethylene propylene diene monomer (EPDM), it is found that it can reduce the membrane unit contribution to the total greenhouse gas emissions almost by half” [14]. If the membrane material is changed to an ethylene propylene diene monomer, EPDM, the emissions that are given off could be decreased dramatically. MBR technology is generally very sustainable, but with these slight changes, even more advantages can come out of the process.

**Membrane Fouling**

Membrane fouling is the major drawback impeding MBR’s to spread into more applications for wastewater treatment. This is because it significantly reduces membrane performance and lifespan, which ultimately leads to an
increase in costs for maintenance and operation. According to the International Union of Pure and Applied Chemistry (IUPAC) Working Party on Membrane Nomenclatures, membrane fouling is “the process resulting in loss of performance of a membrane due to the deposition of suspended or dissolved substances on its external surfaces, at its pore openings, or within its pores” [15]. Membrane fouling is attributable to certain substances, which can be microorganisms, cell debris, colloids, solutes, or sludge flocs, that deposit on the surface of the membrane and go into the pores. This can lead to three different scenarios: pore narrowing, pore clogging, and cake formation [15].

Increasing temperatures lead to increased amounts of fouling. “Very low temperatures are associated with an increased occurrence of filamentous bacteria, which produce more SMPs in the MLSS, hence more propensity for membrane fouling.” [15]. SMPs are soluble microbial products, which contribute to membrane pore blockage and thus cause fouling. In order to overcome these problems associated with low membrane temperatures, MBRs should operate at ambient temperature and sudden temperature changes should be avoided. Lastly, feed and biomass characteristics play key roles in membrane fouling. Mixed Liquor Suspended Solids (MLSS), Extracellular Polymeric Substances (EPS), Floc size, and pH are all factors associated with feed and biomass characteristics. As for pH, it has been found that low pH levels cause more severe fouling. Zhang et al. concluded, “that a repulsive energy barrier exists between sludge flocs and the membrane surface; and, this repulsive energy barrier decreases with decreasing pH which in turn facilitates the attachment of foulants to the membrane” [15]. In order to avoid low pH levels causing a large amount of fouling, alkalinity is required to buffer the hydrogen ions that are generated in MBR processes [15]. All in all, membrane characteristics, operating conditions, and feed and biomass characteristics are all key factors that influence membrane fouling in molecular bio-reactors.

As for the temperature, it has been reported that lower temperatures lead to increased amounts of fouling. “Very low temperatures are associated with an increased occurrence of filamentous bacteria, which produce more SMPs in the MLSS, hence more propensity for membrane fouling.” [15]. SMPs are soluble microbial products, which contribute to membrane pore blockage and thus cause fouling. In order to overcome these problems associated with low membrane temperatures, MBRs should operate at ambient temperature and sudden temperature changes should be avoided. Lastly, feed and biomass characteristics play key roles in membrane fouling. Mixed Liquor Suspended Solids (MLSS), Extracellular Polymeric Substances (EPS), Floc size, and pH are all factors associated with feed and biomass characteristics. As for pH, it has been found that low pH levels cause more severe fouling. Zhang et al. concluded, “that a repulsive energy barrier exists between sludge flocs and the membrane surface; and, this repulsive energy barrier decreases with decreasing pH which in turn facilitates the attachment of foulants to the membrane” [15]. In order to avoid low pH levels causing a large amount of fouling, alkalinity is required to buffer the hydrogen ions that are generated in MBR processes [15]. All in all, membrane characteristics, operating conditions, and feed and biomass characteristics are all key factors that influence membrane fouling in molecular bio-reactors.
highlight the fact that modifications must be made to the membrane itself and procedures involving the treatment of the membrane. The hydrophilicity of the membrane is a surface modification that can affect the amount of fouling. In this case, many commercial membranes are made from hydrophobic polymers that are prone to the absorption of fouling substances. To counteract this, the hydrophilicity of the membrane surface should be increased. “Due to the formation of hydrogen bonds, a thin layer of bounded water exists on the surface of the hydrophilic membrane. This layer can prevent or reduce undesirable adsorption or adhesion of the foulants on the membrane surface” [16]. A more hydrophilic, or water loving, membrane can lead to less amounts of fouling in the membrane. Many other surface modifications including coating and nanoparticles can target and decrease fouling in membrane bioreactor systems. Researchers should focus on new aeration systems, cleaning methods, and emerging technologies in order to further reduce the effects of fouling in MBRs [16].

INDUSTRIAL APPLICATIONS

Below are shown the two basic configurations of MBRs that are used in industrial settings: submerged (b) and side-stream (a).

Because of the submerged system’s lower flux rate, more capital is required, specifically membrane material, to effectively purify the water, compared to the side-stream system which does not encounter this problem.

MBR and the Real-World

The underlying technology behind MBRs is clearly valid, however like all technology MBRs have disadvantages. Yet, industries have had great success with the technology, specifically the brewing industry in Africa and PepsiCo Frito-Lay’s snack manufacturing.

In Africa, the borehole from which the water was being collected from began to become increasingly contaminated with high levels of seawater. Researcher’s primary goal was to decrease water consumption from the borehole. This would hopefully allow the borehole water quality to increase, hence protecting it from further contamination. Therefore, they employed a MBR-reverse osmosis system, which has shown “excellent performance” [12]. This application of MBRs shows how MBR technology is contributing to water conservation efforts. Rather than continuing to use the decreasing water supply, this industry has taken advantage of a developing technology to not only decrease water consumption, but to increase the remaining borehole water purity for the use of others.

PepsiCo. is also utilizing MBR technology, but their use of MBRs can be classified as water management, rather than solely conservatory. Frito-Lay in Casa Grande, Arizona, PepsiCo. was the first food manufacturing company in the United States to be awarded with a U.S. Water Prize from the Clean Water America Alliance (CWAA). They earned the award for utilizing membrane technology to clean water up to the Environmental Protection Agency’s (EPA) drinking water standards [18]. They reused this water in their snack food plants to transport foods from one station to the next. Recycling water has enabled them to save millions of gallons of water, as well as free up land space for solar panels that now power their plant [18]. PepsiCo also installed the MEMPulse MBR by Evoqua from Siemens’ Industry Automation Division in their Santiago, Chile plant [19]. This system utilizes the combined biological process of activated sludge along with the membrane technology discussed throughout this paper. Evoqua lists the key benefits of this product as, “dependable process performance, low operation and maintenance costs, automated operation, reduction in energy costs, superior effluent quality, drastically reduced system footprint, and up to 90 percent biosolids reduction,” [20]. A Siemen’s statement explains the MBR technology is used to clean the initial water used in the potato chip and other snack food production systems, which is then recycled in the manufacturing processes [19]. PepsiCo is trying to implement water reusing processes across all of it plants because of a growing corporate initiative towards green technology. Their use of the MEMPulse MBR system is.
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“more advanced than conventional wastewater treatment processes, producing consistently high-quality effluent in a smaller footprint.” [19].

Not only have industries improved water quality and reduced water consumption with MBR systems, but they have saved money due to less energy consumption. [3]. Because water is a finite resource, production costs will rise because of increasing demand with a growing population. Technologies like MBRs and reverse osmosis systems will become more significant to reduce costs. Industries have also largely scaled down their environmental footprint through being open-minded to new advanced approaches. Making steps towards sustainable facilities is a commitment, but by even taking small steps, such as turning off the faucets or hoses and fixing leaky pipes [1], companies can improve images that large corporations are wasteful and inefficient.

SUBSTANTIAL PROOF FOR SUSTAINABILITY

Sustainability typically implies that a product or design is environmentally friendly, socially acceptable, or economically viable both now and for the future. As evident throughout this essay, membrane bioreactors exhibit characteristics of all three. This technology is especially innovative because of its flexibility in these categories as well. In the section “Turning Disadvantages Into Advantages”, it was determined that while there are environmental drawbacks to this design, there are ways to combat them and the overall benefits far exceed the disadvantages. MBR technology was developed to diminish wasteful water use and increase the reuse of water, resulting in a benefit for the community. Currently, MBRs are reducing water usage and saving companies money in wastewater treatment; however, if further technology is pursued, it may be possible to expand the technology by incorporating technology like MBRs into daily life. Finally, MBR technology is economically friendly due to variability, its defining characteristic. MBRs can be designed for an application’s specific need; therefore, it can be designed as cost efficient as well. Encompassing all aspects of sustainability not only provide further proof of the importance of this technology, but prove that technology can develop in a sustainable manner.

RELATING INDUSTRIAL METHODS TO EVERYDAY LIFE

In conclusion, to continue to grow as a society, problems must be approached in different fashions. The use of MBR systems and MBR hybrid systems, including reverse osmosis, enable industries to turn away from detrimental environmental habits and form sustainable, long-term solutions. However, individual citizens may not see the benefits of such actions; therefore, it is the job of engineers to transform this success into something more impactful. This leads to the bigger question; can we take this industrial application and turn it into something that we could use daily?

SOURCES

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