Poly-Cera™ Membranes: Combining the Economics of Polymers with the Robust Performance of Ceramics

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ABSTRACT

Ceramic membranes are thermally, mechanically and chemically robust, and hence, fouling-tolerant and easy to clean. They are preferred in challenging separations like industrial wastewater and oily water treatment. Traditionally, ceramic membranes are expensive, challenging to manufacture and produce low-packing density modules, and hence, large footprint plants. In contrast, polymeric membranes are easy and inexpensive to manufacture in high packing density modules and compact plant sizes, but they are less robust, do not tolerate fouling and degrade when cleaned too frequently. Also, they cannot be used in high temperature and extreme pH applications or for highly fouling prone waters. ***A membrane material that has the complementary strengths of ceramics and polymeric membranes is a long sought after innovation.*** Water Planet Engineering's next generation "polymeric-ceramic" or *PolyCera*™ membranes exhibit high thermal, chemical and mechanical stability like ceramics while retaining the ease of manufacturing, high packing density and favorable economics of polymers. It is envisioned that such a breakthrough membrane material could find widespread use in challenging water and wastewater treatment applications such as oil and gas produced water treatment, membrane bioreactors and beyond.

Keywords: Membrane, ceramic, polymer, ultrafiltration, wastewater

1 BACKGROUND

Since 2005, scientists at the University of California - Los Angeles (UCLA) California NanoSystems Institute (CNSI) have been exploring membrane formation from novel polymer nanostructures; as membranes these materials appear ceramic-like but are made from inexpensive polymeric building blocks. This fundamental materials science research lead to the development of a new class of patented and patent pending polymeric membrane materials that have disruptive potential in treatment of challenging waters in a range of industrial and municipal separations.

The membranes exhibit a host of interesting material properties, including: MF/UF separation performance, super-hydrophlic and super-oleophobic "glass-like" surfaces, anti-bacterial reactivity without nanoparticles or release of toxic compounds, high thermal, mechanical and chemical stability. Such a unique blend of properties in an inexpensive polymeric membrane material suggest obvious advantageous over traditional, commercially-available polyeric and ceramic membranes. Water Planet Engineering (WPE) is in the process of translating this breakthrough technology to commercial scale. Herein, we provide a brief introduction to *PolyCera*™ membranes and outline how these compare to the state-of-the-art.

2 *POLYCERA*™ MATERIAL ADVANTAGES

Tunable permeability and selectivity: Various derivatives of *PolyCera*™ membranes have been developed to provide a range of pore sizes from ~200 nm to 2 A. This property enables the material to become potentially applicable within a wide range of membrane based applications from microfiltration (MF) and ultrafiltration (UF) to gas separations, pervaporation and forward omosis. Certain formulations have produced MF-like permeability (high water flux) while providing UF-like selectivity (macromolecular separation). Other formulations have been formed into high-performance forward osmosis (FO) and pervaporation (PV) membranes.

Figure 1: Various polymeric derivatives formed into membrane flatsheet coupons.

Ceramic-like fouling resistance: PolyCera™ membranes have been shown to exhibit super-hydrophilic and super-oleophobic interfaces that attract water and repel oil hydrocarbons like ultra-clean glass and ceramic materials. For example, a hexadecane droplet in water contacting a relatively oleophilic polysulfone membrane surface forms a contact angle of ~110 degrees, which means oil tends to spread out onto the membrane without any imposed external force (like the force of permeation drag). In contrast, the contact angles of hexadecane in water on ultra-clean glass and *PolyCera™* membranes are 155^o and 160^o, respectively. These very large contact angles are indicative of super-oleophobic (easy to clean) materials. *PolyCera™* membranes appear intrinsically more hydrophilic, and hence, fouling resistant than all conventional polymeric membrane materials including: cellulose acetate, polyacrilonitrile, polyethersulfone, polysulfone, polyethylene, polyvinylidine flouride, etc.

In addition to the "ceramic-like" hydrophlicity and oleophobicity of *PolyCera™* membranes, the polymer appears to be instrincally anti-bacterial, which means it can resistant biofouling without the need for continuous chlorination. This is critical in applications like membrane bioreactors for wastewater treatment as well as food and beverage applications where chlorine and other bacteriocidal disinfectant chemicals cannot be applied in process. Of course in wastewater bioreactors, live viable bacteria are required to achieve basic treatment objectives, while in food and beverage applications disinfecting oxidants can alter produce flavor, aroma or other important food product properties.

Ceramic-like robustness: PolyCera™ membranes have been operated continously at temperatures up to 90^{o}C. This allows the membrane to be used in an array of industrially important separations ranging from high temperature water treatment to certain food and beverage-related separations, as well to be intermittently steam sterilized. The material also appears stable when exposed to most common industrial acids at pH as low as 0 and most bases at pH as high as 14, which suggests the material will be much easier to clean that conventional polymers, like ceramics.

Polymeric-like economics: While the material exhibits material properties and robustness typically seen only in ceramic membranes, the materials are realtively inexpensive like conventional polymeric membranes. The membranes can be formed by traditional phase inversion methods, and hence, can be produced using conventional membrane manufacturing infrastructure. The membranes also exhibit excellent mechanical stability, which means that various form factors, including tubular, hollow fiber, flat sheet spiral wound or plate-and-frame are feasible.

3 COMPARATIVE ANALYSIS

Table 1 compares various performance metrics projected for *PolyCera™* membrane materials relative to state-of-the-art ceramic and polymeric membranes. As can be observed, in all the categories, the *PolyCera*™ membrane characteristics are best in class with the only unknown factor being useful life. As this is a new membrane material useful like can only be proven over time, but given the material properties that have been characterized to date it is anticipated that the high robustness of *PolyCera*™ materials would provide longer than normal useful life relative to traditional polymeric materials approaching that of ceramics.

Table 1. Performance characteristics of *PolyCera™* in comparison to current state-of-the-art

Performance characteristics	***PolyCera™* Membrane**	**S.O.A.* Ceramic**	**S.O.A.* Polymeric**
Water flux (GFD)	**HIGH**	**HIGH**	LOW
Operating pressure	**LOW**	MED	HIGH
Extendend membrane life (Years)	TBD	**10-20**	3-5
Temperature stability (steam cleanable)	**HIGH (Y)**	**HIGH (Y)**	MED (N)
Chemical stability (pH range)	**HIGH (0-14)**	**HIGH (0-14)**	MED (2-11)
Module form factor	**Spiral, Hollow Fiber, & Tubular**	Tubular & monolithic	**Spiral, Hollow Fiber, & Tubular**
High packing density (m^2/m^3)	**HIGH**	LOW	**HIGH**
Membrane cost ($\$/m^2$)	**LOW**	HIGH	**LOW**
CAPEX ($\$/m^3$)	**LOW**	HIGH	**MED**
OPEX ($\$/m^3$)	**LOW**	**LOW**	MED

Note: Items in **GREEN** indicate best available technology.
*state-of-the-art"
Y=yes, N = no

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