Characterization and Assessment of Fouling Resistant Membrane Surfaces for Water and Wastewater Treatment

Presented by,

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Presentation Outline

- Introduction
  - Water Treatment
  - Membranes
  - Membrane Fouling
  - Objective
- Materials and Methods
  - Characterization
    - Physical
    - Chemical (XDLVO)
  - Membrane performance
- Results and Discussion
- Conclusion

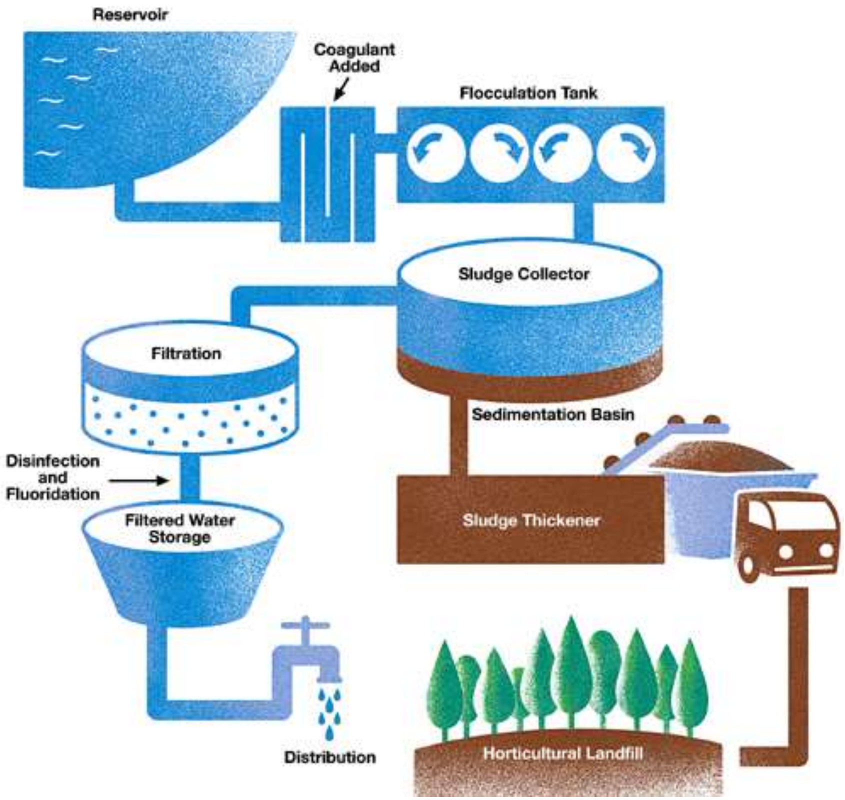
Introduction – Water Treatment

- The world faces a global water crisis as a result of continued population growth and the contamination of existing freshwater supplies
- It has been necessary to find ways of maximizing water utility, recycling being the most effective
- Treatment of wastewaters is widely applied across the globe to recycle contaminated water

Introduction – Water Treatment

- Drinking water supply involves treatment of water from fresh water sources like rivers and lakes
- Harmful substances are removed to comply with municipal or EPA drinking water standards
- Ocean waters also undergo a process known as desalination where salty water is converted to drinking water

Introduction – Water Treatment



- Water treatment involves are series of steps
- Filtration is the final step and removes any suspended particles left from previous steps
- The most common filtration media used is sand

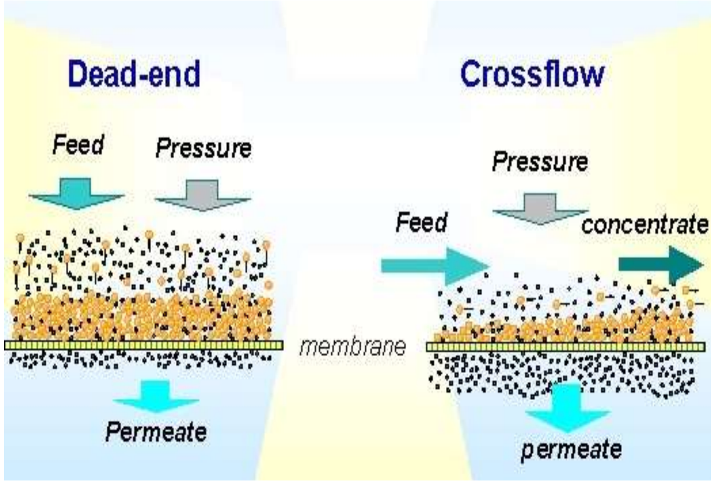
Introduction – Membranes

- In recent years, membranes have been introduced as an alternative to conventional filtration in drinking water and reuse systems
- Membranes are thin materials capable of separating substances when driving force is applied across them
- Advantages membranes have over conventional filtration are;
  - Lower capital costs
  - Superior product water quality
  - Lower chemical requirements
  - Smaller equipment footprint

Introduction – Membranes

- Membrane processes have been found to more easily meet new and more stringent drinking water regulations e.g. arsenic and disinfection by products
- Membrane separation processes are differentiated on the basis of;
  - Pore size
  - Molecular weight cut off (MWCO)
  - Mechanism by which solute is separated

Introduction – Membrane Fouling



- A major challenge facing membrane processes is fouling
- Fouling results from the deposition, adsorption and/or accumulation of rejected species on the surface
- Fouling results in the deterioration of permeate water flux and quality

Introduction - Fouling

- Fouling mechanisms vary based on physical and chemical properties of the membrane
- Chemical properties include
  - Surface charge
  - Hydrophobicity/ Hydrophilicity
- Physical properties include;
  - Pore size
  - Surface roughness

Introduction - Membranes

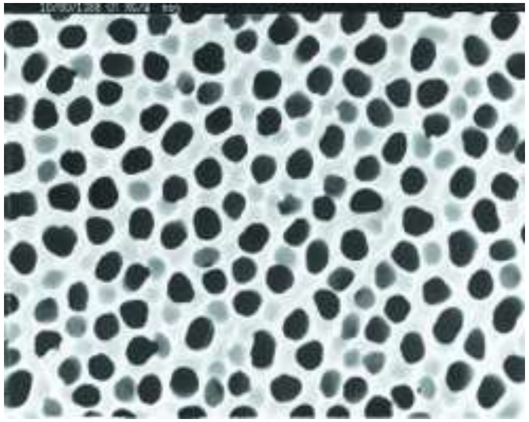
- Two general approaches can be used to alleviate fouling;
  - Pretreatment of the feed waters to get rid of substances that are known to dominate fouling in the system
  - Development of materials and surfaces that are less susceptible to fouling
- However, fouling mitigation is further complicated by the great diversity of foulants and characteristics that exist in any system

Introduction - Objective

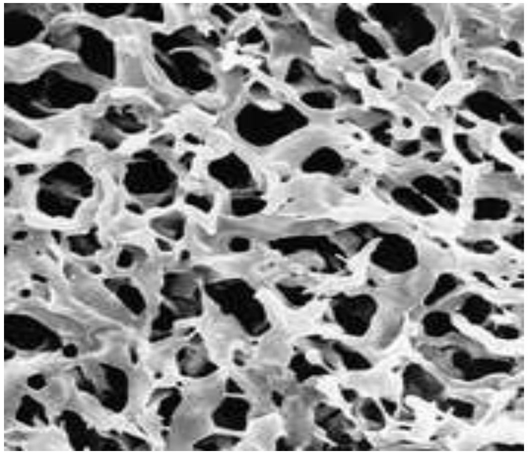
- This project evaluated the abilities of two new nanostructured surface coatings, diamond-like carbon (DLC) and hydroxyapatite, for mitigating fouling of ceramic membranes (alumina)

Materials and Methods

Alumina



Durapore



- Annodized alumina membranes were used as the support substrate onto which HA and DLC were deposited
- Pulsed laser deposition (PLD) was used to deposit the coatings
- Durapore membranes made from polyvinylidene flouride (PVDF)
- Bovine serum albumin (BSA) was used as the model foulant

Materials and methods

Surface properties and their associated measuring equipment

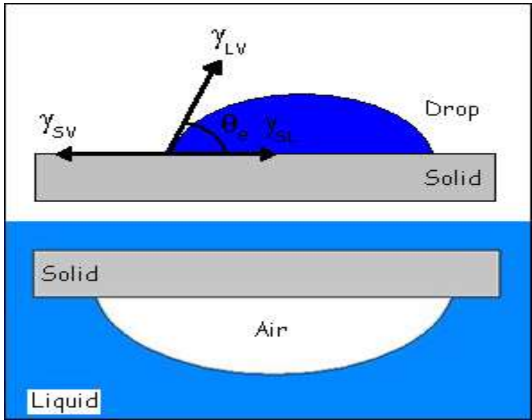
Properties	**Measuring Equipment**
Surface Roughness / Pore Size	Atomic Force Microscopy (AFM)
Hydrophobicity / Hydrophilicity	Geniometer (KrÜss Scientific)
Surface Charge	Streaming Potential Analyzer
Membrane Performance	Dead-end stirred filtration cell (Sterlitech)

Materials and Methods

- Contact angle measurements were taken using 3 probe liquids; DDW, formamide and diiodomethane
- The surface energy parameters for each of the surfaces of interest, calculated using the Extended Young equation:

$$(1+\cos\theta)\,\gamma_l^{TOT} = 2\,(\sqrt{\gamma_s^{LW}\gamma_l^{LW}} + \sqrt{\gamma_s^{+}\gamma_l^{-}} + \sqrt{\gamma_s^{-}\gamma_l^{+}}\,)$$

- The free energy of interaction determined from these parameters can then be used to judge the hydrophobicity/hydrophilicity of the samples



Materials and Methods

- Using the contact angle measurements, the following interaction energies between the foulant and surfaces were determined;
  - Lifshitz-van der Waals (LW)
  - Electrostatic (EL)
  - Acid-base (AB)
- The total interaction forces between membranes and colloids are calculated as follows using the extended Derjaguin-Landau-Verwey-Overbeek (XDLVO) theory:

$$U^{Tot} = U^{EL} + E^{LW} + U^{AB}$$

- Force plots were then generated based on the XDLVO theory

Materials and Methods

- Dead end filtration was used to evaluate membrane performance
- Permeate flux was observed as a function of time
- The mass balance and pressure transducer were interfaced with a computer allowing real time monitoring
- Membrane fouling was investigated at a fixed ionic strength (I=0.01M NaCl) and constant BSA concentration (100mg/L)

Materials and Methods

- Doubly deionized water (DDW) was first run through the system to determine the pure water flux of the membranes
- A constant flux at which to run fouling tests on all the membranes was determined – each membrane had a unique operating pressure at this flux
- Fouling tests were then run for each individual membrane at its predetermined operating pressure
- The performance of the membrane was judged by how much the permeate flux changed after fouling

Results and Discussion

Select physical properties of the studied membranes

Membrane	**Thickness nm**	**Average Pore Size µm**	**Material(s) of Construction**
Durapore	150	0.22	PVDF
Unmodified Anodisk	100	0.20	Alumina
HA	100	0.12	Alumina/HA
DLC	100	0.12	Alumina/DLC

Results and Discussion

AFM membrane surface roughness statistics for each of the studied membranes

	Unmodified Anodisk	HA	DLC	Durapore®
Avg. Roughness (nm)	102.97	48.03	57.15	45.32
Root Mean Square Roughness (nm)	127.98	62.96	73.92	55.41
Surface Area (μm^2)	81.01	48.19	53.95	53.88
Surface Area Difference (%)	225.30	93.89	116.22	116.78

Results and Discussion

Surface potentials for the protein and membrane surfaces

Colloid/Membranes	Surface Charge (mV)
BSA	-9.7
DLC[1]	-14
HA[2]	-8
Durapore	-20

Results and Discussion

Contact angle results for the protein and membrane surfaces

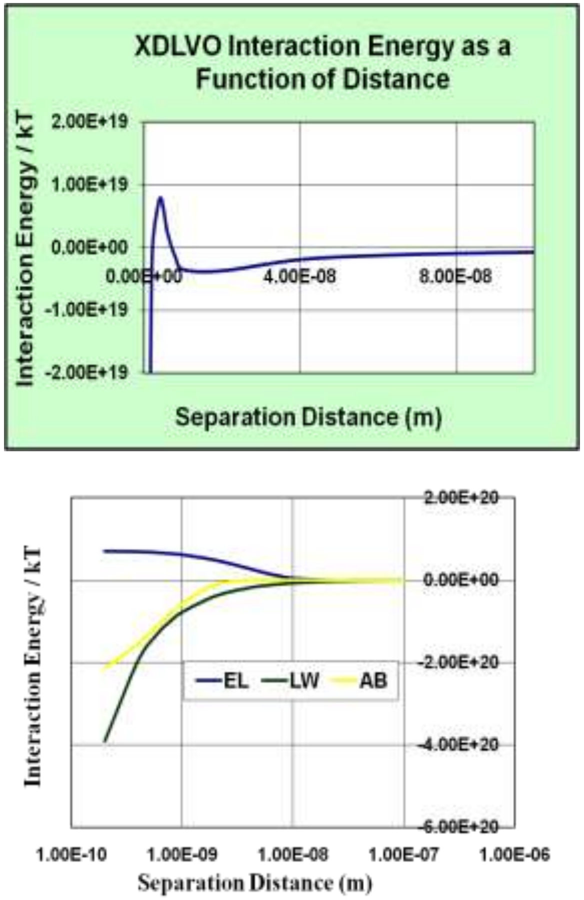
	DDW	**Diiodo-methane**	**Form-amide**
BSA protein	18.0^{o}	39.0^{o}	31.0^{o}
DLC	70.8^{o}	42.7^{o}	43.4^{o}
HA	61.1^{o}	53.6^{o}	55.4^{o}
Durapore	31.9^{o}	48.9^{o}	40.6^{o}

Membrane and protein surface energy parameters (mJ/m^2) at $20^{o}C$

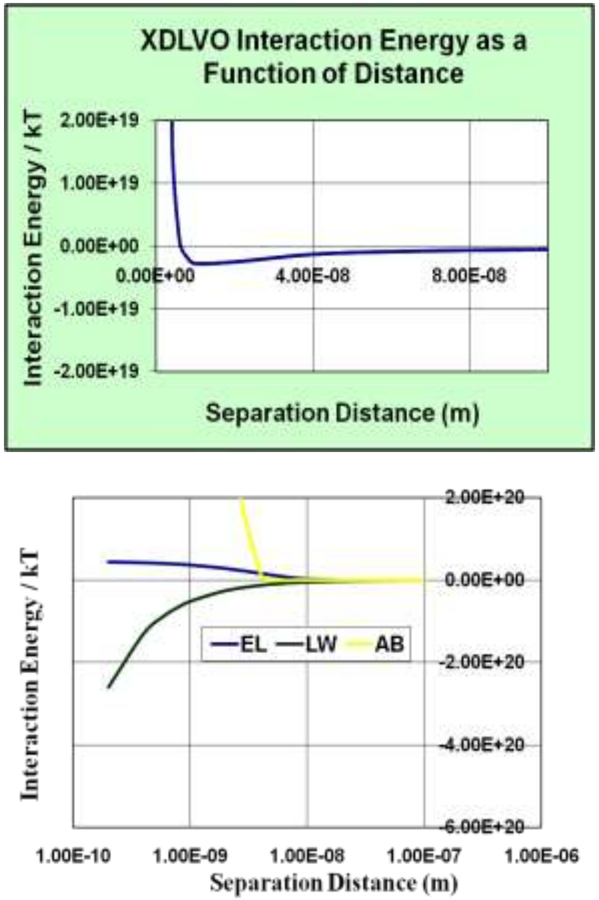
	γ^{LW}	γ^{+}	γ^{-}	γ^{AB}	γ^{TOT}	$\boldsymbol{\Delta G^{SWS}}$
BSA protein	40.1	0.2	61.0	6.3	46.4	**45.7**
DLC	38.2	1.4	7.2	6.3	44.5	**-41.2**
HA	32.2	0.1	25.7	3.8	36.0	**-1.7**
Durapore	34.9	0.2	54.7	7.0	41.9	**39.9**

Results and Discussion

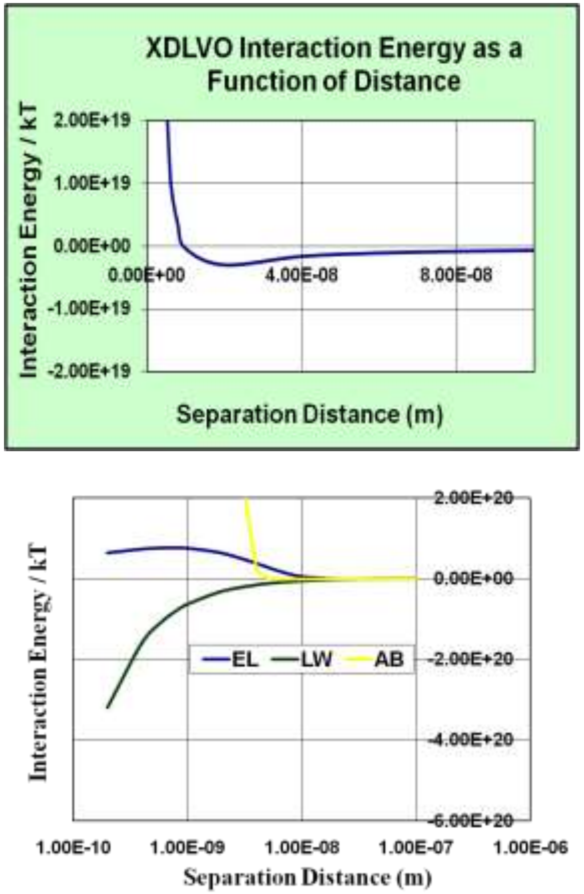
Interfacial interaction energies as a function of separation distance for the membranes and BSA protein (I = 0.01 M NaCl; pH = 5.9; T = 20°C)



DLC



HA



Durapore

Results and Discussion

Summarized membrane performance and fouling results

Membrane	Operating pressure psig	Initial Pure Water Flux m^3/m^2.day	Final Pure Water Flux m^3/m^2.day	Flux Loss %
Unmodified Anodisk	33.33	256.63	167.65	-34.67
Diamond-like Carbon	25.64	202.19	110.87	-45.17
Hydroxyapatite	24.07	190.03	158.24	-16.73
Durapore	19.90	202.50	182.29	-9.98

* All membranes were operated at a starting flux of 200 m^3/m^2.day prior to each fouling test

Conclusion

- Based on the XDLVO models obtained for each membrane surface, DLC would be expected to be most susceptible to protein fouling
- The hydroxyapatite surface coating appears to improve the resistance to protein fouling of the alumina anodisks studied
- This is attributed to an improvement in the interaction between the membrane surface and the BSA molecules

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QUESTIONS?

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