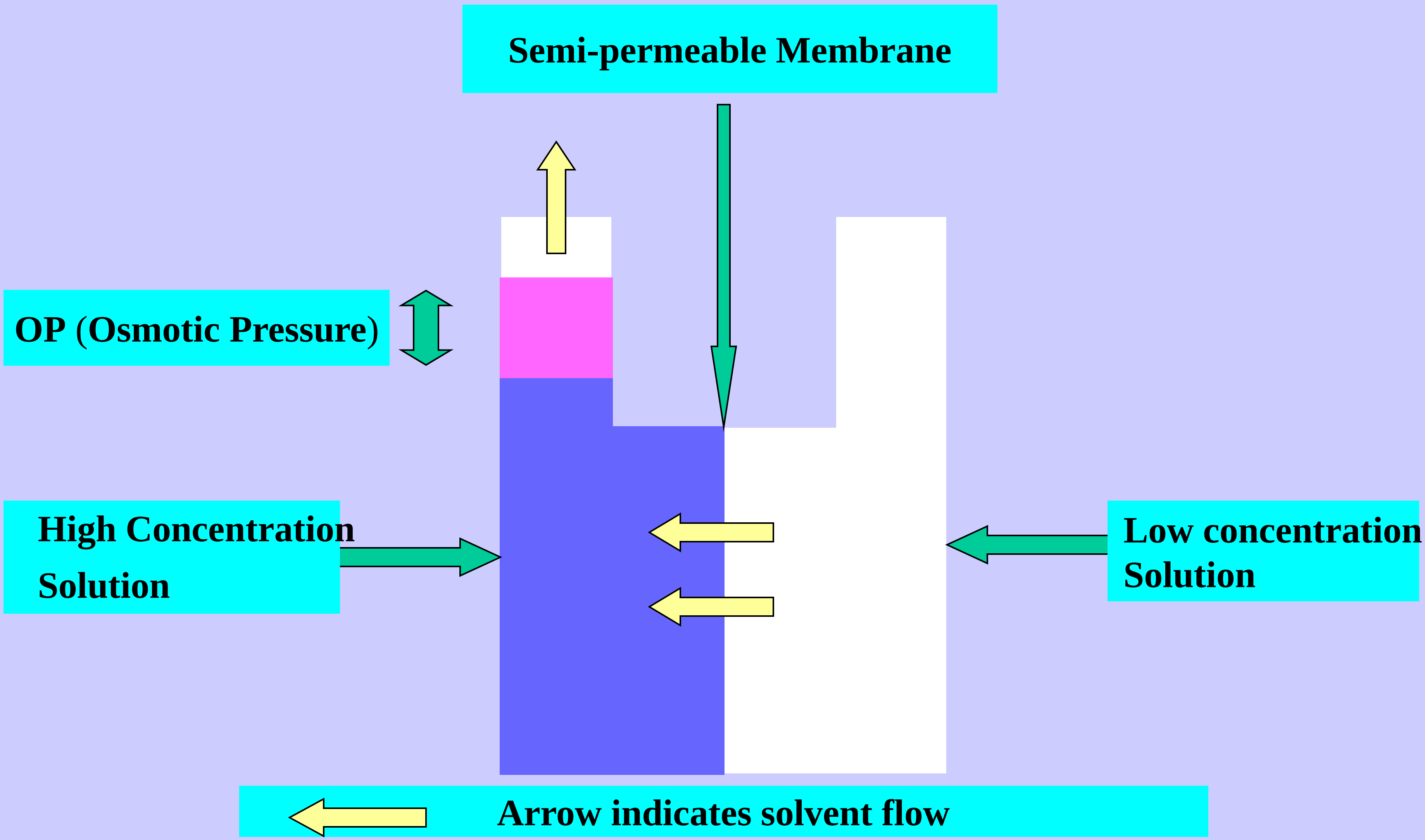
OSMOSIS

When two solutions of different concentrations are separated by a semi-permeable membrane, solvent will pass through the membrane from the dilute to the concentrated solution.

OSMOTIC PRESSURE

- **The maximum differential pressure across the membrane for any two solutions is called the osmotic pressure.**
- **Osmotic pressure depends upon the difference in concentration of the two solutions.**

OSMOSIS

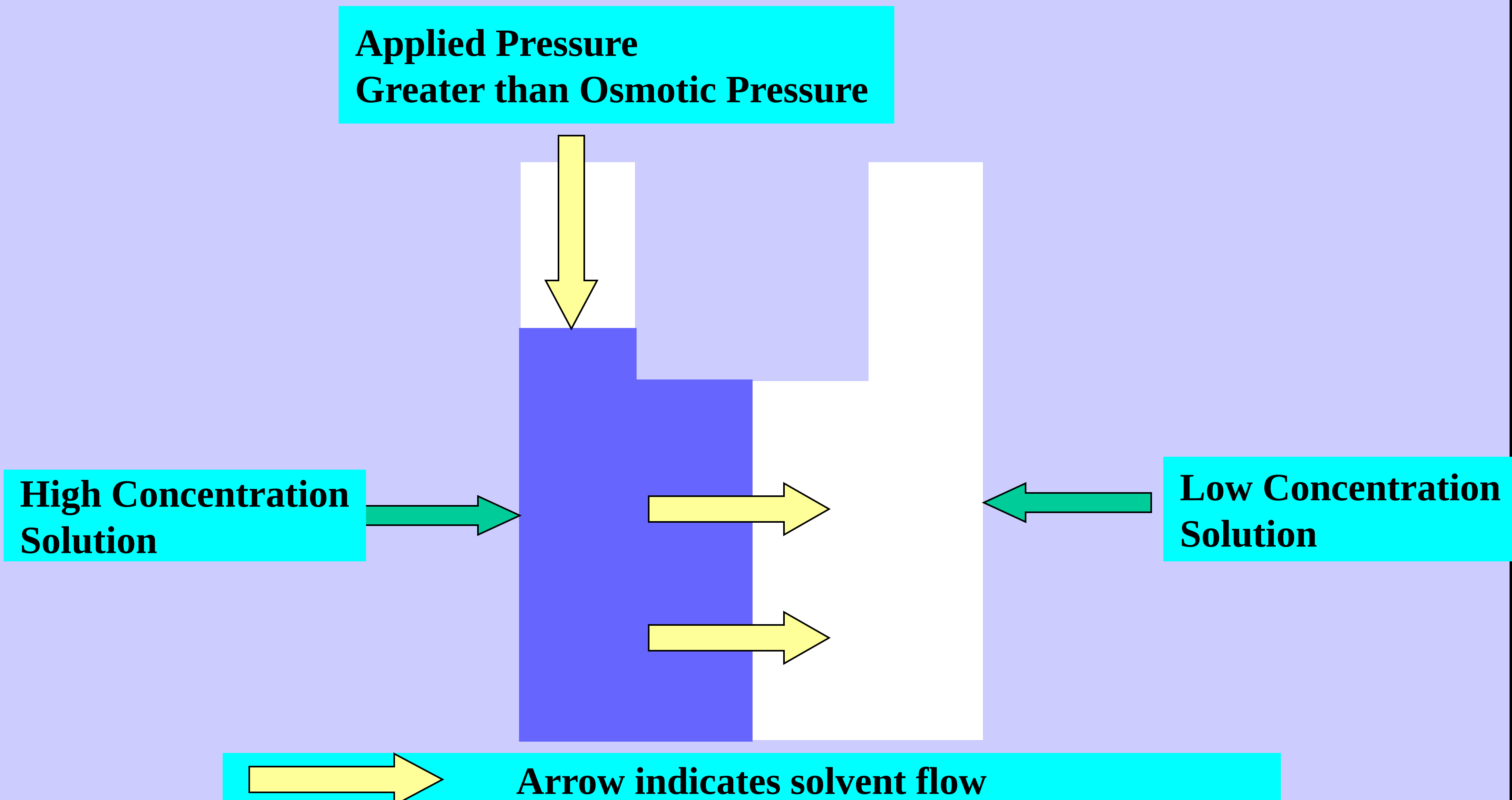

Semi-permeable Membrane
OP (Osmotic Pressure)
High Concentration Solution
Low concentration Solution
Arrow indicates solvent flow

REVERSE OSMOSIS

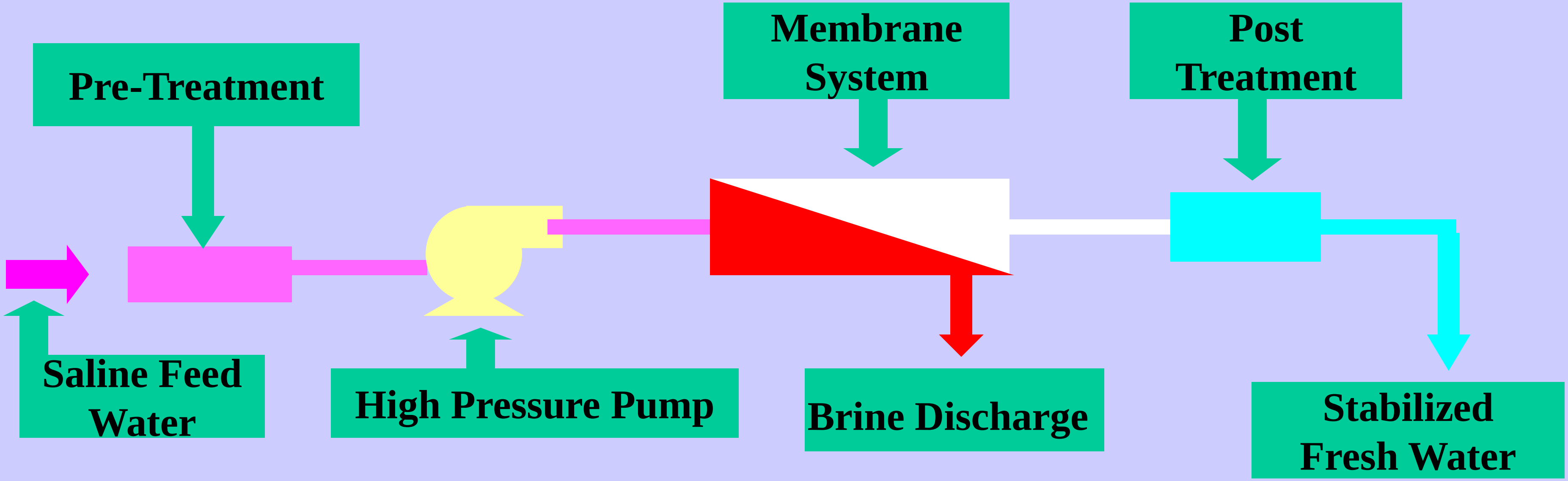
If a pressure greater than the osmotic pressure is exerted on the concentrated solution the flow path will be reversed, and the solvent will pass from the concentrated to the dilute solution.

This is called Reverse Osmosis (RO).

REVERSE OSMOSIS



REVERSE OSMOSIS PLANT



TERMINOLOGY

- **Feed:** The solution that enters the membrane system.
- **Permeate:** The portion of the feed which passes across the membranes.
- **Membrane:** The material which separates the concentrated solution from the product and allows only the solvent to pass through.

TERMINOLOGY

- **Brine:** The portion of the feed that does not pass across the membranes or is rejected by the membranes.
- **Pressure: Vessel** The tube shaped vessel that holds one or more membrane elements.
- **Permeator:** The total membrane system.

TERMINOLOGY

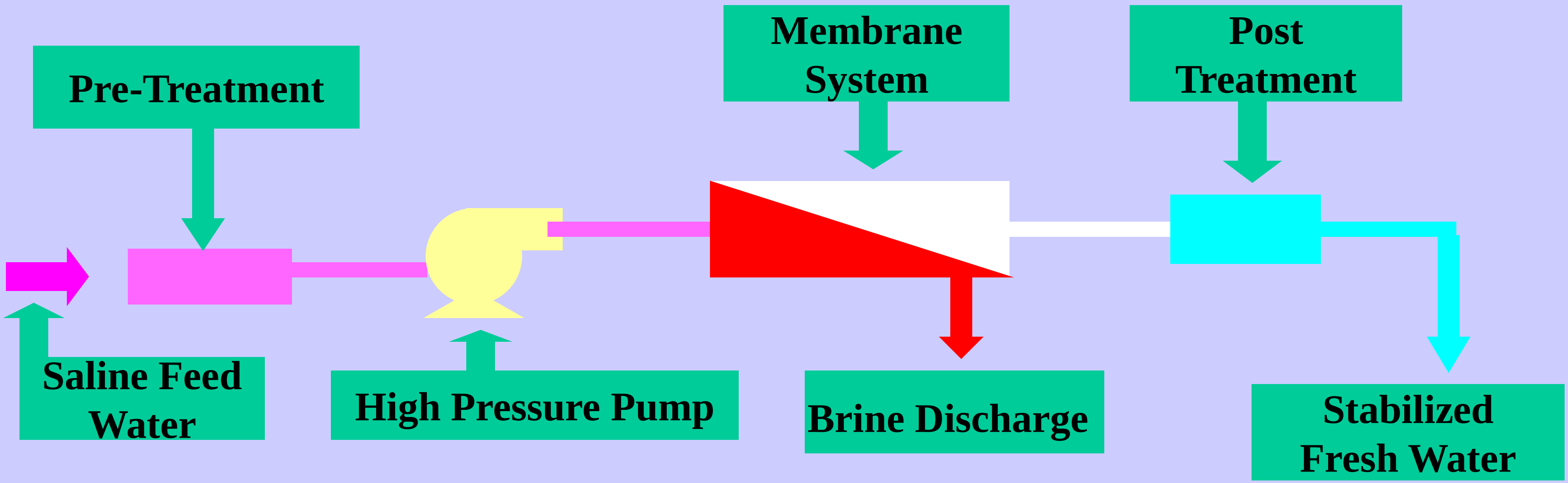
- **Recovery:** Water conversion factor, the ratio of product to feed flow expressed as percentage.
- **Salt Passage:** The ratio of salt concentration in the product and feed expressed as percentage.
- **Concentration Factor:** The ratio of feed to Reject.

REVERSE OSMOSIS PLANT

RO Plant consists of four main components

1) Pretreatment
2) High pressure pump
3) Membrane System
4) Post Treatment

REVERSE OSMOSIS PLANT



REVERSE OSMOSIS PLANT

REVERSE OSMOSIS PLANT

1. **Pretreatment**

   The feed water to the RO plant is treated to make it compatible and non damaging to the membrane system by mechanical and chemical processes.

REVERSE OSMOSIS PLANT

2 High Pressure Pump

The high pressure pump provides the driving force necessary to over come the natural osmotic pressure existing between the feed and the product water.

REVERSE OSMOSIS PLANT

3 Membrane System

Membranes inhibit the passage of dissolved salts and allow only water molecules to pass through it, producing almost salt free water

REVERSE OSMOSIS PLANT

4 Post Treatment

The product water usually needs some form of chemical treatment before use.

For potable water use calcium and alkalinity must be added to comply WHO limits.

For process use, the addition of corrosion inhibitor should be considered.

MEMBRANE SEPERATION PROCESS

Sr. No.	Process for Separation	Operating Pressure Psi.	Particle size removed
1	Particle Filtration (PF)	< 10.00	5 – 10 microns
2	Micro Filtration (MF)	< 10.00	0.1 – 1.0 microns
3	Ultra Filtration (UF)	15 – 100	Up to 1.0 micron i.e. Molecular Wt. In the range, 1,000 to 100, 000

MEMBRANE SEPERATION PROCESS

Sr. No.	Process for Separation	Operating Pressure Psi.	Particle size removed
4	Nano Filtration	50 – 250	Molecular weight 200 – 1,000
5	Reverse Osmosis (Hyper Filtration)	200 – 1,100	Molecular weights < 100

MEMBRANES

Two most common materials from which membranes are made are, **cellulose acetate** and **polyamide**.

Polyamide Membranes	Cellulose Acetate Membranes
Oxidized by chlorine.	Tolerant to chlorine.
Can operate at higher pH range.	Limited operating pH range.
Acid addition can be eliminated.	Acid addition is a must.
Higher installation cost and lower operating cost.	Lower installation cost and higher operating cost.

MEMBRANE

MEMBRANE

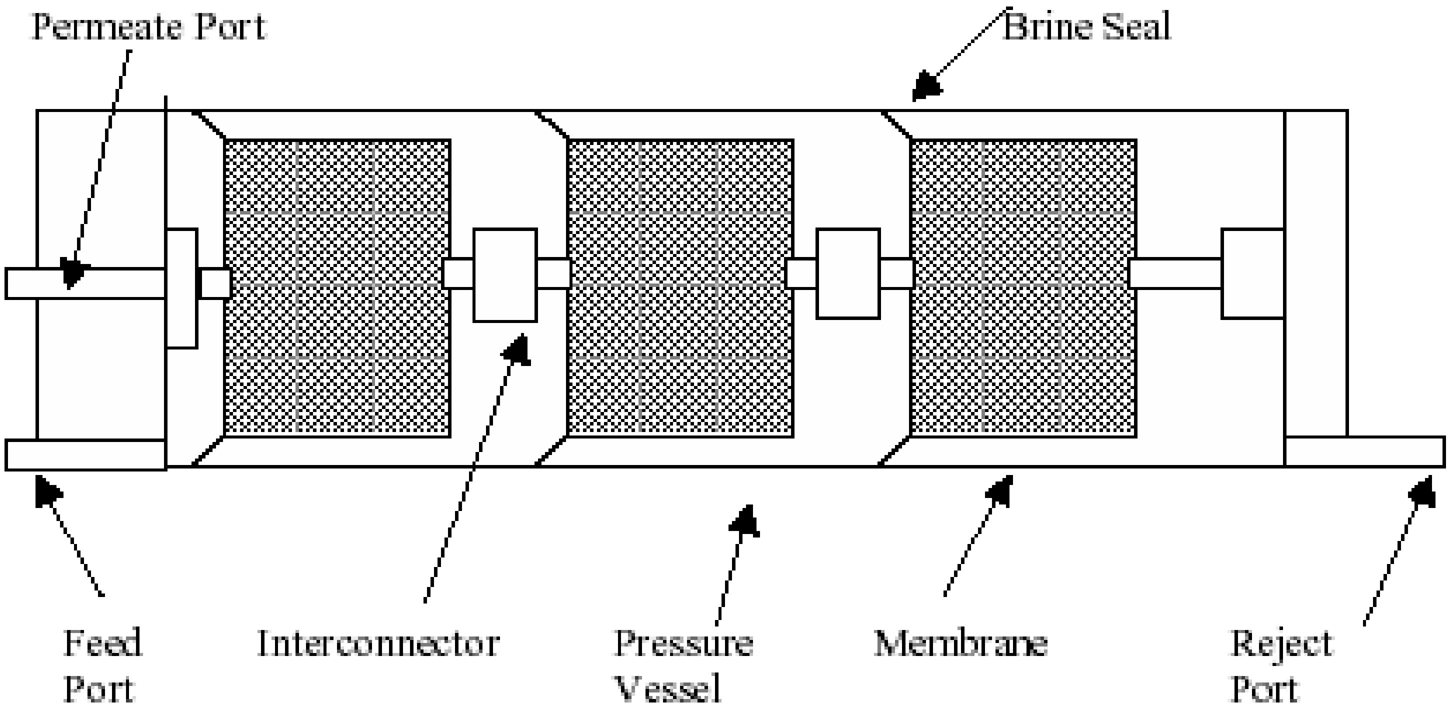
MEMBRANE

MEMBRANE

FLOW CONFIGURATION

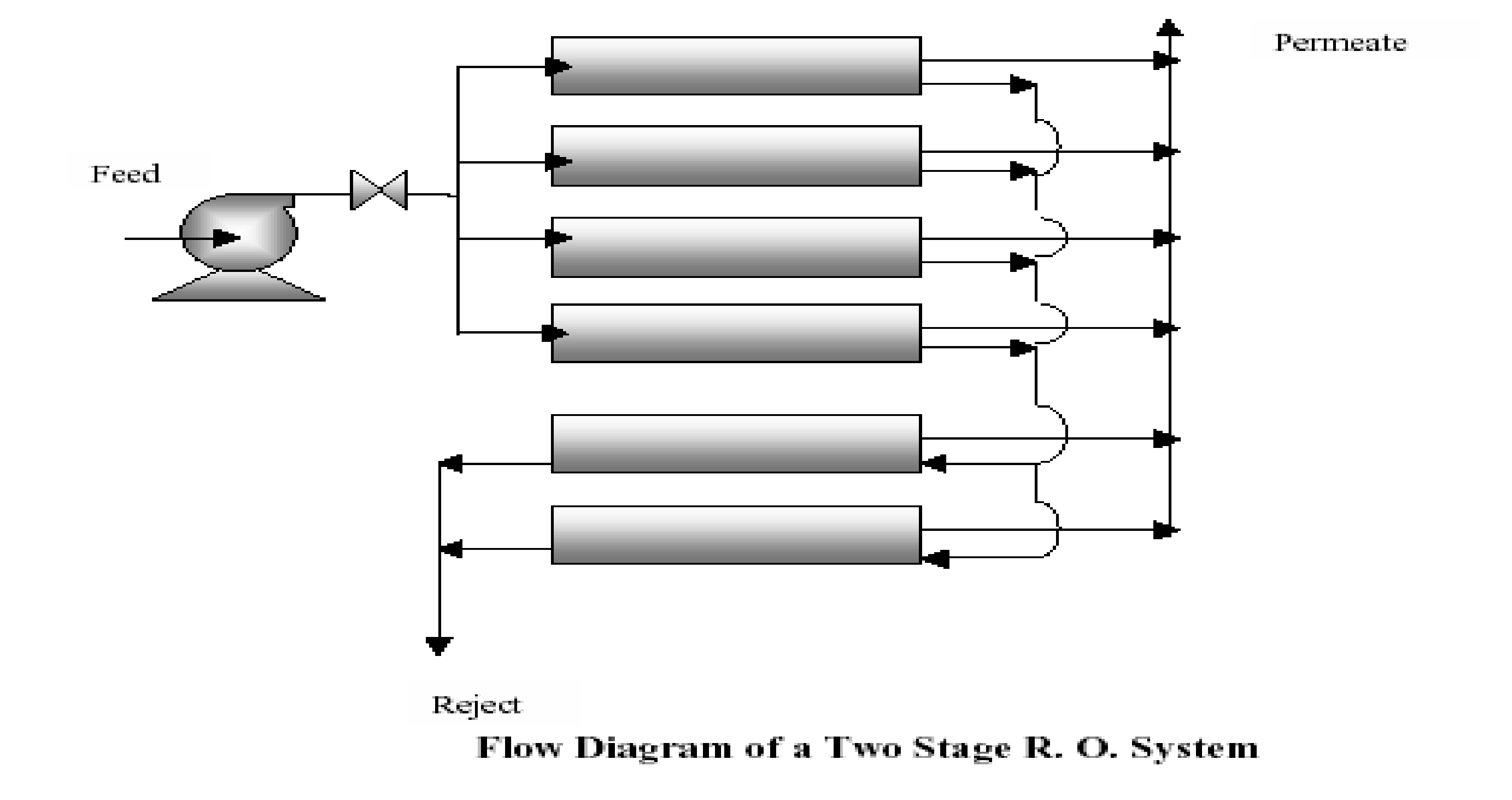
- SINGLE STAGE
- TWO OR MORE STAGES
- CONCENTRATE RECIRCULATION
- TWO STAGES WITH PERMEATE THROTTLING
- TWO STAGE WITH INTERSTAGE PUMP
- PERMEATE STAGING

SINGLE STAGE WITH THREE MEMBRANES

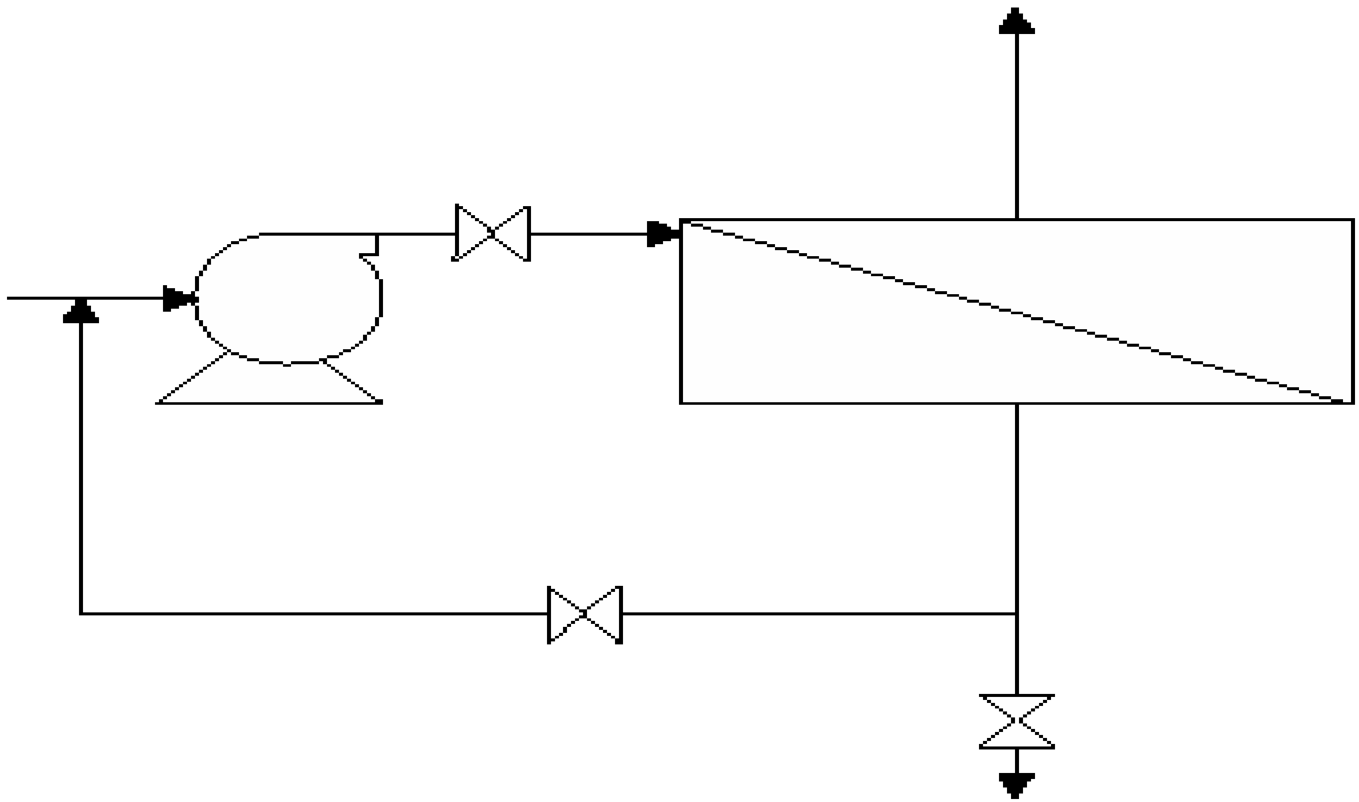


Pressure Vessel with Three Membrane Elements

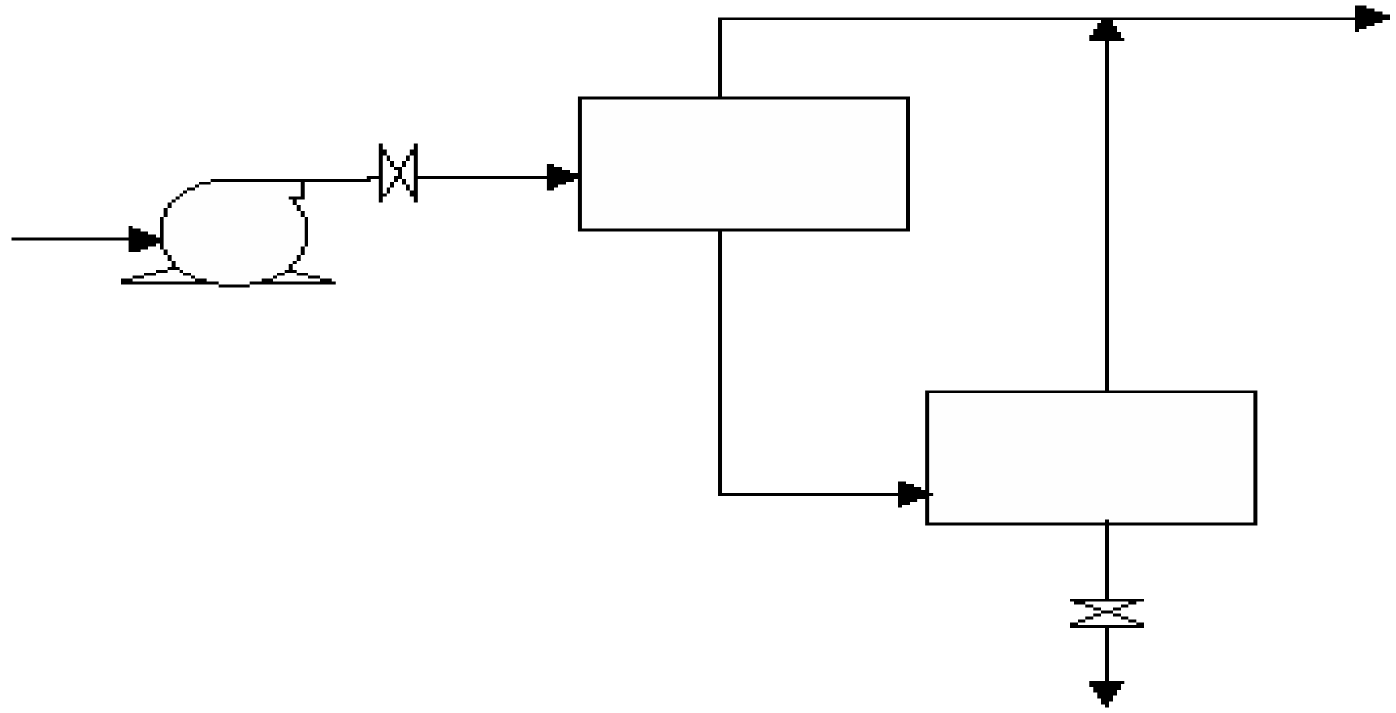
TWO STAGE R. O.



REJECT RECIRCULATION

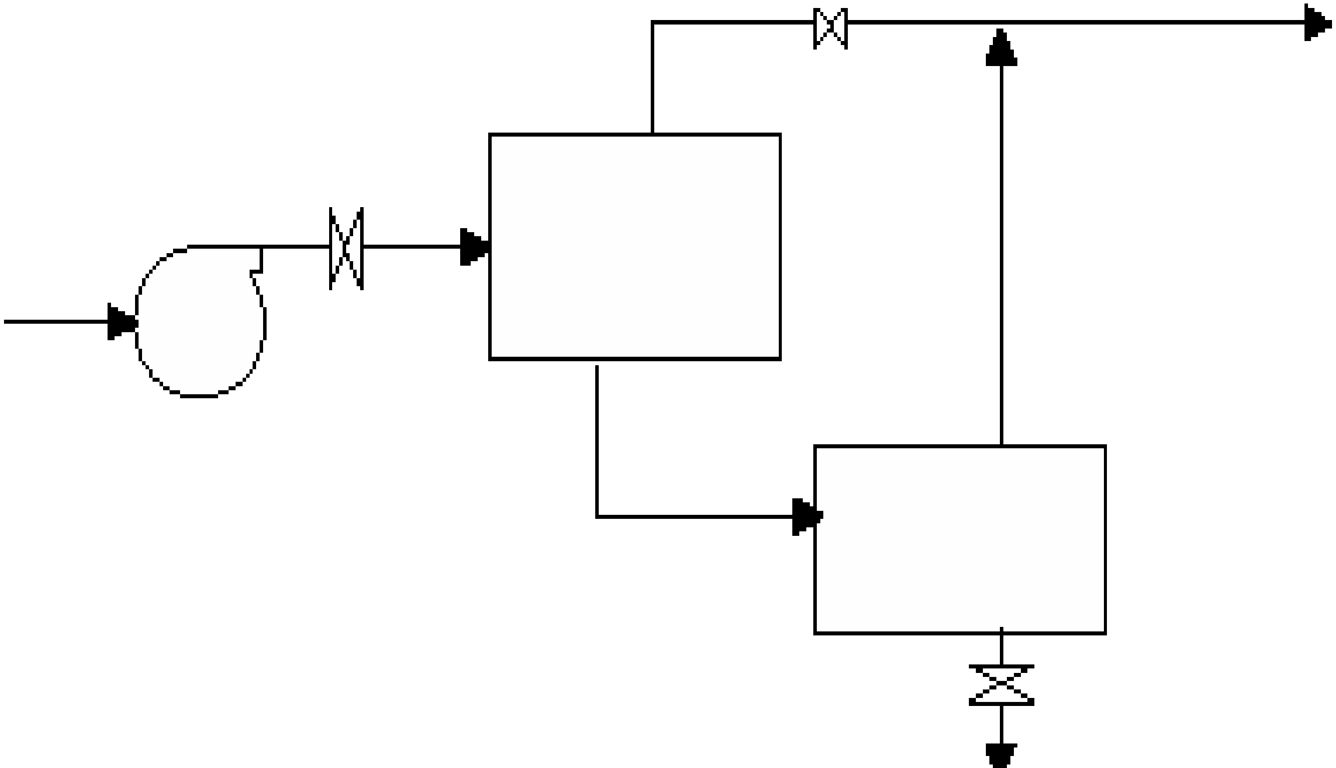


TWO STAGE SCHEMATIC



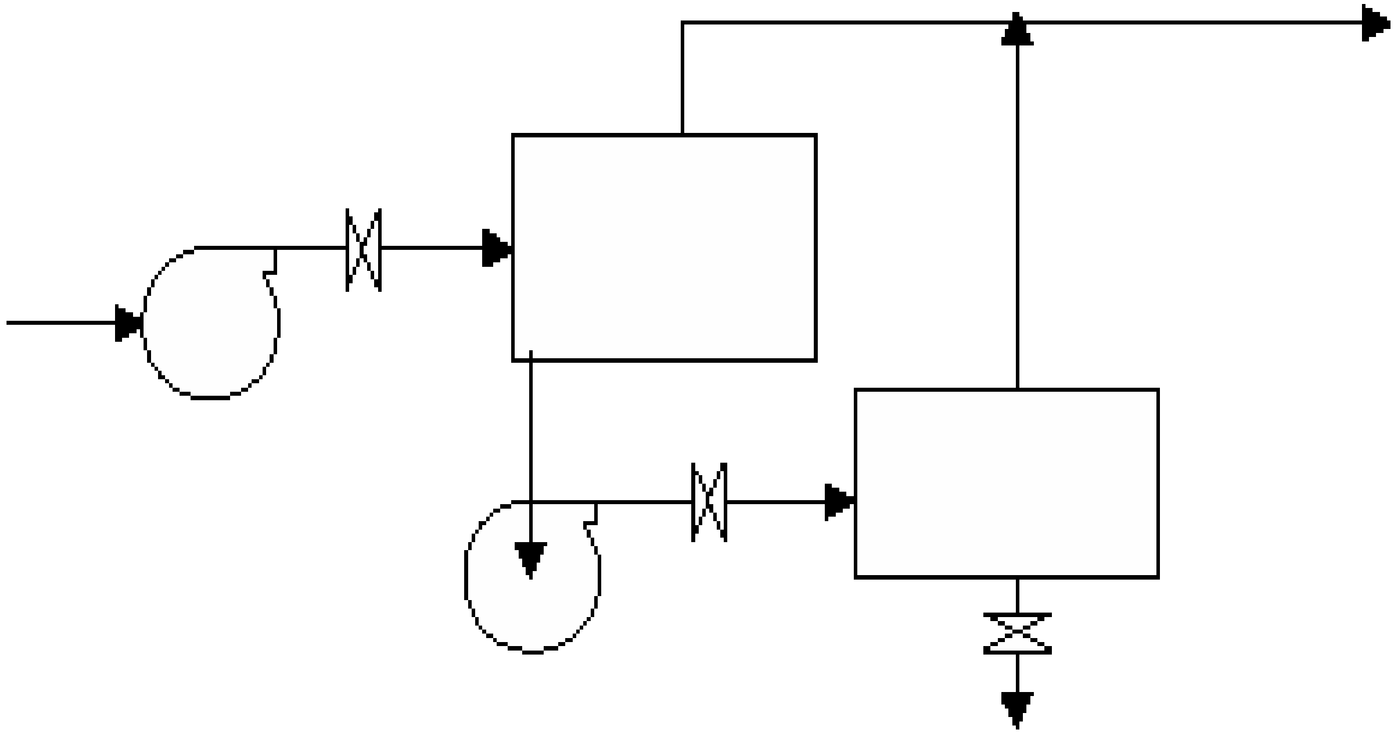
Flow Diagram of a Two Stage R. O. System

TWO STAGE WITH PERMEATE THROTTLING



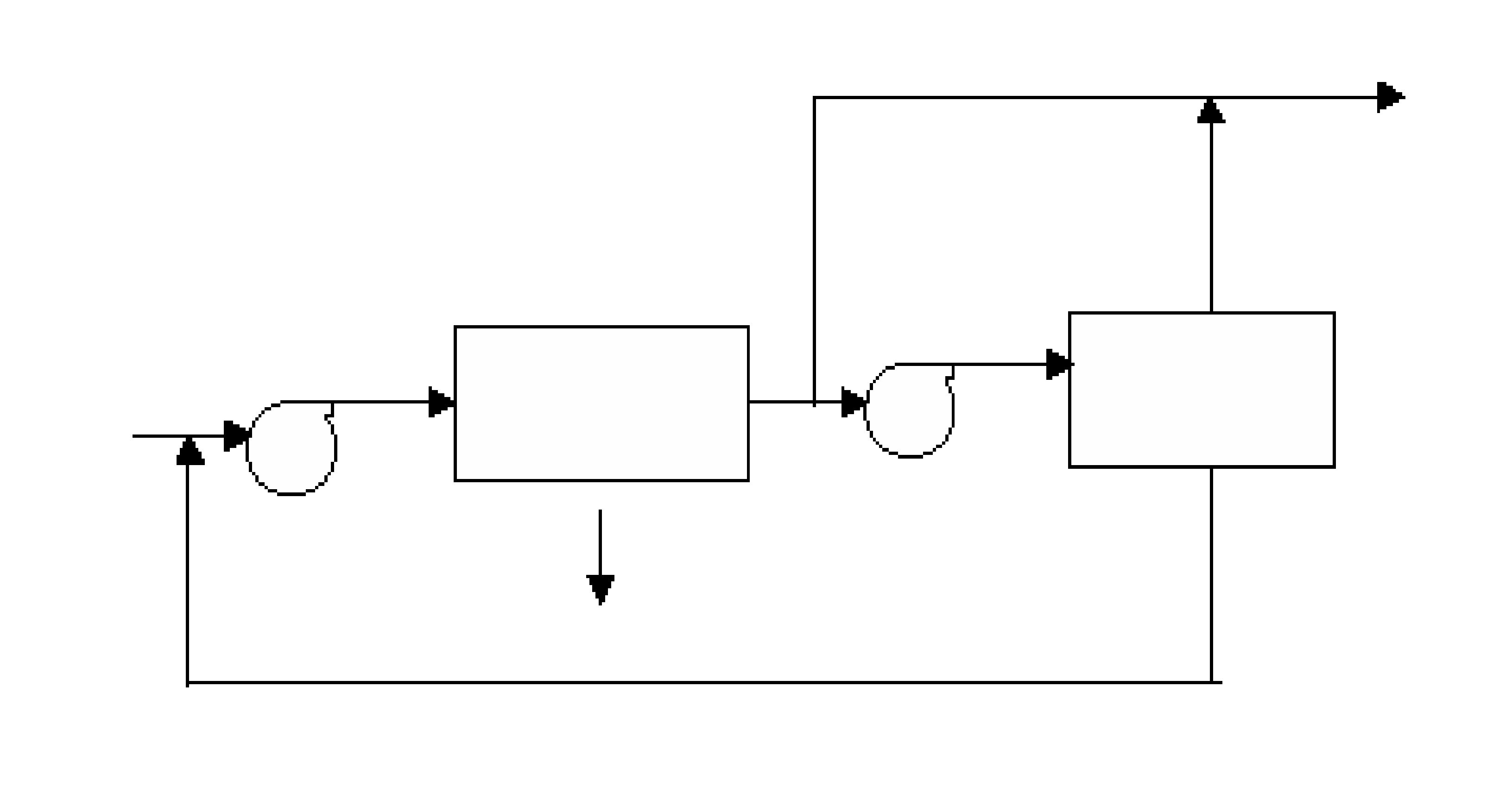
Flow Diagram of a Two Stage R. O. System with Permeate Throttling

TWO STAGE WITH INTERSTAGE PUMP



Flow Diagram of a Two Stage R. O. System with Interstage Pump

TWO STAGE WITH PERMEATE STAGING



FACTORS AFFECTING R.O. PERFORMANCE

Increasing	Permeate Flow	Salt Passage
Pressure	↑	↓
Temperature	↑	↑
Recovery	↓	↑
Feed TDS	↓	↑
Time (Ageing)	↓	↑

ADDITIONAL FACTORS AFFECTING R.O. PERFORMANCE

• **Systematic Operation**
• **Proper Maintenance**
• **Adequate Pretreatment**

MAJOR PROBLEM IN R. O. PLANT OPERATION

MEMBRANE

SCALING

&

FOULING

EFFECTS OF MEMBRANE SCALING & FOULING

1. **Reduced product water flow**
2. **Increased ‘Pressure Drop’**
3. **Increased product water TDS**
4. **Increased operating cost**

EFFECTS OF MEMBRANE SCALING & FOULING

5. **Increased cleaning frequency resulting in increased operating cost, increased downtime of plant and reduced life of membranes.**

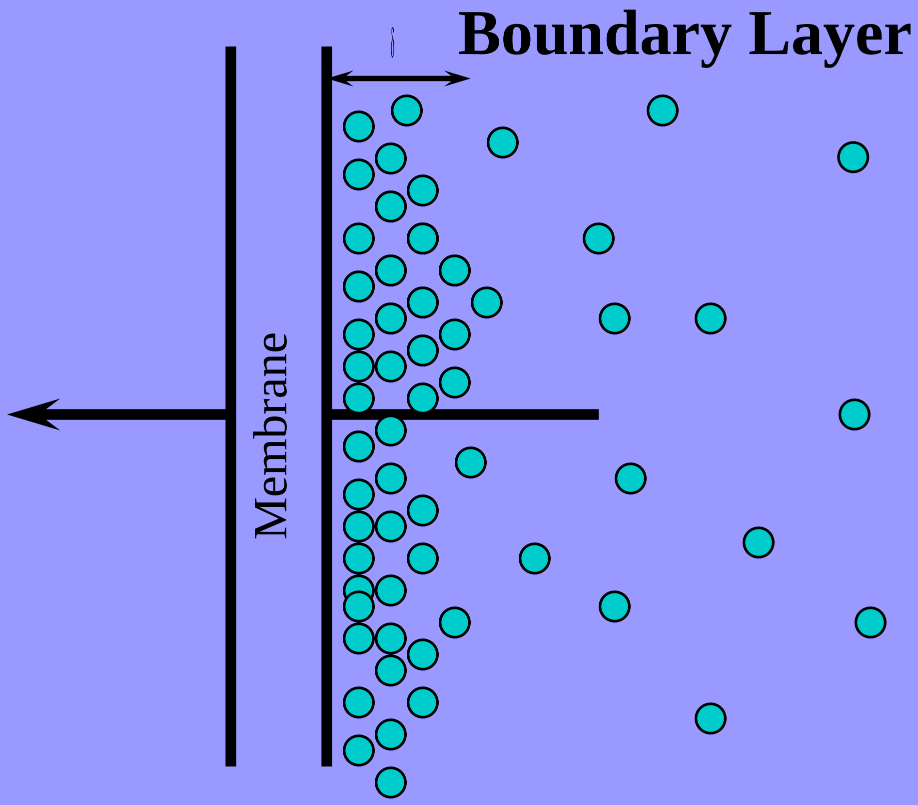
6. **Severe deposits can cause irreversible membrane damage requiring replacement.**

SCALING & FOULING MECHANISM

As the product water continuously passes through the membrane, dissolved and suspended solids concentrate at the separating surface creating a boundary layer, an effect known as **“Concentration Polarization”**

Within this boundary layer salts may precipitate and suspended solids can start to deposit on the membrane surface and spacers of spiral wound system.

Concentration Polarisation



THERE ARE 6 MAIN CAUSES OF MEMBRANE SCALING & FOULING

1. **Scaling by hardness salts**
2. **Scaling with silica**
3. **Fouling with metal oxides**
4. **Plugging by suspended solids**
5. **Colloidal fouling**
6. **Biological fouling**

SCALING

Inorganic scales which may form and cause reduced plant performance include,

- **Calcium Carbonate ($CaCO_3$)**
- **Magnesium Carbonate ($MgCO_3$)**
- **Calcium Sulphate ($CaSO_4$)**
- **Magnesium Sulphate ($MgSO_4$)**
- **Barium Sulphate ($BaSO_4$)**
- **Calcium Fluoride (CaF_2)**
- **Strontium Sulphate ($SrSO_4$)**

IONS FOUND IN WATER

Ca^{2+} HCO_3^-

Mg^{2+} SO_4^{2-}

Sr^{2+} Cl^-

Ba^{2+} CO_3^{2-}

Fe^{3+}/Fe^{2+} NO_3^-

Na^+ Mn^{4+} F^-

K^+ SiO_2

FACTORS RESPOSIBLE FOR SCALING

- **Concentration of Scale forming Salts**
  - **Concentration in Feed Water**
  - **Recovery**
- **pH of Feed Water - Most scale forming salts have lower solubility at higher pH**
- **Temperature - Many of the Scale forming Salts have reverse solubility with respect to Temperature**

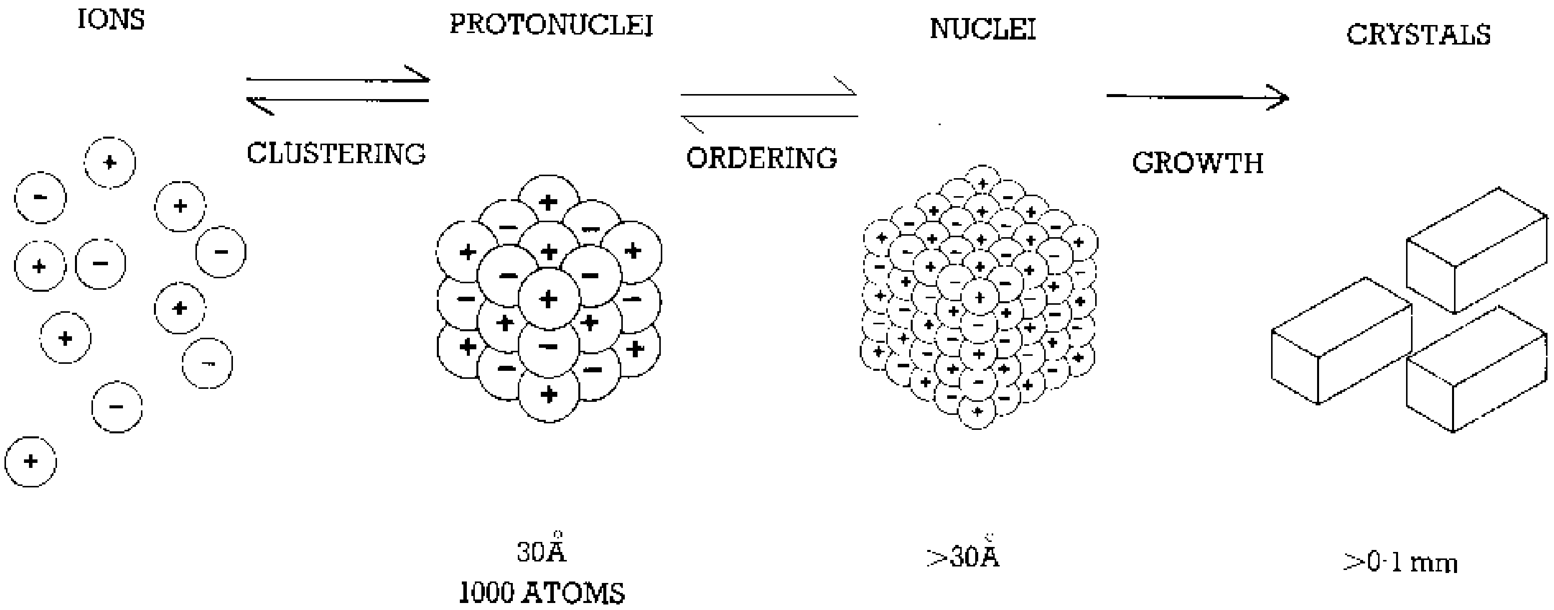
STAGES OF SCALE FORMATION

- Ions in solution concentrate in the boundary layer and start clustering as a protonuclei of up to 1000 molecules.

- The protonuclei grow and start ordering themselves in a regular shaped nuclei.

- Nuclei grow in to crystal.

STAGES OF CRYSTALLIZATION



SILICA SCALING

It is essential to operate the membrane system out side silica scaling limits because once the silica deposit is formed it is very difficult to remove.

In practice silica deposition is controlled by reducing the recovery rate to a safe level.

FOULING WITH METAL OXIDES

Iron is the commonest of these foulant and is often present in the borehole water in its reduced ferrous state.

Other problem metals are Aluminium and Manganese.

SUSPENDED SOLIDS PLUGGING

Suspended solids can include bacteria, silt and clay.

Plugging occurs when suspended solids pass through the feed system and are trapped at the membrane surface.

COLLOIDAL FOULING

Colloidal iron, silica and aluminium silicates are particular forms of suspended solids.

The colloidal particle size varies between 0.3 to 1.0 micron and can pass easily through normal filtration system.

COLLOIDAL FOULING

The suspended solid loading of the feed water can be determined by the **'Silt Density Index' (SDI).**

SDI < 3.0	**Little or no fouling is expected.**
SDI 3.0 – 6.0	**There may be some fouling and additional pretreatment may be required.**
SDI > 6.0	**Can cause significant fouling and additional pretreatment is necessary.**

BIOLOGICAL FOULING

Biological fouling is responsible for a large portion of problems like flux decline and poor salt rejection.

Poor chemical pretreatment and failure to control microbiological growth in any part of the feed water system may cause bacteria, algae, fungi and Yeast to enter the membrane system.

BIOLOGICAL FOULING

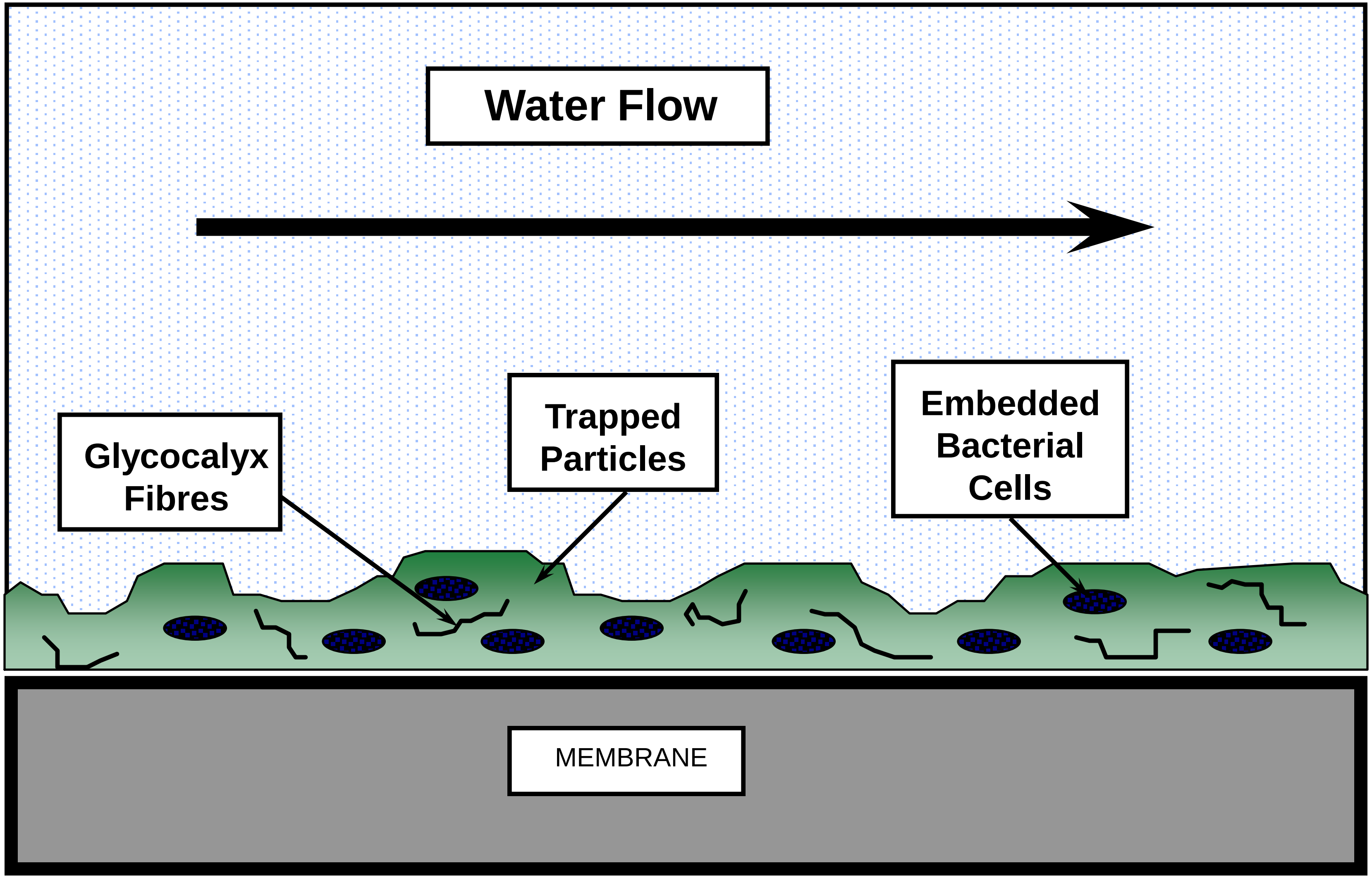
- Microorganisms multiply very fast
- Generate biomass that deposits on membrane surface
- Most microorganisms secrete slime that acts as a binding material for other suspended and precipitated matter thus compounding the problem of deposition
- Once introduced in the system, is very difficult to control

BIOLOGICAL FOULING

Accumulation of biofilm occurs in four stages.

1. **Adsorption of organic matter resulting in a ‘conditioned’ surface.**
2. **Transportation of microbial cells to the ‘conditioned’ surface.**
3. **Adhesion of microbial cells.**
4. **Biofilm development.**

Membrane Biofouling



BIOLOGICAL FOULING

Biofilm is an adhesive polysaccharide material (or glycocalyx). It acts as a trap for organic debris or as a source of further microbiological adsorption on growth.

MEMBRANE FOULING CONTROL

Scaling by hardness salts: Dosing of Acids, Threshold Inhibitors and Dispersants in feed water.
Scaling by silica: Reducing the recovery rate to a safe level. Some antiscalants can control silica scaling up to certain level.
Fouling with metal oxides: Phosphonate based antiscalants can take care of iron fouling up to certain limit.

MEMBRANE FOULING CONTROL

Plugging by suspended solids: Removal of suspended solids by filtration of feed water.
Colloidal fouling: Removal of colloidal matter from feed water using suitable coagulants/ Polyelectrolytes and special methods such as iron removal.
Biological fouling: Removal of biological material by Chlorination, Ozonation or Ultraviolet irradiation of feed water.

INORGANIC FOULING CONTROL CONVENTIONAL METHODS

- **ACID DOSING IN FEED WATER**
- **SODIUM HEXAMETAPHOSPHATE DOSING**

ACID DOSING

- Converts Carbonates and Bicarbonates to more soluble salts such as Sulfates and Chlorides depending on acid used
- High concentration of sulfates cause scaling
- Handling Hazards
- Dosing rates should be monitored precisely. Very low pH can cause irreversible membrane damage

SODIUM HEXAMETAPHOSPHATE (SHMP)

- The oldest Threshold Inhibitor
- Not completely effective against Sulfate Scale
- Very low thermal and hydrolytic stability, hence can give rise to phosphate scales
- Acts as a nutrient and hence enhances microbiological growth

MODERN METHODS OF SCALE CONTROL

- PHOSPHONATES
- DISPERSANTS

SCALE INHIBITION

Phosphonate and Polymer based scale inhibitors work by three closely related mechanisms, which interfere with one or more stages of crystal growth.

SCALE INHIBITION

1. **Threshold Effect:**

   These inhibitors retard the precipitation of salts, which have exceeded their solubility.

2. **Crystal Distortion Effect:**

   These inhibitors distort normal crystal growth and produce an irregular crystal structure with poor scale forming ability.

3. **Dispersancy:**

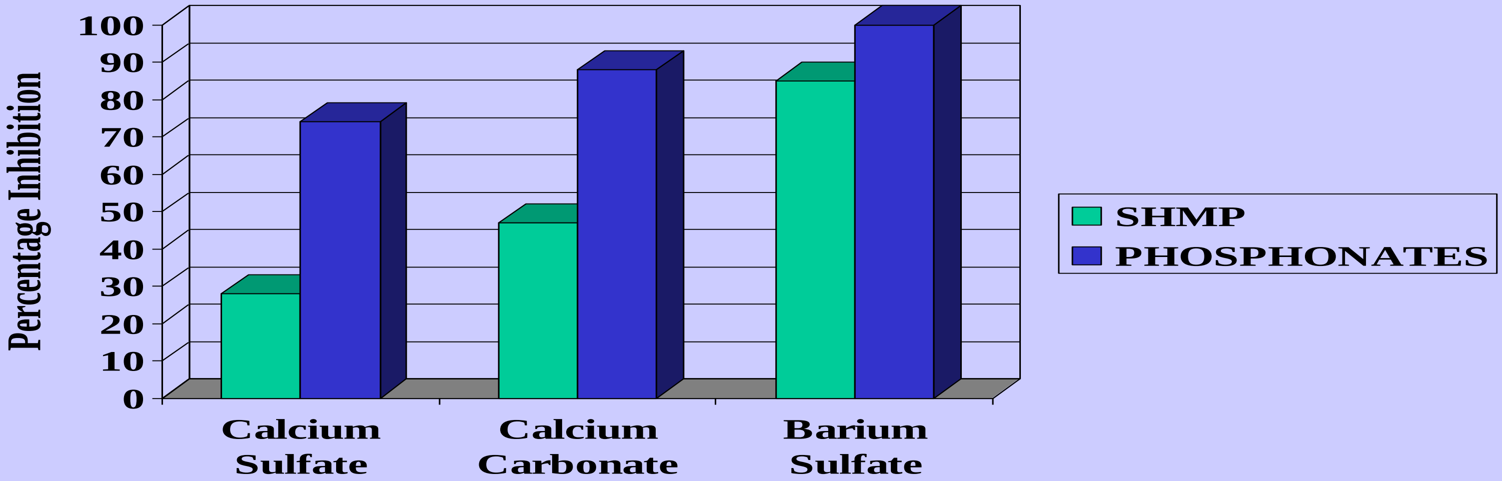
   Dispersants work by placing a surface charge on the crystal. Comparable charges cause the crystal to repel one other and are dispersed in to the bulk water.

ADVANTAGES OF PHOSPHONATES / DISPERSANTS VS SHMP

- **High Thermal and Hydrolytic Stability**
- **Excellent control of Carbonate and Sulfate Scales**
- **Does not support microbial growth**
- **Very High Threshold inhibition compared to SHMP**
- **Being a Dispersant, it prevents deposition even if precipitation occurs at high concentration of scalants**

COMPARISON OF PHOSPHONATES AND SHMP:

THRESHOLD INHIBITION AT 40 Deg C



AQUACARE-A-101Fe

EXCELLENT CONTROL OF CARBONATE AND SULFATE SCALE

- **CONTROLS IRON FOULING**
- **SPECIFICALLY USEFUL FOR HIGH SULFATE, SILICA & IRON**
- **NEUTRAL pH**
- **DOES NOT SUPPORT MICROBIOLOGICAL GROWTH**
- **APPROVED NY NSF FOR DRINKING WATER R. O.**

AQUACARE-A-101Fe

- **NSF APPROVED FOR POTABLE WATER APPLICATION**

AQUACARE-A-101Fe APPLICATION

- **DOSE : 2- 5 PPM IN FEED WATER**
- **EXACT DOSE LEVEL DEPENDS ON WATER QUALITY, RECOVERY**
- **CAN BE DOSED AS SUCH OR DILUTED WITH WATER**
- **ENSURE THAT DILUTION WATER IS BACTERIA FREE R.O. PRODUCT**

SELECTION OF R.O. ANTISCALANTS:

- **FEED WATER QUALITY: pH, HARDNESS, IRON, SILICA, SDI**
- **ACID DOSING**
- **PLANT CAPACITY**
- **RECOVERY**
- **PRETREATMENT**
- **COMPETITION**

SELECTION OF R. O. ANTISCALANTS

- R.O. ANTISCALANT PROJECTION PROGRAM
  - SELECTS THE RIGHT TYPE OF ANTISCALANT FOR GIVEN CONDITIONS
  - SUGGESTS OPTIMUM DOSAGE
  - INDICATES VARIOUS POTENTIAL PROBLEMS

MONITORING OF R.O. ANTISCALANTS

- **OPERATING PARAMETERS: RECOVERY, FEED WATER ANALYSIS, TEMPERATURE, PRESSURE DROP**
- **ANTISCALANT DOSING**
- **MICROBIAL CONTAMINATION IN FEED WATER**
- **PRETRETMENT**
- **REGULAR CLEANING OF ANTISCALANT DOSING TANK**
- **CHLORINATION AND DECHLORINATION**
- **PERIODIC CLEANING OF MEMBRANES**

MEMBRANE CLEANING

WHY CLEANING IS REQUIRED ?

- INADEQUATE PREATMENT
- PRETREATMENT UPSET CONDITIONS
- CHEMICAL DOSING SYSTEM FAILURE
- IMPROPER OPERATION CONTROL
- BUILD UP OF PRECIPITATES OVER EXTENDED PERIODS
- CHANGE IN FEED WATER COMPOSITION
- BIOLOGICAL CONTAMINATION OF FEED WATER

WHEN TO CLEAN MEMBRANES

- NORMALIZED PERMEATE FLOW DROPS BY 10 %
- NORMALIZED SALT CONTENT OF PRODUCT WATER INCREASES BY 10 %
- DIFFERENTIAL PRESSURE (DP) INCREASES BY 15 %

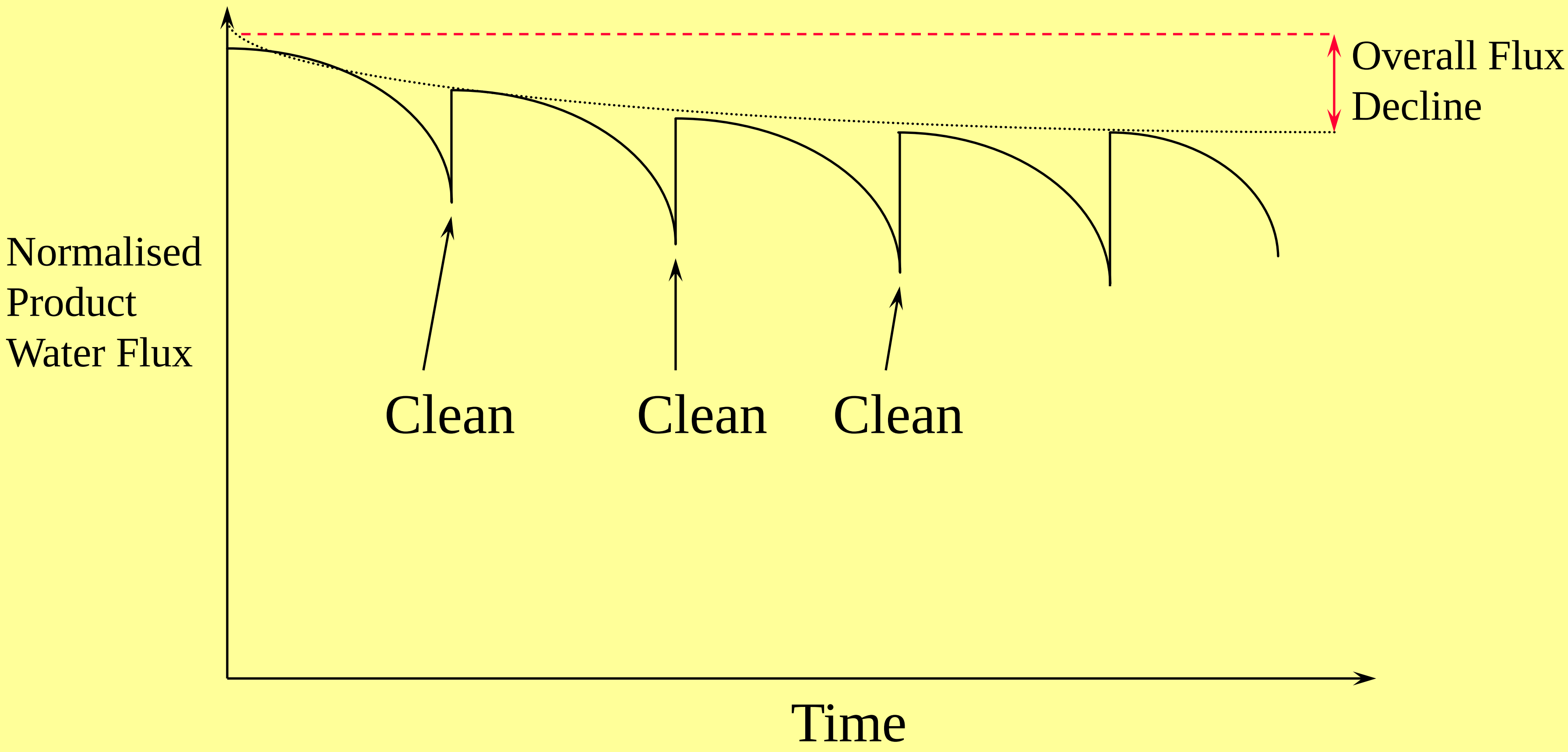
TYPES OF CLEANING CHEMICALS

- ACIDS
- ALKALI/ CHELANTS
- SURFACTANTS
- CHEMICALS FOR SPECIFIC PROBLEMS
- DISINFECTANTS
- POST TREATMENT

SYSTEM SURVEY BEFORE DECIDING CLEANING CHEMICALS

- PLANT PERFORMANCE DATA
- FEED WATER ANALYSIS
- RESULTS OF PREVIOUS CLEANING
- FOULANTS COLLECTED ON A MEMBRANE FILTER
- DEPOSITS ON A CARTRIGE FILTER
- INSPECTION OF INNER SURFACE OF FEED LINE
- USE OF WRONG CHEMICALS CAN WORSEN THE SITUATION

Membrane Cleaning Cycles



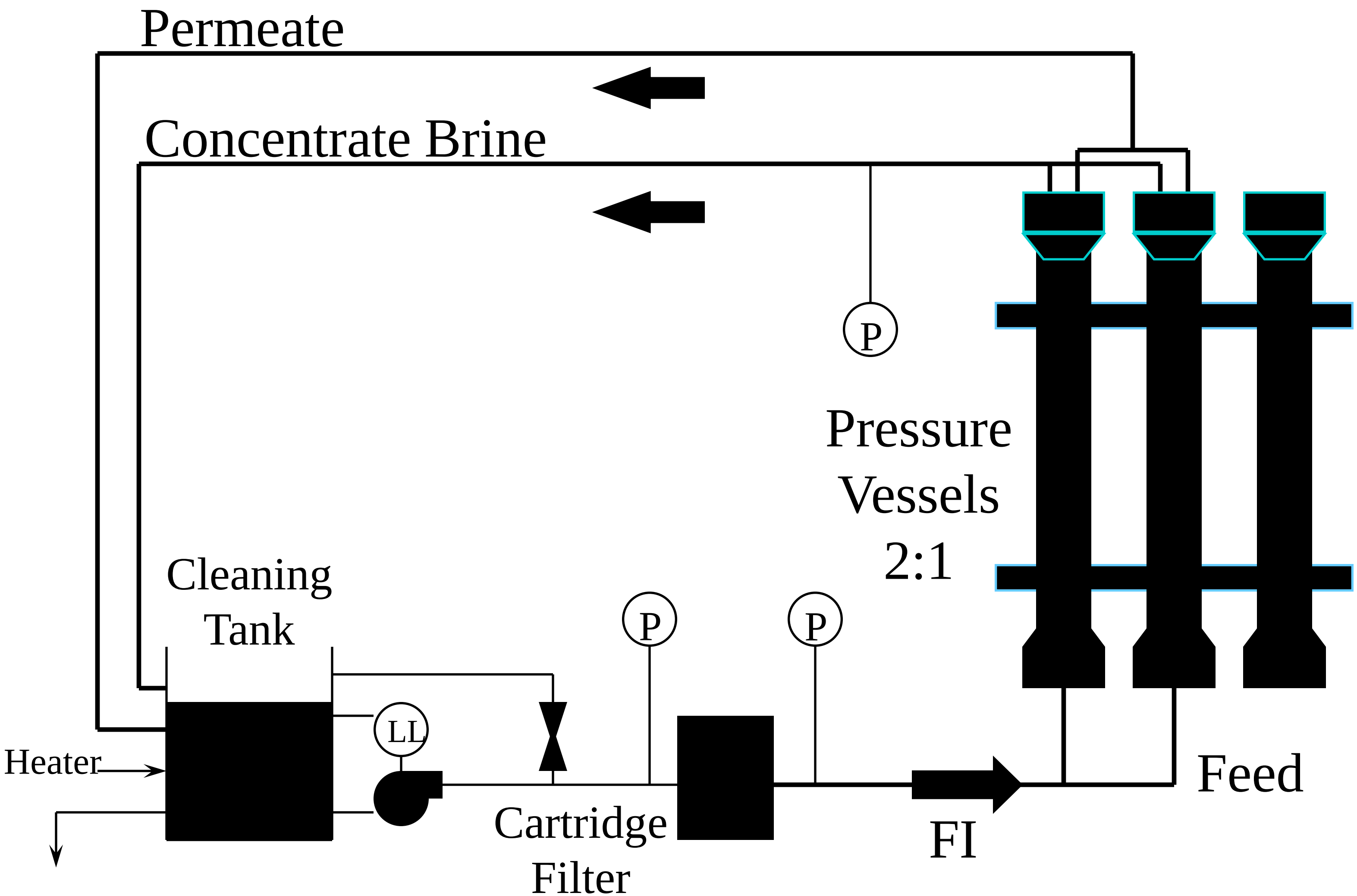
CLEANING GUIDELINES

- PRESSURE < 4 BAR
- FLOW < 175 l/min PER 8” X 40” ELEMENT
- USE ALKALINE CLEANERS FIRST IF ORGANIC FOULING SUSPECTED
- CLEANING SOLUTION VOLUME: 30-40 LITRES PER 8” ELEMENT
- SOLUTION TEMP (20 - 30^{0}C)
- SOAK MEMBRANES
- PREFERABLY CLEAN ‘STAGE BY STAGE’

CLEANING GUIDELINES

- FOLLOW MEMBRANE MANUFACTURERS GUIDELINES.
- CLOSELY MONITOR :-
pH, TEMPERATURE, PRESSURE, CONDUCTIVITY, FLOW + HYDRAULICS.
- FLUSH WITH GOOD QUALITY CHLORINE-FREE WATER BETWEEN CLEANING STEPS AND RETURN TO SERVICE.
- DON`T PANIC!

Cleaning Circuit



MEMBRANE CLEANING SYMPTOMS & SOLUTIONS

Foulant	Salt Passage	Delta P	Product Flow	Cleaning Chemicals
Scale & Inorganic Deposits	10 – 15 % Increase	10 – 40 % Increase	< 10 Decrease	**AWC-C-216** **AWC-C-217**
Metal Oxides & Hydroxides	> 2 X Rapid Increase	> 2 X Rapid Increase	20 – 40 % Decrease	**AWC-C-218** **AWC-C-217**
Colloidal Fouling	> 2 X Gradual Increase	> 2 X Gradual Increase	> 50 % Decrease	**AWC-C-219** **AWC-C-218** **AWC-C-217**
Biofouling	Variable depends on Biofilm type	> 2 X Rapid Increase	50 % Decrease	**AWC-C-216** **AWC-A-315R** **AWC-C-218** **AWC-C-217**
Organic Matter	Increase	Small Increase	> 50 % Decrease	**AWC-C-216** **AWC-C-218** **AWC-C-217**

MEMBRANE AUTOPSY

- Important to identify problems in RO
- Transporting Membranes to be tested
- Performance Testing of Membrane: Salt Passage, Permeate Flow, Pressure Drop
- Physical Inspection of Various parts of the membrane
- Physical & Chemical Analysis of the Deposits at various locations on the membrane
- SCM (Scanning Electron Microscopy)
- T-EDXA(Targeted Energy Dispersive X-Ray Analysis)
- FTIR (Fourier Transform Infrared Spectroscopy)
- BART (Biological Activity Reaction Test)
- Membrane Cleaning Tests

Element as received

Feed-end

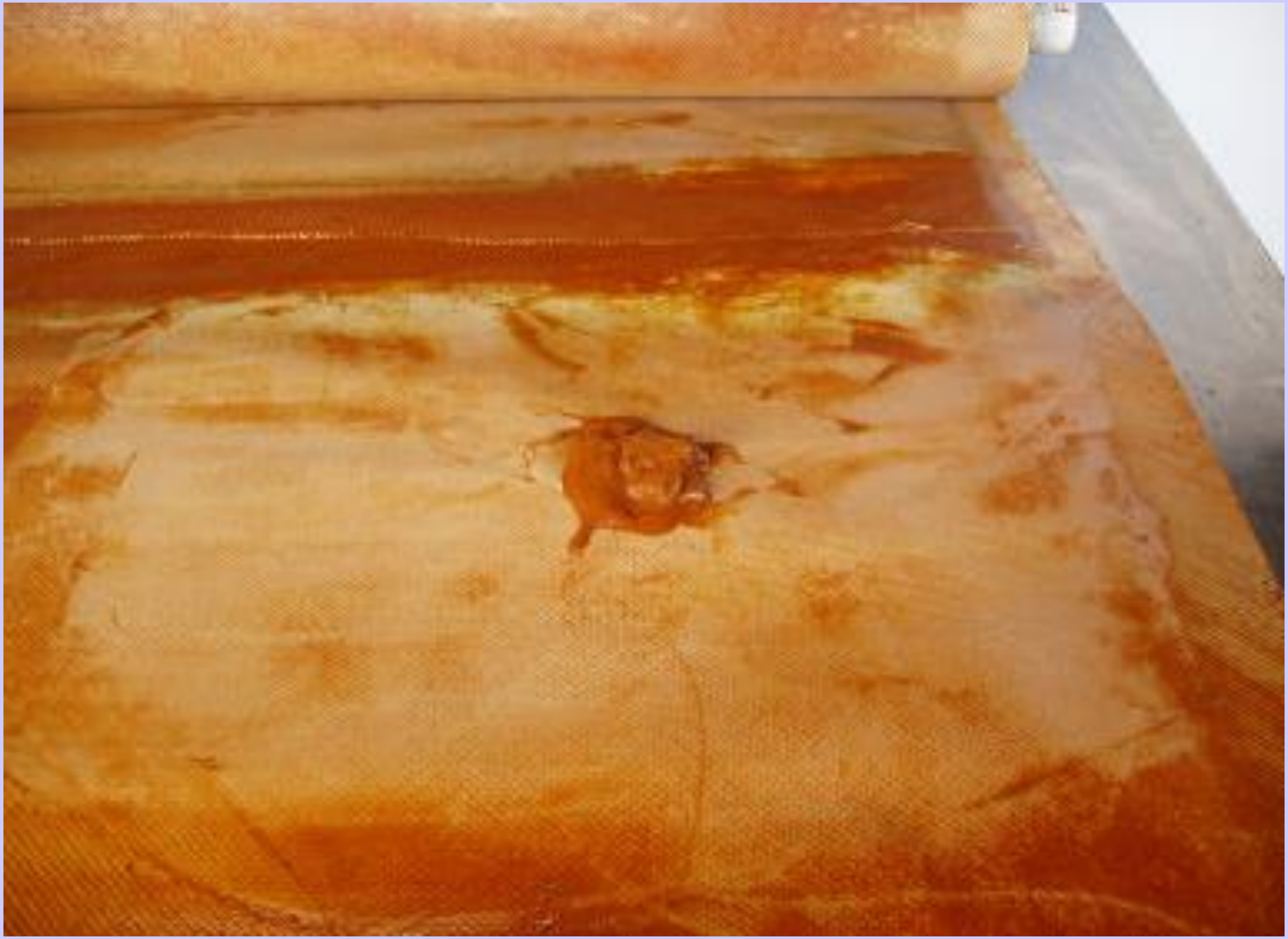
Concentrate-end

Feed-end

concentrate end

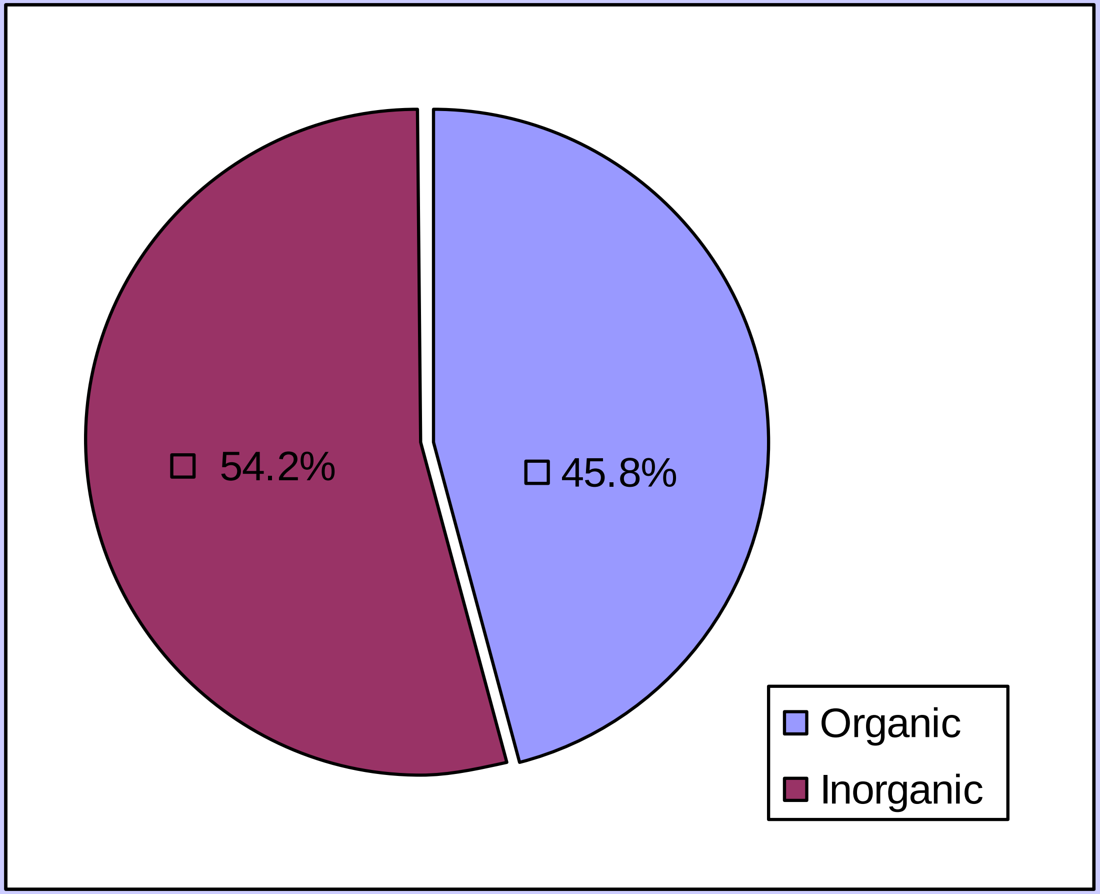
Element dissected and unrolled

un-rolled feed-end. Note the heavy accumulation of foulant
and depressions in the membrane leaf caused by foulant and pressure

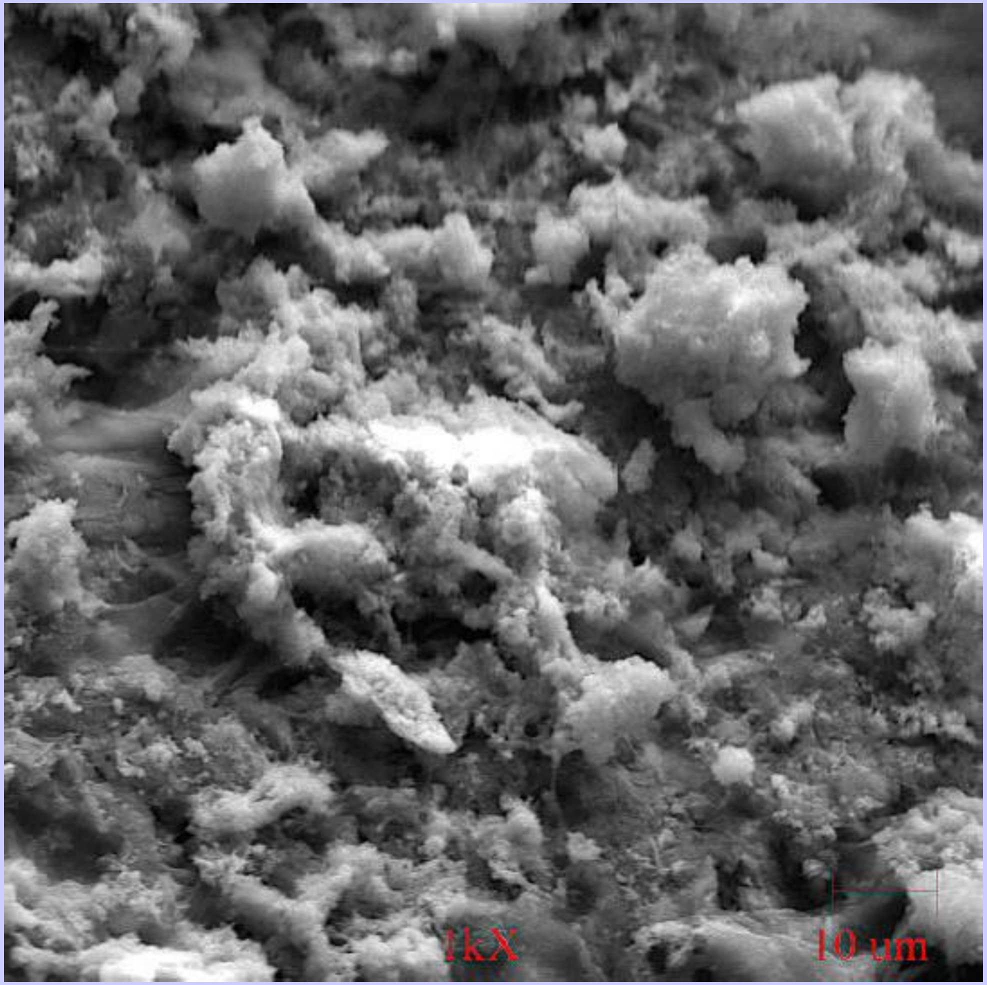


Foulant collected from the surface of a membrane leaf from element

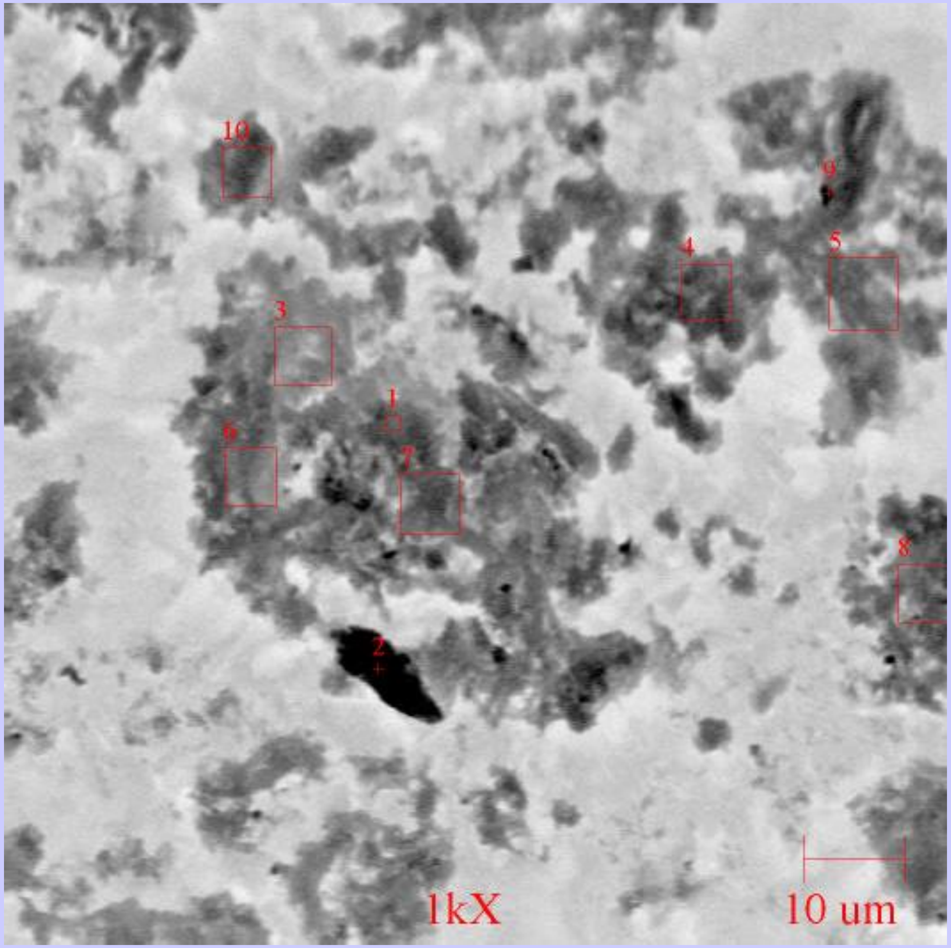
MEMBRANE AUTOPSY



Graphical representation of the organic and inorganic portions of the foulant sample from element

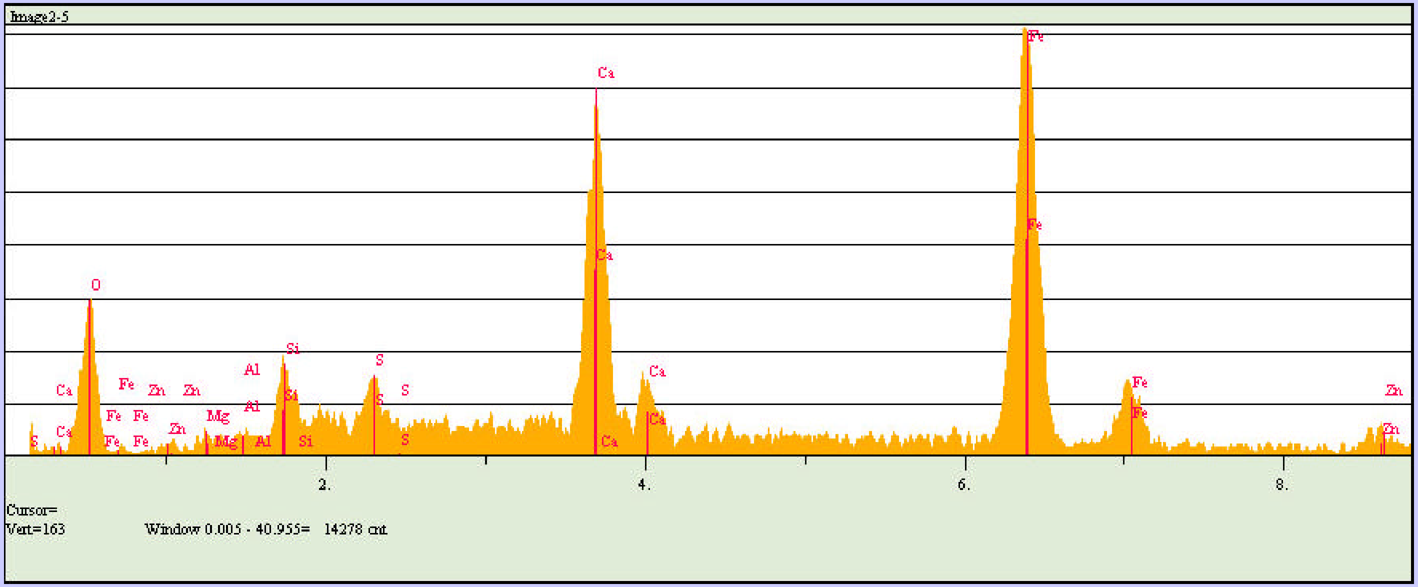


Scanning electron microscope image of the foulant collected from the membrane surface of element Magnification 1000X.



Back scatter image of the foulant collected from the membrane surface of element Magnification 1000X.

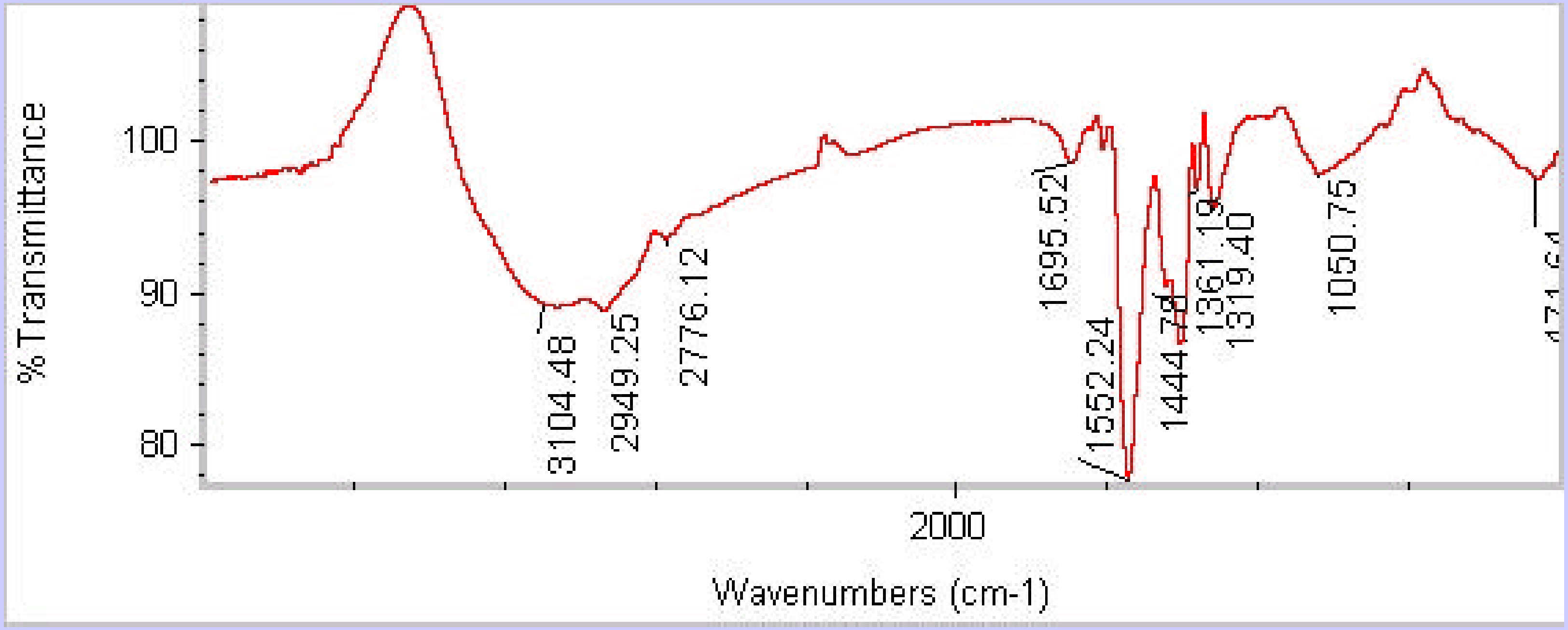
MEMBRANE AUTOPSY



Targeted-EDXA spectrum of the elemental portion of the foulant collected from element

60.3% iron, 18.4% calcium, 10.7% zinc, 5.7% sulfur, 3.0% silica, 0.8% phosphorous, 0.7% magnesium, 0.3% chlorine, and 0.1% aluminum

MEMBRANE AUTOPSY



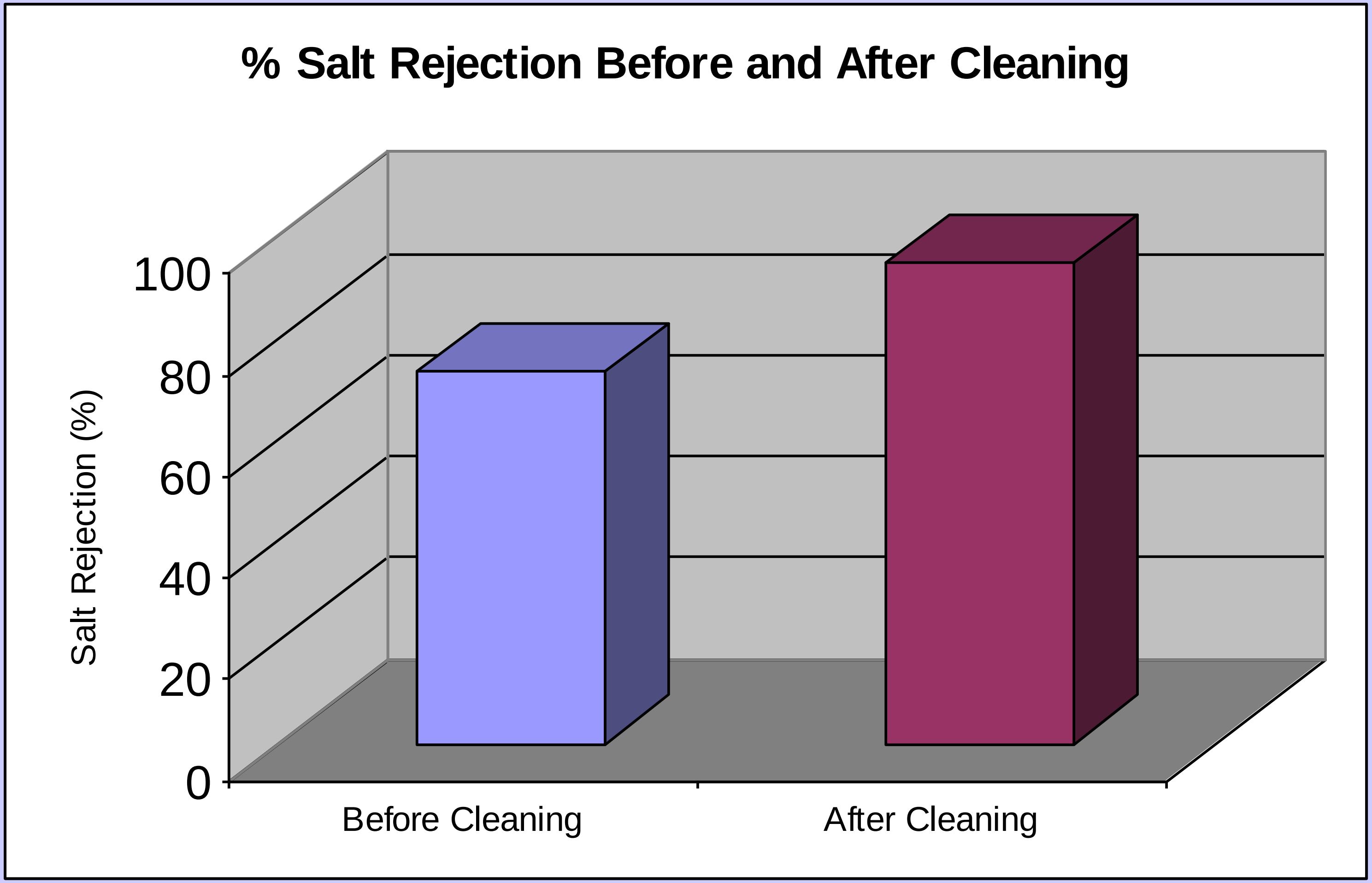
FTIR spectrum of the extracted organic component of the foulant removed from element

Spectral analysis and interpretation indicates that the organic portion of the foulant contains peaks suggesting an unsaturated polymeric salt

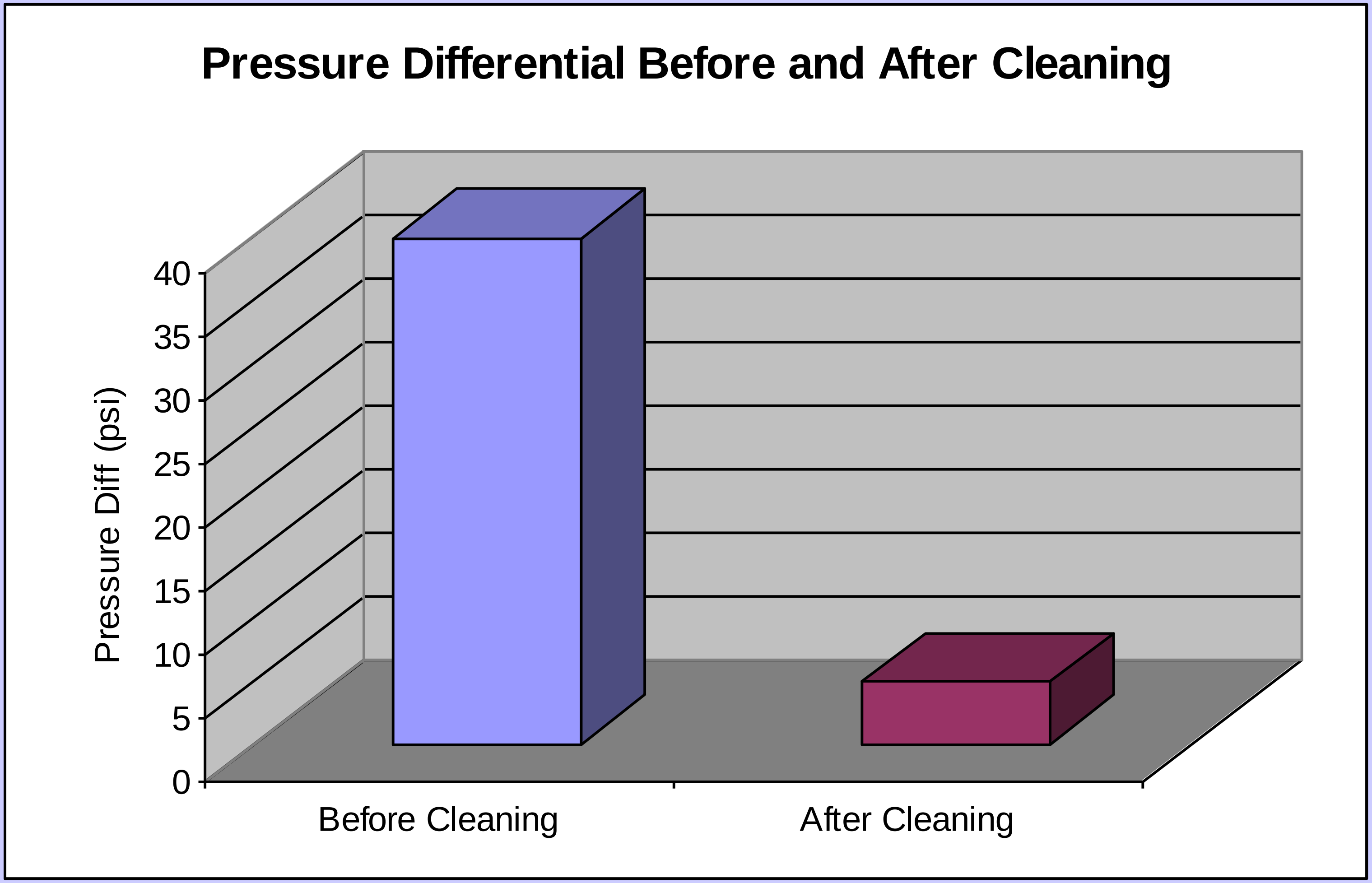
MEMBRANE AUTOPSY

Positive Heterotrophic bacteria test. The bleaching of the solution on the right indicates the positive reaction. The upward direction of the bleaching indicates predominately aerobic bacteria and some facultative anaerobes present

MEMBRANE AUTOPSY



MEMBRANE AUTOPSY



MEMBRANE AUTOPSY