Ceramic Crossflow Membranes for Industrial Applications

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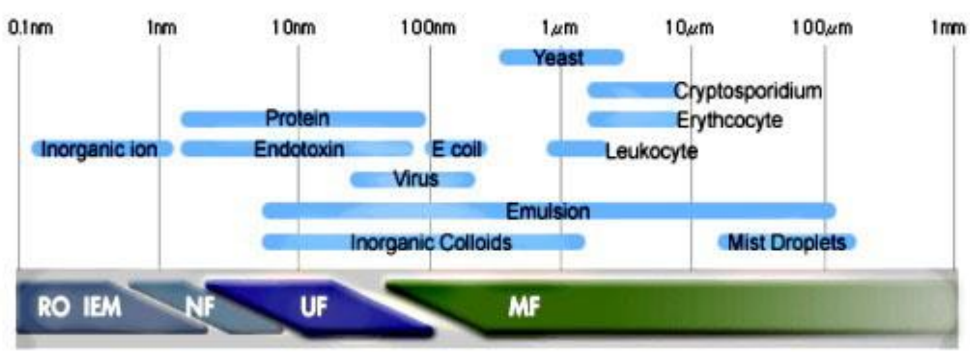
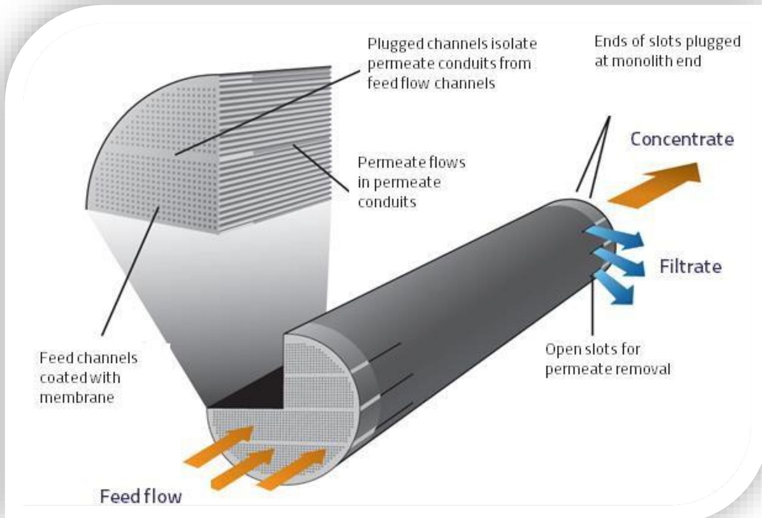
You may be considering the use of ceramic membranes for your next filtration project but would like to know more about what they are and how they are employed.

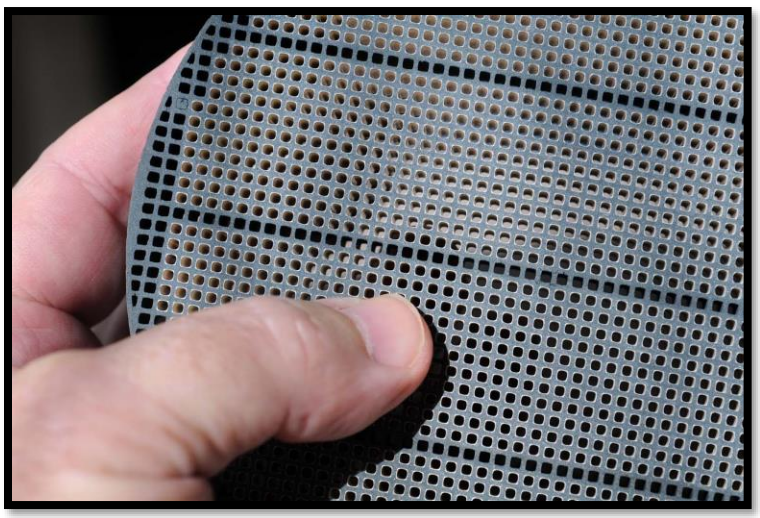
Ceramic membranes are manufactured from silicon Carbide (SIC) as a support layer with the membrane surface made from TiO2, SiO2, Al2O3, or SiC. The membrane separation layer has pore sizes ranging from 1.0 micron to 5 nanometers. This covers the particle classification range from microfiltration, ultrafiltration to nano filtration. They are not tight enough however, to separate molecules or ions. For many applications, dissolved solids and heavy metals are chemically treated to produce a filterable suspended solid. These membranes are not employed as reverse osmosis (R/O) membranes removing NaCl but in drinking water applications as pre-filters to remove solids and oils to protect the polymeric R/O membranes. The individual ceramic elements may be tubular or flat plate with maximum temperatures to 400° C and pH resistance ranging from 1 to 14.



Pore size	Molecular mass	Process	Filtration Pressure	Removal Cutoff
> 0.1 µm	> 5000 kDa	microfiltration	< 2 bar	larger bacteria, yeast, particles
100-2 nm	5-5000 kDa	ultrafiltration	1-10 bar	bacteria, macromolecules, proteins, larger viruses
2-1 nm	0.1-5 kDa	nanofiltration	3-20 bar	viruses, 2- valent ions
< 1 nm	< 100 Da	reverse osmosis	10-80 bar	salts, small organic molecules

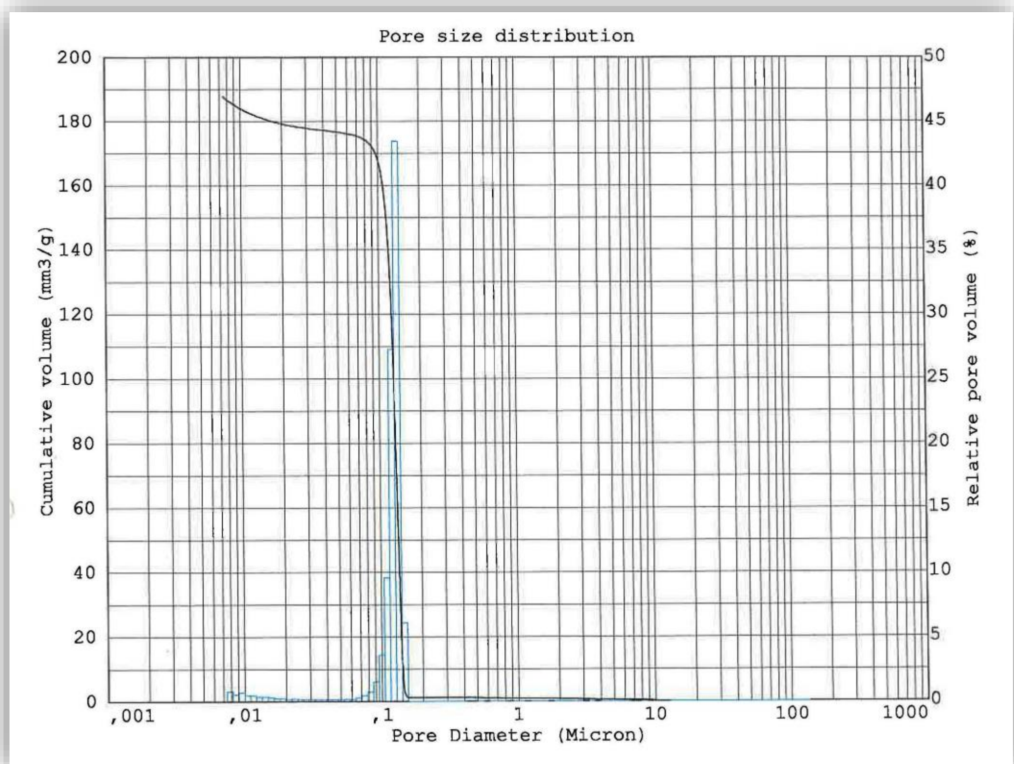
A Ceramic Tubular Membrane Element is Shown Below:

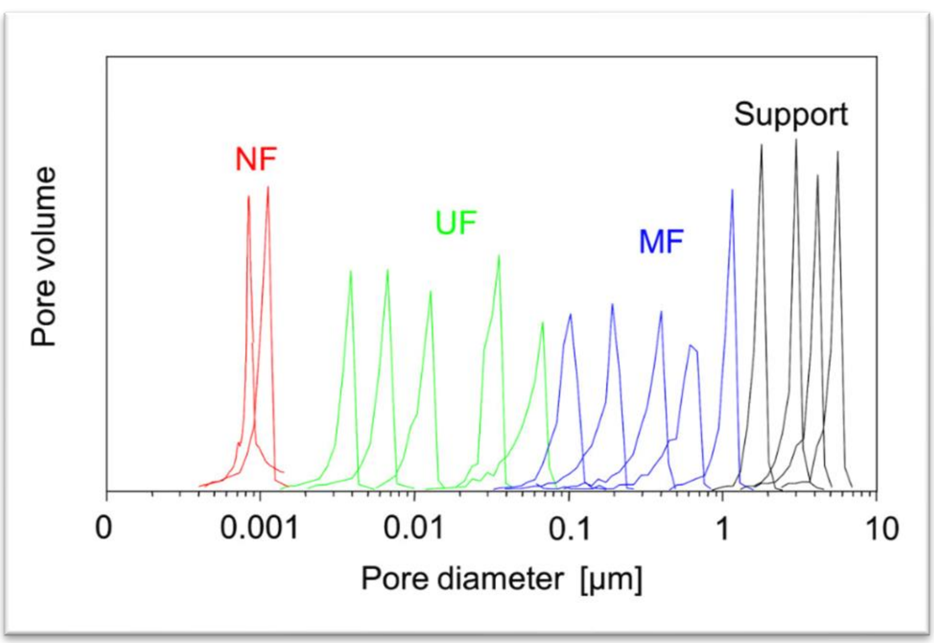




Membrane Element and Stainless-Steel Housing

The pore structure of a ceramic membrane may have a wide or tight size distribution allowing for targeted particle removal. Ceramic membranes are not absolute rated however when targeting a particular size range or an individual particle size for removal, the options available for distribution size of the membrane can be selected for your project objectives.

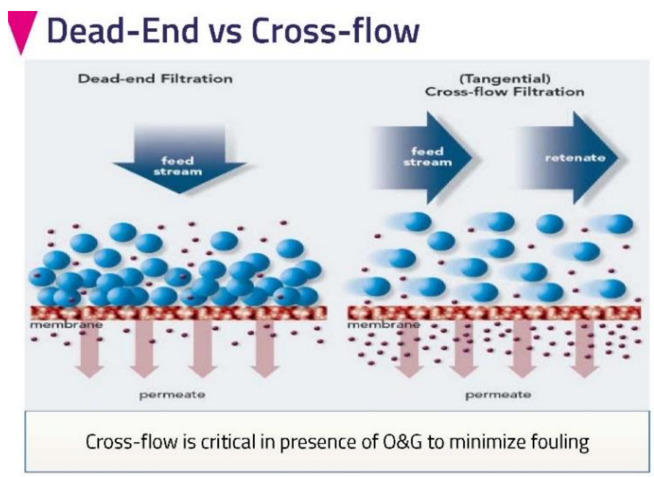




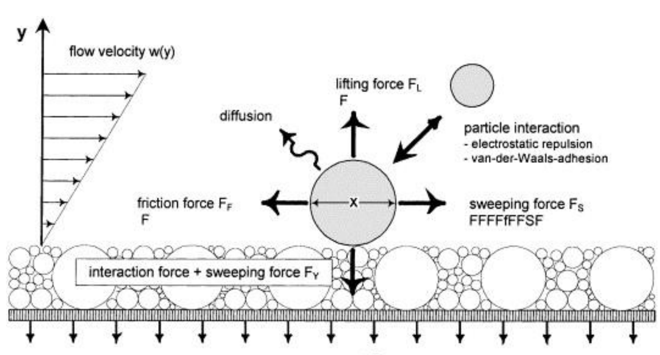
In what circumstances are ceramic membranes chosen instead of polymeric membranes, distillation towers, vacuum distillation, disposable filters, filter presses, or centrifugal separators? Some obvious applications are apparent such as temperature sensitive beverages, delicate solids, reactive components, fines below 0.5 microns, or high temperature liquids and gasses, aggressive solvents, acids, hydrocarbons, corrosive liquids and gasses, and radioactive materials. Ceramic membranes are robust and last many years in harsh environments. They can be cleaned by back pulsing, back washing, solvent cleaning or steam & chemical sterilization, or autoclaving. They can be manufactured to be highly hydrophilic, hydrophobic, and oleophobic. Usually, a real-world filtration system includes a combination of technologies such as settling tanks, prefilter screens, centrifuges, hydrocyclones, distillation, chemical pretreatment, and more.

Your process may be better suited to a continuous automated system. Your streams may have very fine particles that are difficult to remove or they may be required to be captured and recycled back to the process. The streams may also be delicate, temperature sensitive, very hot, corrosive, or explosive. Your process equipment may require treatment with chemicals, steam or high temperature alkaline solutions to maintain a sterile system and product. Or, you may want a ceramic system that will simply offer you a long-lasting stable filtration system you can count on for years.

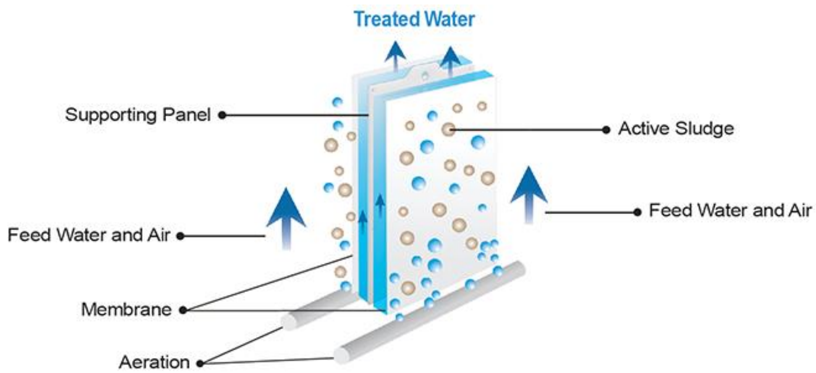
Ceramic membrane systems may be housed in stainless steel, CPVC, or fiberglass housings with seals determined by the fluid temperature and composition. Flow may be dead-ended into the media or use tangential flow (cross-flow). Systems may use a vacuum to draw the clean fluid though as in submerged flat plate water treatment or pervaporation application or pressure to drive the fluid through the element.



Cross flow systems employ sweeping forces at the membrane surface to reduce fouling as the permeate is removed resulting in the stream becoming more concentrated for batch processes as it is recycled and filtered to its maximum concentration factor.



Flat sheet ceramic membranes are commonly employed as submerged membrane bioreactors (SMB's) for wastewater treatment. Ceramic flat plate membranes are directly submerged in the bioreactor and a vacuum is applied to draw the wastewater into the membrane. Air bubbles are employed below the membrane to feed the activated sludge and also clean the surface of the membrane. These are also backflushed to remove foulants.



Ceramic Crossflow membranes are similar to Reverse Osmosis membranes but ceramic membranes are designed to remove suspended solids, not dissolved solids or ions. Ceramic Crossflow membrane systems are employed for oily water, wastewater, caustics, acids, laundry rinse water, heavy metals removal, brine, bacteria separation, and clarification of beer and wine. Unlike many polymeric membranes, ceramic membranes are naturally hydrophilic and do not require pre-treatment wetting or solvent rewetting to be hydrophilic.

Terms employed for ceramic crossflow systems:

Membrane Pore Size-the size of the open channel structure allowing filtered permeate to pass and rejecting the solids retentate mixture. This is approximately 4 nanometers to 10 microns for ceramic membranes.

Hydrophilic-Water loving, allows water to wet the surfaces and pass through the media

Hydrophobic-Water hating-rejects water, water is rejected from the surface of the membrane

Oleophobic-Rejects oil but water will pass through.

Permeate-the filtered product you wish to produce.

Flux-the permeate flow per unit area of membrane surface. More surface area, more flow.

Trans Membrane Pressure-the pressure required across the membrane to produce the desired permeate flow.

Retentate-the residue or rejected stream. In some processes this is the desired product stream.

Concentration Factor-For batch processes, the maximum concentration of the recycle steam before it fouls the membrane surface.

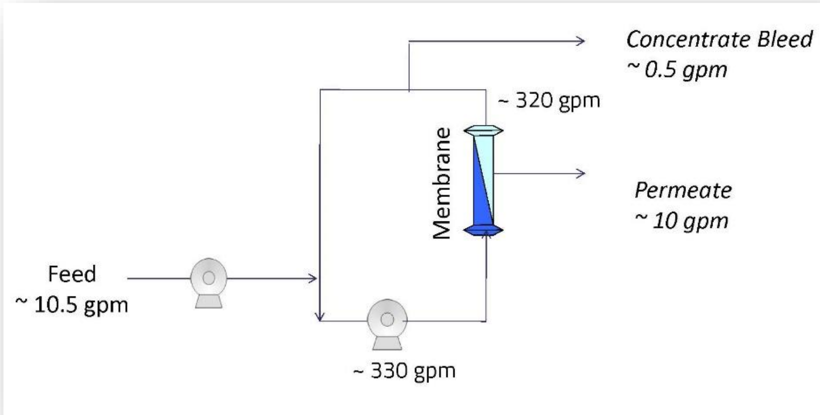
Recycle Stream-the retentate stream that is recycled in a loop to supply the fluid/solids mixture to the membrane element at a determined velocity to maintain membrane surface cleanliness

Feed Stream-the stream introduced to the system that replaces the permeate and retentate bleed streams.

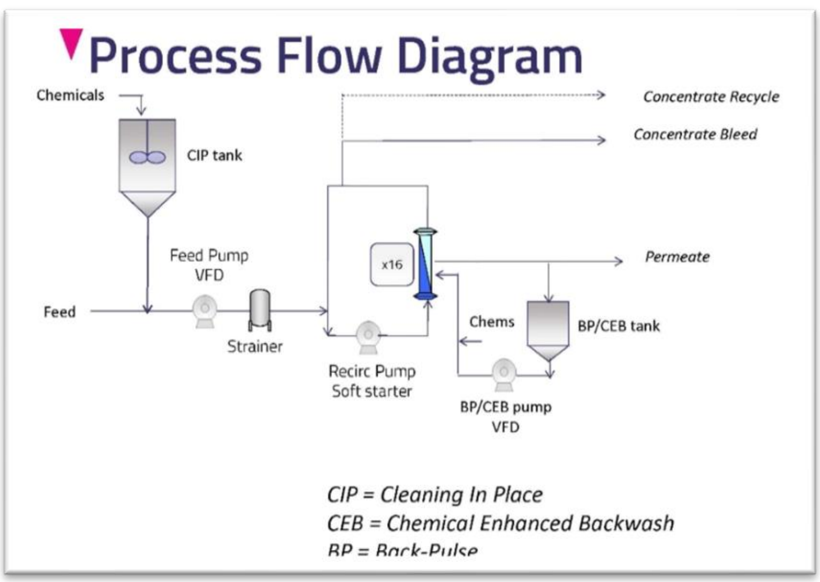
Permeability-Flux/Trans Membrane Pressure

Recovery-A comparison of a new membrane element flux to a fouled element after a cleaning step.

A simplified cross flow filtration process is shown below:

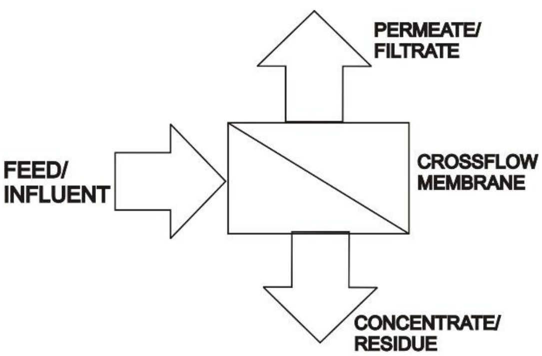


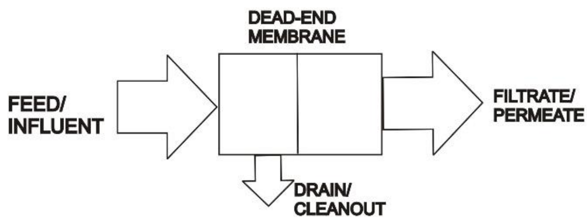
A cross-flow design employs a large recycle stream that is sized to maintain a constant velocity in the membrane channels to sweep solids and foulants from the surface of the membrane. Two centrifugal pumps are recommended to maintain even system flow, a small feed pump with a larger recirculation pump. Pump pressure is much lower and less expensive that R/O applications, usually less than 2 bar. Pilot testing helps to determine optimum channel size and velocity in the membrane channels to optimize permeate flow and maximize run time between cleaning of the membrane surface. Cleaning is accomplished by employing the permeate to back pulse or backwash the system. Chemicals may also be employed to enhance the cleaning operation.



Industrial applications may be batch or continuous and may have non constant feed flow rates and concentrations in addition to product stream requirements. Lab testing and pilot units are employed to fine tune operating parameters before a full-scale system is built. You need to consider your objectives and your process to determine a starting point in the testing and design of a membrane system. A data sheet detailing your process information is the first step.

Process Information	Feed Stream Information
1. Application is: New ☐ Retrofit ☐	1. Flow Rate: ☐GPM ☐GPH
☐ Module replacement	Feed / Permeate / Residue
Present module manufacturer	2. Temperature: °F☐ °C☐
	3. pH: / 4. BOD_5: mg/l
Module Model No.:	5. COD: mg/l
	6. Conductivity: µS/cm
Number of Trains: Number of Stages:	7. Specific gravity:
Number of Vessels Per Stage:	8. Silt Density Index SDI
Number of Membranes Per Vessel:	9. Total Hardness: m Total Alkalinity: p
Micron rating:	10. Viscosity::
2. Process will be: ☐Continuous ☐Batch ☐Semi-continuous	@ ambient temp: cp @ feed temp: cp
3. Project type: ☐ Waste treatment ☐Product recovery ☐ Other	11. Material compatibility: ☐304 SS ☐316 SS ☐ Non- Corrosive ☐316L SS ☐Hastelloy C
4. Permeate: ☐ Recycled ☐ Disposed	12. Total Suspended Solids, TSS: mg/l
5. Residue: ☐Recycled ☐Disposed	Specific Gravity of Suspended Solids:
6. Feed Source:	13. Total Dissolved Solids, TDS: mg/l
	14. Total organic carbon, TOC: mg/l
	15. Chloride/Halogen: mg/l
	16. Free Chlorine
	17. Turbidity: NTU





Feed Stream Description

Component	M. W., weight % or Particle Size Range (µm)	Soluble	Suspended	Feed Wt. %	Filtrate Wt. %	Concentrate Wt. %
A.		☐	☐			
B.		☐	☐			
C.		☐	☐			
D.		☐	☐			
E.		☐	☐			

Membrane System Information

Process objectives:	
Describe Previous membrane separation experience for the proposed process	
Simple sketch of the present system:	Simple sketch of proposed system including membrane:
Please note cost targets such as ¢/unit of feed, ¢/unit of filtrate, ¢/unit of concentrate. Please specify units:	

Current Operating Cost Data

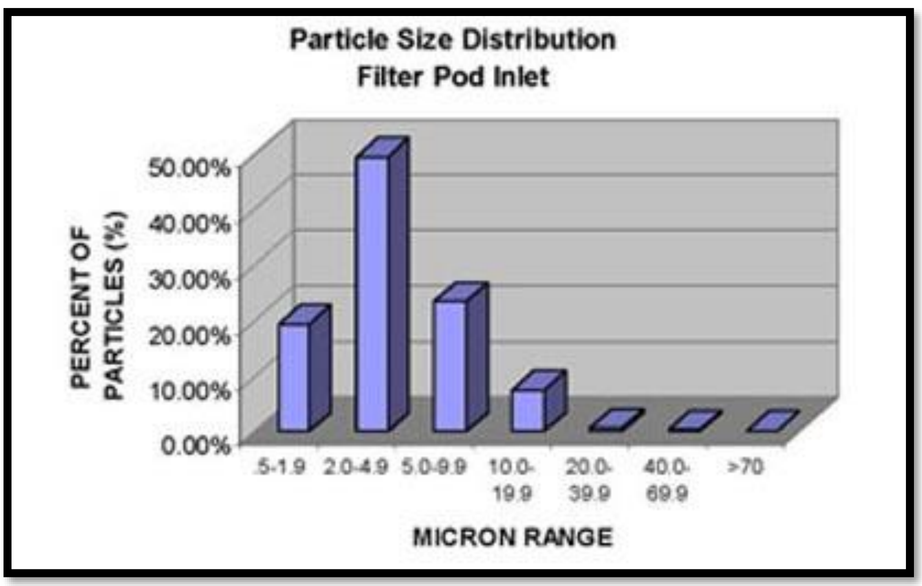
In order to assess optimal/cost effective systems designs for your separation requirements, please provide the following basic applicable cost data for your intended operating location.	
Electricity: ¢ perk kwh	Operating labor: $/hr.

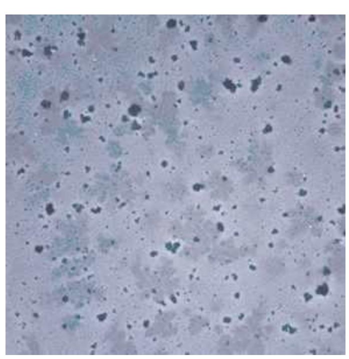
Projected/Estimated Timing for Project (Quarter or Month/Year)

Test System:	Purchase:	Installation:

Ceramic membranes are highly hydrophilic and due to their physical composition also allows them to be oleophobic thus rejecting oil. They are employed for oily water and emulsified oil water streams which usually also contain particulates. The ceramic membrane surfaces can be modified to increase oil rejection from 95 to 97%. For most applications, a filterable suspended particle must be present to be removed by ceramic filtration.

Your particles have a characterization profile which must be determined. Particle characterization is the process of identifying various particles by particle shape, size, surface properties, charge properties, mechanical properties, and microstructure. Your particles may be complex in shape, they may be hard or sticky. Samples will be tested to determine the particle size distribution to determine the correct membrane pore size. Various lab testing techniques are employed to characterize your particles such as microscopes, automated imaging, light scattering, and laser diffraction.





Particle Photomicrograph 50x

Particle testing labs including those of the filter supplier are employed to characterize the stream to be filtered. Once your particles are characterized the next step is to determine feasibility with a lab or pilot sized membrane system. In many cases, your process is proprietary or requires a controlled environment and testing must be performed onsite requiring rental systems whose data can be scaled to full-sized Industrial systems

Pictured below are a suitcase sized test unit, a computer controlled automated pilot unit, and a full scale system. The operation of the pilot units optimizes velocities, pressures, concentration factors, flux, permeate flow rate, recycle rates, fouling rates, backpulse and backflush timing.

A novel application for ceramic membranes is pervaporation. Close boiling components like ethanol and water which have an azeotropic condition at their similar boiling points do not allow a separation greater than 95.6% employing atmospheric boiling. However, azeotropes can be broken employing the different diffusivity rates of the components through a membrane instead of their boiling points. A vacuum is applied to the permeate side of the membrane For example treating a 90% mixture from an evaporation process can produce 99.999% ethanol. For industrial purposes there are much more valuable close boiling mixtures which can benefit from employing ceramic membrane pervaporation.

Common applications:

Oil & Gas, Refining and Petrochemical

- Produced water: steam flood, water flood, surface discharge, reinjection, reuse
- Completion fluid filtration
- Sulfuric Acid filtration for reuse
- Workover fluid filtration
- Disposal well reinjection
- Desalter brine
- FPSO slop water
- EOR fluids
- Oil filtration for oil recovery
- Solvent Deasphalting
- Vacuum Residual Oil Recovery
- Pervaporation

Chemical Process Industry

- Sodium bicarbonate brine filtration
- Chlor-alkali brine filtration
- Membrane biological reactors (MBR)
- Acid filtration for recycle/reuse
- Caustic filtration for recycle/reuse
- Oil filtration
- Pervaporation

Environmental

- Oily Wastewater Treatment

Primary Metals Industry and Metal Finishing

- Heavy metals removal
- Oil & grease removal
- Dewater spent water soluble coolants and rolling oils
- Caustic cleaner and degreaser recycle
- Oil filtration for recovery

Marine industry

- Bilge water filtration

Industrial Laundry

- Wastewater recycle and reuse

Mining industry

- Tailings pond filtration

Pulp and paper industry

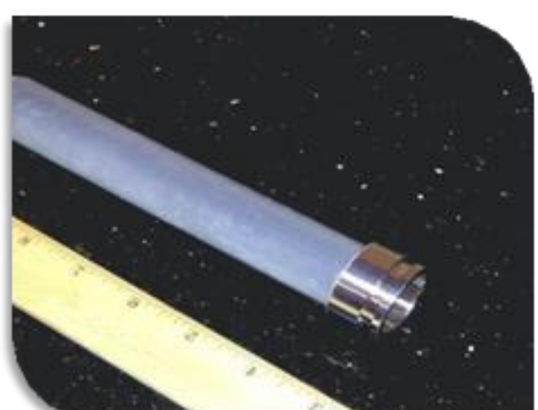
- Black liquor

Disaster relief

- Emergency drinking water

Food and beverage industry

- Fermentation broth clarification
- Wine filtration



Lab Sized Element

- Beer filtration
- Recovery of valuable components from food waste
- Membrane biological reactors
- Caustic cleaner recovery
- Natural spring water
- Pervaporation
  Biotechnology industry
- Fermentation broth clarification

Nuclear power industry

- Wastewater

Multi-Channel Tubular

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