WHITE PAPER

HTI'S Forward Osmosis Membrane Bioreactor Process (OsMBR) – A rugged, versatile and ecobalanced process for Industrial Wastewater plus Reuse:

Truly Sustainable Wastewater Treatment Design for a Changing World

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The topic of wastewater recycle and reuse in industries manufacturing diverse and different products like automobile parts, chemicals, engineering polymers and plastics, pharmaceuticals, ethanol, food ingredients, textiles, microprocessors, leather goods, minerals from mining and metals processing, cosmetics etc. is gaining increasing attention in boardrooms of corporations around the world. This attention stems from the strategic objectives to grow while being thrifty in using a limiting and absolutely necessary resource - ***water.*** Complementary drivers for wastewater recycle plus reuse include a mandatory requirement in many countries as a prerequisite for production capacity expansion and core value of sustainable and eco-balanced growth.

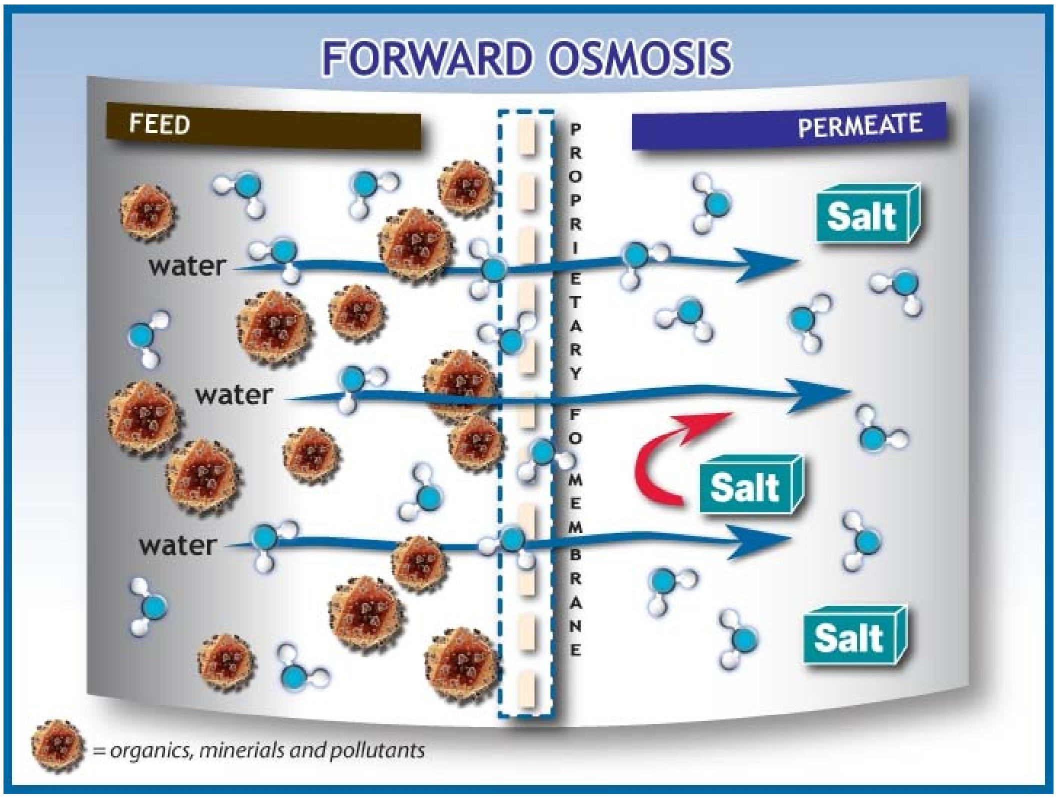
In the last decade, acceptance of membrane bioreactors has experienced a compounded annual growth rate exceeding 15%; mostly in the municipal segment where wastewater chemistry is reasonably homogeneous, while the industrial segment has been more measured in installing MBR systems. Growth in the industrial segment has lagged behind the municipal segment primarily due to the heterogeneity of industrial waste water chemistry based on a variety of products manufactured as well as site specific and shift specific production schedules that fluctuate bioreactor or digester chemistry.

Hydration Technology Innovations (HTI) is developing technology solutions that address the industrial segment with OsMBR™ for Industrial Wastewater Recycle plus Reuse and can demonstrate an attractive return on investment that can justify implementation today!

Forward Osmosis as the Critical Leveraging Technology for MBRs:

HTI has developed an innovative OsMBR to utilize a semipermeable osmotic membrane in the MBR system, thus overcoming many of the disadvantages in present-day MBR systems. As opposed to using a pressure or vacuum driven process employed by present-day MBRs, HTI uses a process called forward osmosis (FO) to extract water out of the mix liquor. FO provides some specific and unique advantages in treatment in this application.

Forward osmosis is a process by which water passes from a solution at lower concentration towards a solution at higher concentration when the two solutions are separated by a semipermeable membrane. In nature, membrane mediated osmosis is responsible for the ability of plants to absorb water through their roots and human beings to absorb water through their digestive system. It is also the mechanism by which biological cells regulate the transport of water in and out of the cell. The cell can be regulated by the concentration of either inorganic salts (electrolytes) or sugars in the cellular fluid, and is mirrored in the range of draw solution used in various HTI products and processes.



HTI is the leading provider of FO technology. We have successfully demonstrated the use of forward osmosis in applications such as fruit juice concentration, treatment of wastewater produced during natural gas extraction and hydration products for military and disaster relief applications. HTI is the only commercial manufacturer and supplier of FO semi-permeable membranes.

HTI's OsMBR™ system for Industrial Wastewater Recycle plus Reuse applies the process of forward osmosis in MBRs. It uses an draw solution which is a concentrated solution of organic and inorganic solutes (dominated by NaCl/salt) with high osmotic pressure, and circulates it on one side (draw side) of the FO membrane while the other side of the FO membrane (feed side) is in contact with the mix liquor in the activated sludge tank. Since the osmotic pressure of the mix liquor suspended solids (feed side) is significantly lower than that of the draw solution, water passes from the activated sludge through the FO membranes into the draw solution. The diluted clean draw solution goes to a polishing process using RO or NF to be reconcentrated and circulated back to the FO membrane, while high quality water is produced for Reuse.

Criteria and performance requisites that differentiate industrial membrane bioreactors from municipal membrane bioreactors are:

>> **SIZE** – Typical size or capacity is much smaller. For example, a 10,000 cubic meters per day capacity would be a large industrial MBR.

>> **Variable wastewater quality** – Industries manufacture an assortment of products with different and proprietary chemistries and formulations. Cosmetics, food canning and CETPs (common effluent treatment plants) are examples where wastewater composition of BOD, COD, TSS, N, P and TOC to TN ratio can change more than once each day.

>> **Wastewater feed composition** - It is not uncommon to see TOC to TN ratio as high as 95% in industrial bioreactors. Municipal wastewater typically has a ratio of 80%. **It is therefore important to have an MBR design and operating procedure to address this higher nitrogen load reliably and consistently.**

>> **Initial start-up and start-up after shut down** – Short seeding time and high separation efficiency of bio solids is important to an industrial site when satisfactory operation of the site's industrial MBR is necessary to begin and sustain production of commercial products for sale.

>> **CAPEX & OPEX** – It is this author's experience that generically, industrial MBRs are designed at lower net average flux rates, and operations management places more emphasis (than municipal MBR operations management) on operating efficiency, lower manpower and chemicals / power use and higher reliability of membrane(s) as separation barriers regardless of the fluctuations in biochemical process parameters.

HTI's Forward Osmosis OsMBR™ system and process:

Principal differences from the better known conventional MBR systems (submerged and external) are summarized below:

1. **Membrane:** The heart of HTI's OsMBR™ system is forward osmosis CTA (cellulose triacetate) or TFC PA (thin film composite polyamide) polymer chemistry membrane. Conventional MBR systems utilize either Microfiltration or Ultrafiltration membrane. If one takes a quick look at the liquid separations spectrum showing MF, UF, NF and RO pore sizes, FO membrane pore size is similar to RO, offering similar rejection characteristics. **However, since principles of operating FO are very different than RO, HTI's FO membrane in an OsMBR process operates at similar or slightly HIGHER NET FLUX (different than instantaneous flux) of a tubular or a flat sheet conventional MBR process.**

2. **TOC removal efficiency:** The FO membrane in HTI's OsMBR process has a measurably **higher** TOC removal efficiency than a Microfiltration or Ultrafiltration pore regime based conventional hollow fiber, flat sheet or tubular MBR process. TOC removal efficiencies in conventional MBR processes vary in the range of 30% to 75%, while **HTI's OsMBR™ process with an FO membrane (CTA or TFC PA) has 98% efficiency.** This is important because every industrial MBR customer prefers to install an RO system in an integrated process foot

print to allow reuse of permeate in their production process. Soluble organic matter in permeate of MF or UF membrane based MBR systems is the principal cause of fouling of downstream RO membrane. Fouling causes an increase in TMP (transmembrane pressure), cleaning frequency, power requirements and results in degradation of the polyamide skin layer. **The FO membrane with a 98% TOC removal efficiency will allow the downstream RO to operate in longer cycles, and lower fouling results in longer life before replacement and lower power cost from a slower and more gradual rise in TMP.** An enticingly attractive option for a system designer is to take advantage of this benefit and design the downstream RO (to OsMBR) at a higher flux and/or higher recovery than typical for MBR/RO systems.

3. **Removal of Phosphorus (P):** Conventional MBR systems achieve removal of P by addition of flocculants. The larger particle floc then gets filtered or rejected by the MF or UF membrane barrier in a physical (size exclusion) separation. **The FO membrane based OsMBR system rejects P more cost effectively because the removal is based on size exclusion (without flocculation) and charge density separation.**

4. **Bioreactor design:** Bioreactor VSS (volatile suspended solids) is generally based on membrane permeability and membrane efficiency estimations. The flexibility of HTI's OsMBR™ process makes it adaptable to a membrane configuration external to the bioreactor or internal to the bioreactor. For example, in a design where the FO membrane is external to the bioreactor, the OsMBR can be operated at high cross flow velocities using high TMP and VSS values in excess of 30 grams per liter.

5. **Placement flexibility:** HTI's OsMBR™ system allows the industrial MBR customer and design engineer to choose the configuration (internal or external) that best suits the requirements as dictated by site specific parameters like footprint, membrane performance consistency influenced by bioreactor design and CAPEX to OPEX balance.

6. **Flexibility in manipulating HRT (hydraulic retention time) and SRT (solids retention time) balance:** The FO membrane in HTI's OsMBR™ process gives the design engineer more latitude to adjust the time. This point is explained in detail in the Draw Solution section below.

7. **Cleaning cost and ultra-low fouling characteristics:** In a forward osmosis OsMBR process, the lack of hydraulic pressure across the membrane means that colloidal, particulate and chemical foulants are not forced into the membrane skin layer and substrate layer. **Because frequency between cleanings impacts energy requirement, labor, system productivity and membrane integrity, this is an important benefit of the HTI OsMBR™ process.**

8. **Air Scouring:** Conventional MBR system design has evolved to continually improve the economy of energy required for scouring, backwashing and aeration. However, it is true that the MF or UF fibers require an intensity of physical agitation to scour the membrane surface to reduce particulate and colloidal deposition within the pore structure. Moreover, the air diffusers used to scour membrane surface may not be optimal for oxygen transfer into the mix liquor thereby adding to energy consumed.

HTI's OsMBR™ with its FO membrane pore size and the use of osmotic pressure as the driving force means reduction in the propensity to foul and the fouling that happens is not pore but surface – requiring less aeration and energy to clean. In addition, fine bubble diffusion for oxygen transfer and a longer interval between backwashing and cleaning also should require less energy. HTI is accumulating data to substantiate this technical hypothesis.

Performance Efficiency of HTI's OsMBR™ process for Industrial applications:

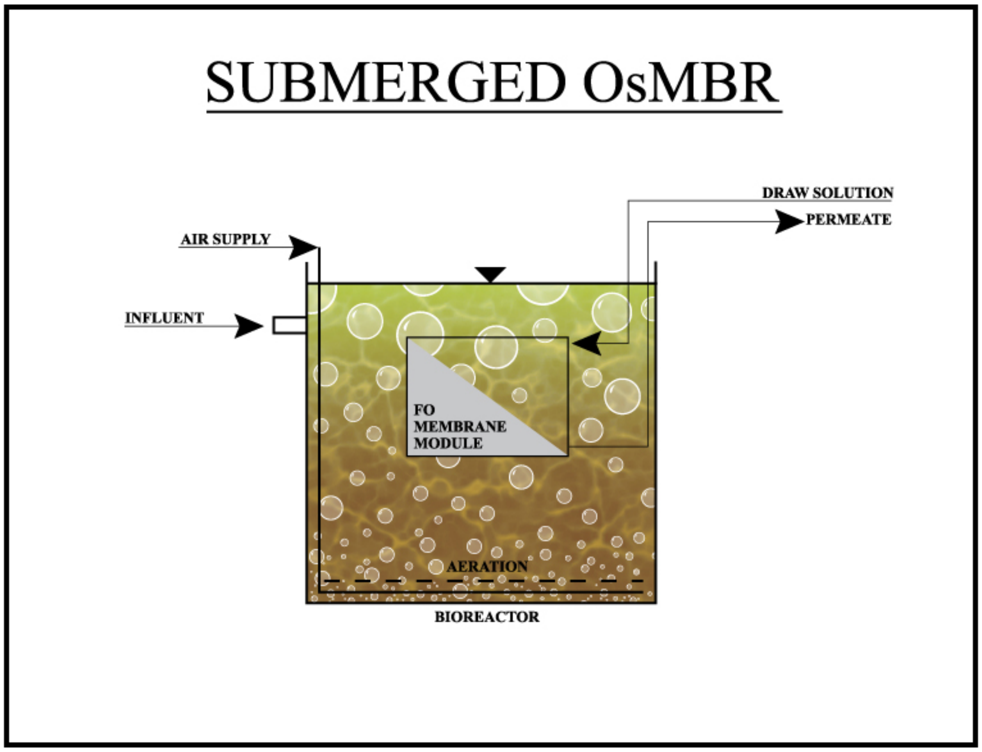
Rejection

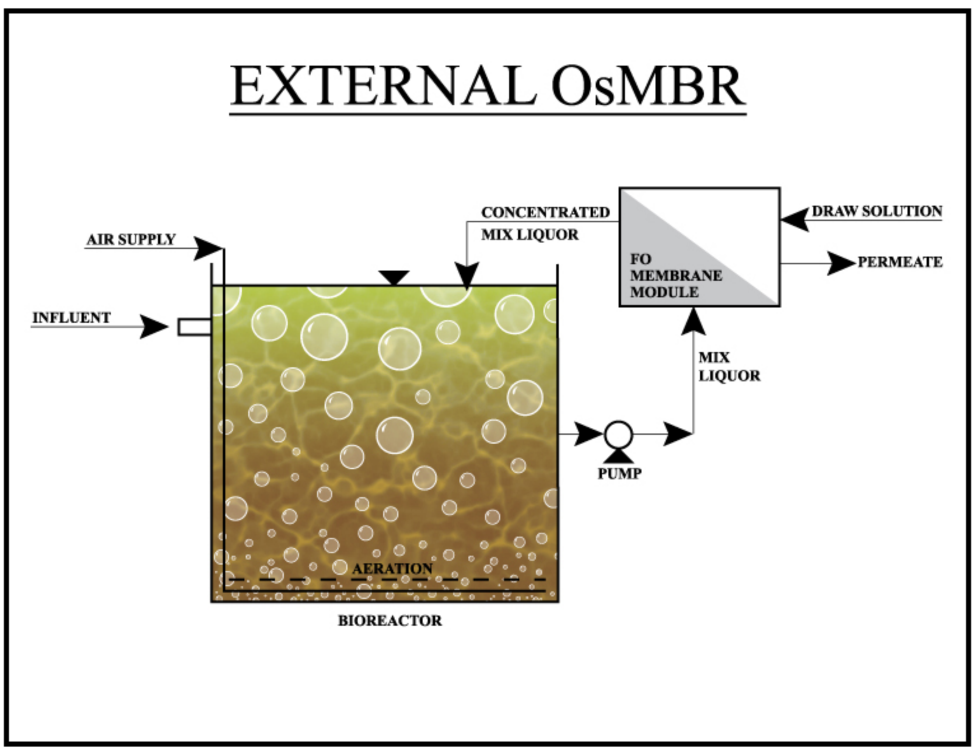
Parameter	% rejection by FO	% removal by OsMBR	% removal by OsMBR plus RO
TOC (mg/l)	>97	>99.7	>99.7
NH4+-N (mg/l)	>90	>97.5	>99.2

Energy Usage per Cubic Meter of Water Treated

	Component	Conventional MBR plus High Quality Water Reuse	HTI's OsMBR™ plus HQ Water Reuse
1	Mixer in the anoxic tanks	0.04kWh/M^3	0.01kWh/M^3 (no anoxic tank)
2	Membrane filtration	0.04kWh/M^3	0.01kWh/M^3 (minimum flow – osmotic drive circulation)
3	Submerged recirculation	0.21kWh/M^3	0.01kWh/M^3
4	Blower for membrane cleaning	0.49kWh/M^3 (Double Deck)	0.15kWh/M^3
5	Blower for auxiliary air diffuser (shortage for 4)	0.12kWh/M^3	0.12kWh/M^3 (minimal membrane cleaning)
6	R0 or NF Polishing for High Quality Reuse	3.30kWh/M^3	2.50kWh/M^3
	Total energy estimate	4.20kWh/M^3	2.80kWh/M^3

Typical HTI OsMBR™ system configurations:





Importance of selecting the optimal Draw Solution in the OsMBR process:

While selection of the right FO membrane, CTA or TFC PA is important, the selection of the right draw solution, its concentration and understanding the impact on the rate of reverse salt transport, relationship of membrane ageing to daily sludge wasting, HRT and SRT - are equally important.

For example, based on HTI's domain know-how, the operating levers to mitigate salt accumulation from reverse salt diffusion in an OsMBR include:

1. Utilizing the interplay between HRT and SRT that specifically suits the morphology and chemistry of an FO membrane instead of emulating the design practice typically used in conventional (MF/UF) MBR.

2. Customizing FO membrane chemistry and substrate structural properties to minimize dilutive internal concentration polarization in the OsMBR process, increasing flux and minimizing reverse salt diffusion.

3. Choosing a draw solution (solute) that has low reverse salt diffusion and is biodegradable. The biodegradability of the draw solution makes the passage from reverse salt diffusion in the bioreactor not just non-toxic but actually useable as nutrient for the bacteria.

4. Internal recirculation factor: By maintaining a high internal recirculation factor (cross flow velocity) as advocated by HTI, the design engineer can count on reduction in per pass concentration of dissolved solids. A higher pressure differential can also be maintained between the feed side and the draw side of the FO membrane thereby allowing higher flux and reducing reverse salt diffusion.

A truly unique and singularly differentiated feature of HTI's OsMBR™ process know-how is the capability to help the industrial MBR customer manage the metabolically disruptive bioreactor / digester upsets caused by variability in feed wastewater chemistry and biology from changes in different manufacturing products being made on a given day. HTI can do this by choosing draw solution formulations to correct the imbalance of nutrients and micronutrients to stabilize the bioreactor microbiology, while the FO membrane system protects the RO system from the damaging constituents of imbalanced filtrate from a traditional MBR upset.

HTI's OsMBR™ system for Industrial Wastewater Recycle plus Reuse, is an evolutionary and adaptable, "bolt on" innovation in MBR Technology. HTI looks forward to developing and commercializing the acceptance of forward osmosis membrane bioreactor (OsMBR) process for Industrial Wastewater Recycle and Reuse applications.

For more information on HTI's OsMBR technology, please contact:

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