Cornell Engineering
Civil and Environmental Engineering

CEE 4540

Sustainable municipal drinking water treatment

Topic: Mid Term Recap & MF/UF Membranes

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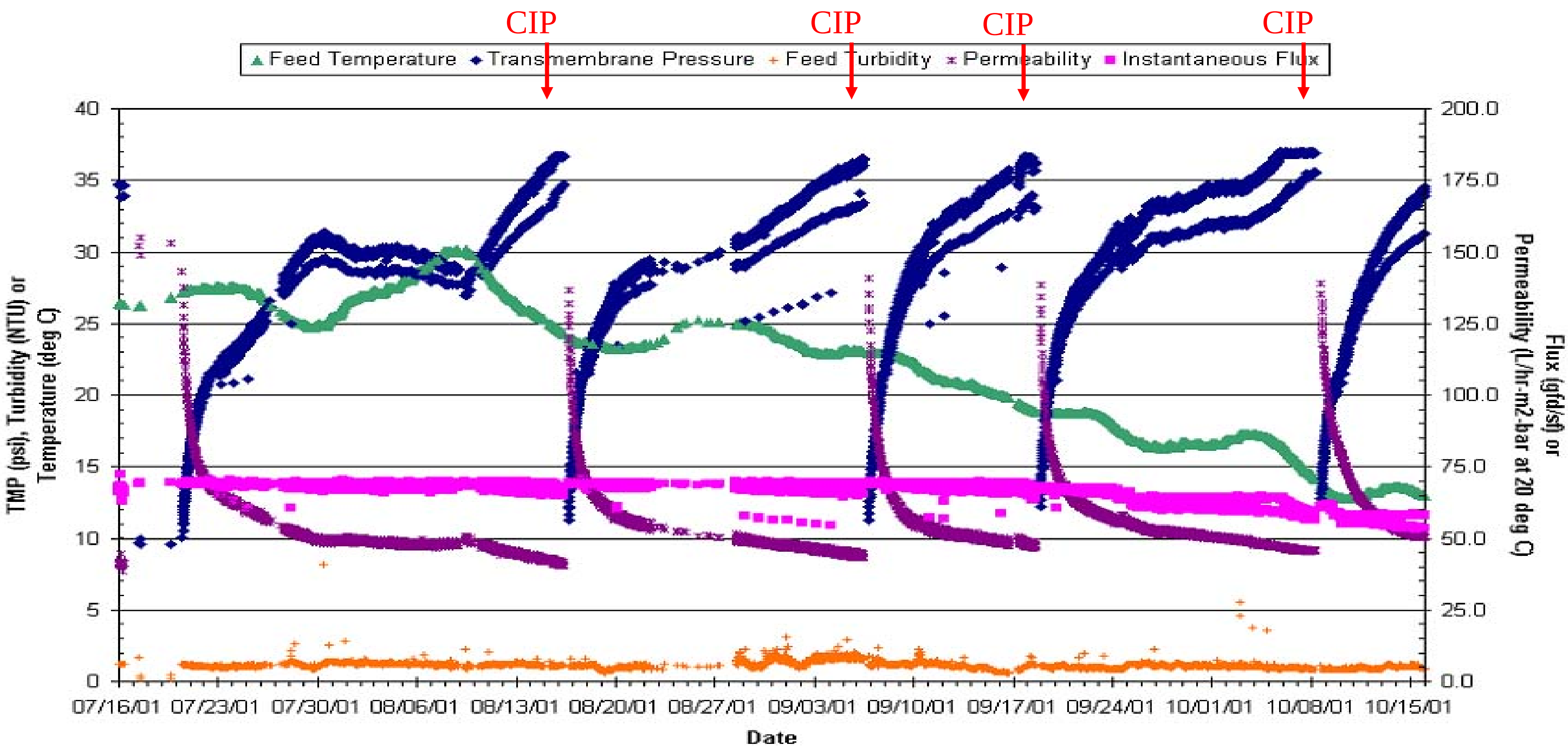
Class #13 10/17/2018 2:55 – 4:10pm

Koch System Performance



Ionics System With Stable TMP and Permeability

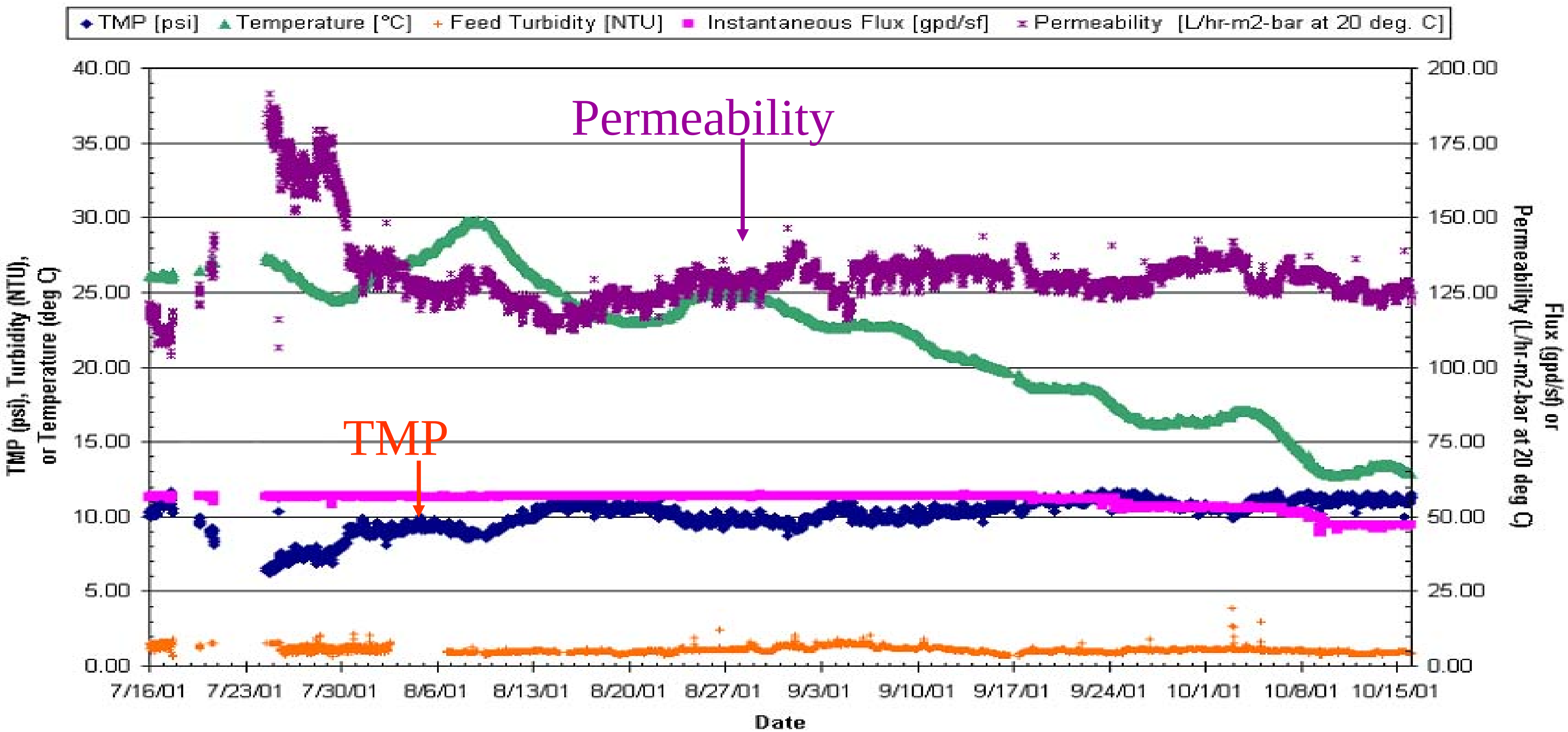


Illustration of Ionics Chemical Enhanced Backwash (CEB)

Backwash

30 sec.

Backwash/Chemical

30 sec.

Backwash/Rinse

60 sec.

Soaking 10 min.

Design Procedure for a Membrane Filtration Plant

- Start with communicating with State Department of Health (DOH)
  - Membrane products approved by the State
  - Log removal credit needed by the new plant
  - Pilot testing requirements
    - Duration
    - Log Removal Credit need to achieve
- Select the right membrane for your application
  - Pilot testing
  - Procurement process: monetary & non-monetary criteria
    - Membrane integrity (fiber breakage) history
    - Lost of membrane permeability

Membrane Permeability (Specific Flux)

- **Flux:** Filtration rate per unit surface area (gfd)
- **Transmembrane pressure (TMP):** Pressure difference across the membrane, driving force for filtration
- **Permeability:** Temperature corrected specific flux (gfd/psi)

$$Permeability = \frac{Flow\ Rate\ \left(\frac{gal}{day}\right) \times Water\ Viscossity\ (cP)}{Membrane\ Surface\ Area\ (ft^2) \times TMP(psi)}$$

- *A normalized parameter that takes into the consideration of Flux, TMP, Temp*
- *An unbiased indicator of membrane heath*

Minimum Permeability (Specific Flux)

$$Perm_{min} = \frac{Design\ Flux\ @\ 20\ ^{o}C}{Max\ TMP}$$

Example:
Design Flux @ 20 ^{o}C = 50 gfd
Maxim allowable TMP = 30 psi
Minimum Permeability = 50/30 = 1.67gfd/psi

Min. permeability needs to be maintain in order to produce design flow when needed

Factors Affecting Permeability

- Membrane feed water quality
  - Turbidity, NOM, Fe/Mn, algae, Cu, FOG, etc.
  - Feed conditioning (coagulation, Cl_2, etc.)
- Operating flux
- Cleaning Approach
  - Frequency, type of chemicals, concentrations

Water Production

- Total water treated: MGD
- Water consumption for cleaning
- Beneficial Use

  = Total Water Treated – Water Consumption

- Water Recovery
  - $R = \frac{Beneficial\ Use\ (mgd)}{Total\ Daily\ Producion\ (mgd)} \sim 90 - 95\%$

Is your Membrane Working too Hard?

- Actual operating flux depends on…
  - Design concept (const. flow or const. flux)
  - Standby and/or redundant units?
  - Actual production down time
    - # of units in backwash
    - Backwash + maintenance clean
    - Backwash + CIP
- Is system operated at flux higher than the instantaneous flux?

Example of Actual Flux Calculations

- Design Capacity: 15 mgd
- # of Units: 7
- Design Flux: 58.5 gfd
- Total Downtime: 216 min
- Single surge (1 unit down): 1,258 min @ 68 gfd
- Double surge (2 unit down): 36 min @ 82 gfd

Membrane operated at flux rates > design flux most of the time!

Comparing CEB vs. CIP

- Advantage of CEB
  - More stable operation
  - Fully automated
- Disadvantage of CEB
  - More chemical consumption
  - More chemical waste

Potential Fouling Material
Particulate/Colloids

- Inorganic particles alone would not cause much fouling
- Inorganic particle cake layer could be easily removed by backwash
- Excessive turbidity could clog membrane fiber lumens
- Inorganic particles mixed with NOM could cause substantial fouling
- Organic colloids could cause significant fouling and could be difficult to clean

Potential Fouling Material
Natural Organic Matter

- NOM with high SUVA
- TOC > 4 mg/L would be a concern
- Organic fouling is “sticky” and difficult to clean
- Organic may serve as “cement” to bind other particulates and form a strong cake layer
- Caustic cleaning (e.g. NaOH) and strong oxidant (e.g. H_2O_2) are effective for NOM fouling cleaning

Potential Fouling Material
Inorganic Material

- Precipitation of Ca, Mn, Mg, Fe, and Al could cause significant fouling
- Prefer a negative Langelier Index

$$Langelier\ Index = Actual\ pH - Saturation\ pH$$

$$Saturation\ pH = 2.18 - \log[Ca^{+2}] - \log[HCO_3^-]$$

L.I. > 0 : Oversaturated (tend to precipitate)

L.I. < 0 : Undersaturated (tend to dissolve more)

Potential Fouling Material
Inorganic Material (cont.)

- Presence of soluble Fe, Al, and Mn could possibly foul membranes
- Fine inorganic colloids (< 0.05 μm) could clog membrane pores and cause fouling
- Acid, EDTA, SBS cleaning could be effective for inorganic fouling

Potential Fouling Material
Synthetic Polymers

- Polymers used for coagulant/filter aids & backwash water treatment
- Presence of polymers in feed water could cause dramatic fouling, and sometimes irreversible
- Free residual polymer is worse than particle-associated polymer
- Cationic polymers are worst
- Some polymers can be easily cleaned with chlorine and therefore are consider compatible with membranes

Flux-Pressure-Fouling Potential

- Higher flux would cause higher fouling potential by…
  - Bringing more fouling material toward the membrane surface during the same operation cycle length
  - Requiring higher pressure to push more water through. Higher TMP will cause more compaction on the material deposited on membrane surfaces
- High TMP (due to higher flux or fouling) could aggravate fouling and cause durable fouling

Fouling Mitigation
Pretreatment

- Reduce TOC level (< 4 mg/L)
- Reduce Turbidity (< 5 NTU)
- Reduce Hardness (< 150 mg/L)
- Avoid substantial change in water chemistry, such as pH and other pretreatment chemicals
- Prevent Oil and Polymers from entering the feed water

Fouling Mitigation
Operation

- Use crossflow if turbidity is high (with higher energy consumption)
- Bleed a portion of the concentrate to avoid solid buildup (not common)
- Operate at a lower flux with lower TMP (more membrane equipment)
- Enhance pretreatment

Fouling Mitigation
Cleaning Strategy

1. Frequent BW (shorter filtration cycle)
2. Longer BW duration
3. Higher BW pressure
4. Add cleaning chemicals in BW water
5. Frequent chemical cleaning

Options 1-3 will increase water consumption and thereby reducing overall recovery.

Membrane Basics

Membrane Cleaning

Membrane Fouling Mechanisms

- Organic & Inorganic
- Particulate & Soluble
- Various Mechanisms
  - Surface & Pore
  - Deposition & accumulation
  - Adsorption, precipitation, coagulation

Membrane Cleaning

- Hydraulic Cleaning (10~30 minutes)
  - Water/Air Backwash
  - Air Scouring
  - Water Flushing
- Chemical Cleaning (1~8 weeks)
  - Free Chlorine (Sodium Hypochlorite)
  - Acid/Base
  - Other strong oxidants, such as H_2O_2
  - Reducing agent, such as SBS
  - Chelating chemicals, such as EDTA
  - Proprietary Chemicals (surfactants)

Homework

- Reading Assignment: Chapter 12
- A membrane plant is designed for 10 mgd at 20C
  - Maximum operation pressure is 30 psi
  - Initial clean membrane operating pressure is 10 psi

- What's the clean membrane permeability?
- What's the plant's production at 5C in the winter time?
- What's the minimum permeability that the plant needs to maintain at any given time to ensure the plant will be able to produce 10 mgd at the end of the membrane's projected life