Low-Cost Membranes for Nanofiltration and Reverse Osmosis Water Purification

B. Berland[1], K. Huntley[2] and M. Misra[3]

[1]ITN Energy Systems, Inc., Littleton, CO, USA, bberland@itnes.com
[2]ITN Energy Systems, Inc. Littleton, CO, USA, kimjhuntley@aol.com
[3]ITN Energy Systems, Inc., Littleton, CO, USA, mmisra@itnes.com

ABSTRACT

ITN has developed a proprietary nanocomposite water filtration membrane that outperforms state of the art membranes with the following attributes:

- Excellent selectivity (passing water while rejecting contaminants)
- High water flux (gallons of clean water per minute produced)
- Chlorine Tolerance
- Anti-Fouling (extended clog-free operating times)
- Durabilty (long lifespan without leaking, breaking, or losing functionality)
- Low cost

ITN's membrane design includes a selective layer made from an inexpensive polymer fabricated onto a robust support to provide good water flow at relatively low pressure, which eliminates the energy and equipment costs of high-pressure pumps. Energy savings can be up to 30% [1]. In addition, the advanced chemistry of ITN's membrane ensures significantly longer membrane life without the fouling (clogging) that occurs with state of the art membranes.

Keywords: water purification, membranes, reverse osmosis, nanofiltration, nanocomposite membrane

1 WATER PURIFICATION

Worldwide demand for water purification capability has skyrocketed due to the following factors:

- Fresh water scarcity (climate change, drought)
- Population growth
- Industrial expansion
- Contamination of surface water (pollution)
- Government regulation (tougher clean water standards)

Water can be purified with various impurity removal and disinfection methods, including:

- Chemical additives to coagulate and precipitate impurities
- Ionic chemicals, ozone, and ultraviolet treatments to kill viruses and bacteria
- Membrane filtration to selectively pass water while blocking contaminants

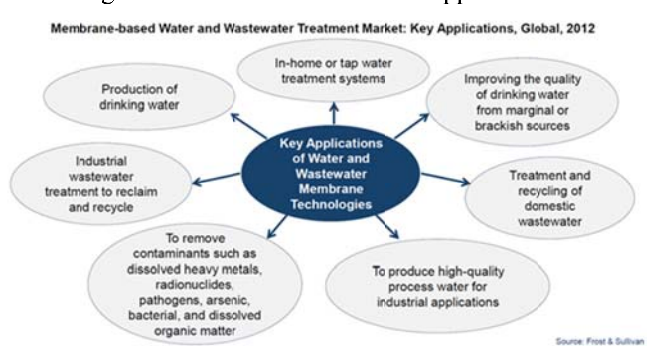
Processes can be effective at removing certain impurities, but not others, i.e. they may kill bacteria but not remove salts or arsenic, or they may detain certain inorganic particulates without removing microorganisms. Of these methods, only membrane filtration can provide a complete purification solution.

Membrane treatment is the most reliable and proven technology for providing safe and high quality water to the growing global population and for industrial applications. Membrane systems offer operating savings and reduced water and energy footprints. New treatment systems are predominately moving to a sustainable all-membrane approach. [2]

In addition to waste water processing, salinity management (removing salt) is expected to become critical to more regions. Membranes are seen as the preferred way to address desalination issues.

Membrane filtration systems can be designed for high water selectivity, which means that contaminants are blocked, while water is allowed to pass through. Membrane systems are available in different grades, from ultra-pure water filtration to home water softeners to less selective systems designed to reduce pollutants for agricultural use, etc. Advanced water filtration technologies yield a much higher quality of water when compared to the existing conventional water filtration technologies.

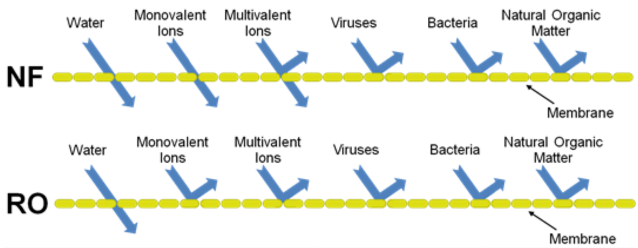
Figure 1—Membrane Filtration Applications



1.1 Water Filtration Technologies

Membrane filtration technologies are classified into 2 categories: 1) Nanofiltration (NF), and 2) Reverse Osmosis (RO). Both are pressure filtration techniques, and both use size sieving as the separation mechanism. RO incorporates finer pore sizes for more stringent filtration, and therefore requires higher pressure (Figure 2).

Figure 2—Nanofiltration vs Reverse Osmosis



	NF	RO
Membrane pore structure	loose	tight
Operating Pressures	75 to 150 psi	250 to 800
Operating Costs	Low	High

1.2 The Opportunity

Current membrane filtration systems are expensive.

- They require high pressures to process large volumes of water, leading to expensive infrastructure and high energy costs for pumps, etc.
- Membranes are prone to frequent fouling (clogging with organic materials that degrade water flow)
- Membranes are susceptible to chemical degradation (primarily from chlorine disinfectants), which causes decreased flow, impaired function, and breakage.

Membrane filtration has benefits for removing contaminants from water.

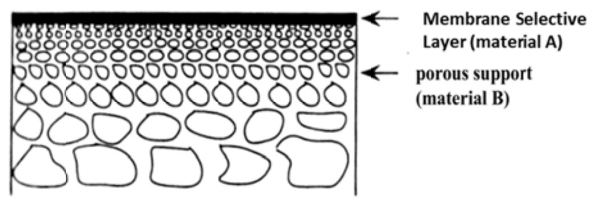
- Unlike water treatment via coagulation, which uses significant amounts of chemicals, membrane filtration eliminates need for these chemicals.
- Similarly, while water quality of coagulation and activated carbon technologies depend on the feed water quality, membrane technology can offer consistent water quality for a variety of sourcing.
- Membrane systems require less space to produce the same quantity of water than other filtration systems.
- Membrane processes are modular to meet a wide range of market demands.
- Membrane-based systems are highly automated which enables low-cost operations and minimizes need for highly skilled labor force and/or native chemical/mechanical supply chains.

1.3 ITN's Filtration Innovations

ITN's membrane design includes an ultrathin selective layer made from an inexpensive polymer fabricated onto a robust support (Figure 3). Since water flux is inversely proportional to the membrane thickness, ITN's submicron selective layer enables high water flow at relatively low pressure, which eliminates the energy and equipment costs of high-pressure pumps. Similar approaches have been employed with thin film polyamide membranes. However, the interfacial polymerization process leads to expensive membranes and difficulty achieving uniform performance over large area in manufacturing. ITN's membrane avoids these problems as the polymers are already formed in the slurry used to cast the selective layer.

Operation of ITN's membranes at reduced pressure significantly reduces the system's long-term cost of ownership. The membrane support employs a highly porous material that doesn't significantly impeded water flow while still providing the needed mechanical strength to the composite membrane.

Figure 3—ITN's Asymmetric Nanocomposite Membrane for Water Purification.



2 TECHNICAL DISCUSSION

2.1 ITN's Membrane Materials

Table 1 shows a comparison of ITN's NF membranes relative to commercially available NF membranes. Typically, one has to choose either high cost membranes with high water flux and poor fouling and chlorine tolerance or lower cost membranes with low water flux and good fouling and chlorine tolerance. ITN's membranes offer a unique combination of a cost-effective membrane with high water flux AND fouling and chlorine tolerance.

We have demonstrated the feasibility of fabricating our polymer-based thin film composite membranes for applications in NF water purification. For the same solute rejection, the expected water flux of ITN membranes in the preliminary experiments was found to be about 2.75 times higher than that of industry leading commercial NF membranes cellulose acetate (CA) membranes. ITN also has encouraging preliminary results and a roadmap to transfer this technology to RO membranes.

Figure 4—ITN's NF membrane performance compares favorably with commercial CA membranes

Large-scale testing (140 cm^2 membrane sheets)		
Performance Characteristics	**Cellulose Acetate commercial NF Membrane**	**ITN's NF Membrane**
Water flux (l/m^2-hr-bar)	2.5	**4.7**
$MgSO_4$ rejection (%)	98.5	**99.0**
Testing conditions: 200 psi, 2000 ppm $MgSO_4$ soln.		

Table 1—ITN's composite NF membrane provides a unique combination of a cost-effective membrane with high flux at low pressure AND antifouling with chlorine tolerance.

Characteristics	ITN's Composite Membranes	Cellulose Acetate Membranes (Commercial)	Polyamide Composite Membranes (Commercial)
Membrane configuration	Thin film composite membrane	Asymmetric membrane	Thin film composite membrane
Water flux	High	Low	High
Salt or contaminant rejection	>99%	97%	>99%
Free chlorine tolerance	≥ 1.0 ppm	Up to 1.0 ppm	< 0.1 ppm
Membrane fouling tendency	low	low	high

2.2 Competitive Advantages

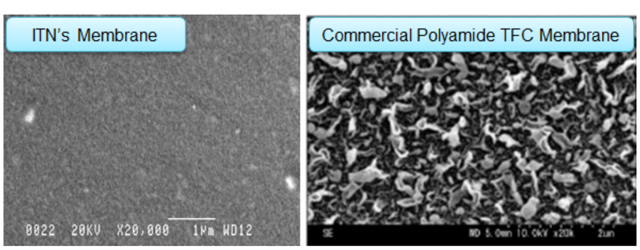
ITN's membrane provides a unique combination of properties that result in the best overall solution for water filtration. These advantages include:

(i) Scalable, large area membrane fabrication and low cost: In the case of polyamide TFC membranes, the polymer is made in-situ on the microporous substrate to deposit a thin film. Thin films of ITN's polymer can be deposited onto a microporous support by either simple dip coating or spray coating, so ITN's membrane fabrication process is scalable to large area membranes with more uniform performance and lower cost.

(ii) Higher water flux from thinner selective layer: Since the thickness of the selective layer is submicron, the ITN membrane has higher water flux than cellulose acetate asymmetric membranes with similar solute and salt rejection properties. Higher flux results in lower energy costs from elimination of high-pressure pumps, which makes the NF technology economically viable.

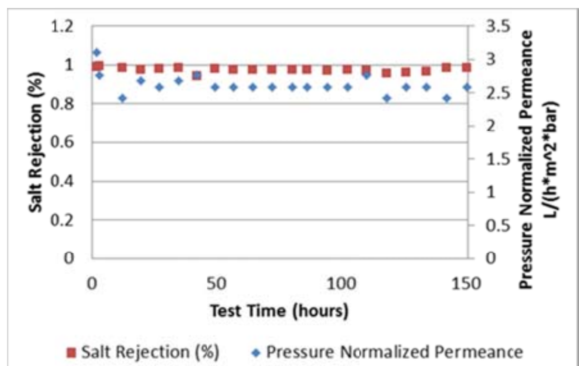
(iii) Lower surface fouling: ITN's NF membrane has significantly lower fouling tendency than other thin film composites due to lower surface roughness (Figure 5).

Figure 5—ITN's NF membrane, with a smooth surface, provide greater resistance to fouling.



(iv) Chlorine tolerance: Many applications employ disinfectants such as chlorine to kill micro-organisms that are dangerous to humans and degrade membrane performance. However, chlorine also attacks polyamide membranes. Figure 6 shows stable operation of ITN's NF membrane with 1 ppm chlorine.

Figure 6—ITN's membranes have demonstrated stable operation in 1 ppm chlorine.



(v) Tunable membrane properties: ITN's membranes have already been demonstrated to have promising properties for NF applications. Further, ITN has promising initial formulations and established a roadmap for to meet market demands for RO membranes.

(vi) Greater durability when dry: While commercial cellulose acetate membranes tend to crack when dried out, ITN's NF membrane remains pliable. (Figure 7)

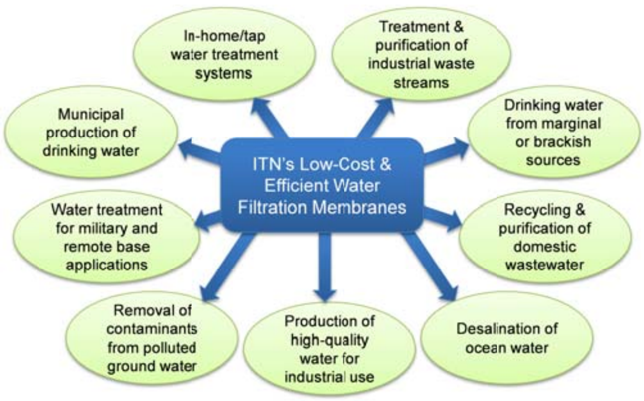
Figure 7—ITN's membrane remains intact after drying, while competing membranes crack and wrinkle when dried.

3 COMMERCIALIZATION

3.1 Market Strategy

ITN's filtration membrane technology can be used for numerous water filtration and purification applications (Figure 8).

Figure 8—Applications for Water Filtration Membranes



The biggest market for filtration membranes is large scale water supply systems for communities that rely on surface water purification to meet their daily needs. Municipal water use in the U.S alone is approximately 45 billion gallons of water per day (Bgal/day). Eighty percent of this (approximately 36 Bgal/day) is from surface water. In 2012, global revenue from membrane-based municipal water treatment reached almost $1.2 billion and is projected to exceed $2.5 billion by 2020.

ITN's technology will gain market penetration because of the competitive advantages described in 2.2, and because of ITN's efforts to work with industry partners with existing market presence. We expect to generate revenue through sales to multiple customer classes. First, the membranes will be sold directly to private and public operators of large scale NF water purification facilities as a direct replacement of current filtration systems. Secondly, they will be sold to filtration system manufacturers and suppliers. Companies such as Dime Water, DAICO, and Pure Aqua can use ITN's technology in new water filtration systems as well as retrofitting more expensive, less efficient water filtration systems.

ITN anticipates pilot scale production, testing, pilot production, and scale-up to mass production within five years. ITN expects to be able to capture 5% market share of the membrane water purification market within the first five years of mass production and commercialization.

Figure 9—ITN's spiral membrane modules was the first step on the roadmap to large commercial production.

REFERENCES

[1] A. Sagle and B. Freeman, "Fundamentals of Membranes for Water Treatment" http://texaswater.tamu.edu/readings/desal/membranetechnology.pdf

[2] North American Industrial Water and Wastewater Treatment Chemicals Markets Cost-effective Solutions will Drive Growth in the Market, Frost & Sullivan report, NAE2-39, May 2012