Electrodialysis 2

Lecture 12

2.5 Operation

- When DC potential is applied across the electrodes, the following reactions take place:
- At the cathode, or negative electrode (-):
- Cations (Na^+) attraction
- Pairs of water molecules break down (dissociate) at the cathode to produce two hydroxyl (OH) ions plus hydrogen gas (H_2).
- Hydroxide raises the pH of the water, causing calcium carbonate ($CaCO_3$) precipitation.

2.5 Operation

- And at the anode, or positive electrode (+):
- Anions (Cl) attraction
- Pairs of water molecules dissociate at the anode to produce four hydrogen ions (H^+), one molecule of oxygen (O_2), and four electrons (e).
- The acid tends to dissolve any calcium carbonate present to inhibit scaling.
- Chlorine gas (Cl_2) may be formed.

2.5 Operation

- **Colloidal particles** or slimes that are slightly electronegative may **accumulate** on the anion membrane and **cause membrane fouling**.
- These fouling agents are **removed by flushing** with cleaning systems.
- In EDR systems, the polarity of the electrodes is reversed two to four times each hour.
- When polarity is reversed, chemical reactions at the electrodes are reversed.

2.5 Operation

2.5 Operation

- Valves in the electrode streams automatically switch flows in the two types of compartments.
- Streams that were in demineralizing compartments become concentrate streams, and concentrate streams become demineralizing streams.
- The **alternating exposure** of membrane surfaces to the product dilute and brine concentrate streams provides a **self-cleaning capability** that enables purification and **recovery higher than 90% of source water**, reducing the burden on water sources, and **minimizing** the volume of **waste that requires disposal**.

2.5.1. Energy requirements:

In an ED process, the energy required is the sum of two terms:

- 1. The electrical energy.
- 2. The energy required to pump the solutions through the ED unit.

2.5.1.Energy requirements:

- The **energy necessary** to remove salts from a solution is **directly proportional** to the total **current** flowing through the stack and **voltage drop** between the two electrodes in a stack.
- The energy consumption in a practical ED separation procedure is expressed by

$$E_{parc} = I\Delta U n t$$

Where: E_{parc} *is the energy consumption*

I *is the electrical current through the stack*

ΔU *is the voltage drop across a cell pair*

n *is the number of cell pairs in a stack*

t *is the time*

2.5.1.Energy requirements:

- The electrical current needed to desalt a solution is directly proportional to the number of ions transferred through membranes from the feed stream to the concentrated brine. It is expressed as:

$$I = \frac{zFQ\Delta C}{\xi}$$

Where: F is the Farady's constant

z is the electrochemical valence

Q is the volumetric flow rate of the feed solution

ΔC is the concentration difference between the feed solution and the diluate

ξ is the current utilization (which is directly proportional to the number of cell pairs in a stack)

2.5.1.Energy requirements:

- **Combining the two equations** gives the energy consumption in ED as a function of the:
- 1. Current applied in the process,
- 2. Electrical resistance of the stack, i.e., the resistance of the membrane and the electrolyte solution in the cell,
- 3. Current utilization and,
- 4. Amount of salts removed from the feed solution:

$$E_{parc} = \frac{n\Delta UtzFQ_f(C_0 - C_d)}{\xi}$$

2.5.1.Energy requirements:

- The equation indicates that the **electrical energy required** in ED is therefore **directly proportional** to the **amount of salts** that have to be removed from a certain feed to achieve the desired product concentration.
- **Energy consumption** is also a **function of the voltage** drops across a cell pair.
- The total **electrical potential** drop across an ED cell consists of the concentration potential due to the different ion concentrations in the diluate and concentrate solutions and on the voltage drop used to overcome the ohmic resistance of the cell.

2.5.2.Pumping energy requirements:

- The operation of an ED system requires 2 or 3 pumps to circulate the diluate, the brine and eventually the electrode rinse solutions through the stack.
- The energy required for pumping these solutions is determined by the volumes to be circulated and the pressure drop.

2.5.2.Pumping energy requirements:

- It can be expressed by:

$$E_p = k_d Q_d \Delta P_d + k_c Q_c \Delta P_c + k_e Q_e \Delta P_e$$

- Where:
- E_p : *is the pumping energy*
- K : *is a constant referring to the efficiency of the pumps.*
- Q : *is the volumetric flow rate*
- ΔP: *is the hydrodynamic pressure loss*
- *d,c,e: referred to diluate, concentrate and electrode rinse solutions, respectively.*

2.6 Design

- In commercial practice, the basic apparatus for ED/EDR is a stack of rectangular membranes terminated on each end by an electrode.
- Flow of the process streams is contained and directed by spacers that alternate with the membranes.
- The membranes are arranged alternately cation and anion.
- The assembly of membrane spacers and electrodes is held in compression by a pair of end plates.

2.6 Design

- The apparatus thus resembles a plate-and-frame filter press.
- Stack is completed with pumps, piping and an electrical subsystem that includes: adjustable DC power supply, rectifiers to convert alternating current (AC) power to DC power, internal control system with controls, reversal timing (only for EDR), and alarms.
- The design of an ED/EDR plant is based on the product water requirements of the application and the characteristic of the inlet water to be treated.

2.6 Design

- Along the pilot study, operators had to been check the **<u>quality of the product in different conditions</u>**, focused in the behavior of several limiting parameters characterizing an ED/EDR system:
- Limiting Current Density (Polarization)
- Current Leakage
- Langelier Saturation Index
- Calcium Sulfate Saturation
- Pressure Drop
- Differential Pressure
- Water Transfer
- Temperature Limits

2.6 Design

- The Langelier or Saturation Index is useful in determining the corrosive or scale-forming tendencies of water. In order to calculate this Index, it is necessary to have the following information:
- pH
- **TF** Temperature Factor
- **CF** Calcium Hardness Factor - determine the PPM of calcium hardness (CH) in the water sample.
- **AF** Total Alkalinity Factor - determine the PPM of total alkalinity (TA) in the water sample.

2.6 Design

- The ideal range for the Langelier or Saturation Index is -0.3 to +0.3.

  Test values more negative than -0.3 (i.e., **-0.6**) are considered **corrosive** and steps should be taken to **adjust the pH**, total alkalinity or calcium hardness, in order to avoid the effects of corrosion.

- Test values higher than +0.3 (i.e., **+0.6**) are indicative of **scale-forming** tendencies and steps should be taken to **adjust the pH**, total alkalinity or calcium hardness, in order to avoid scale formation and turbitiy.

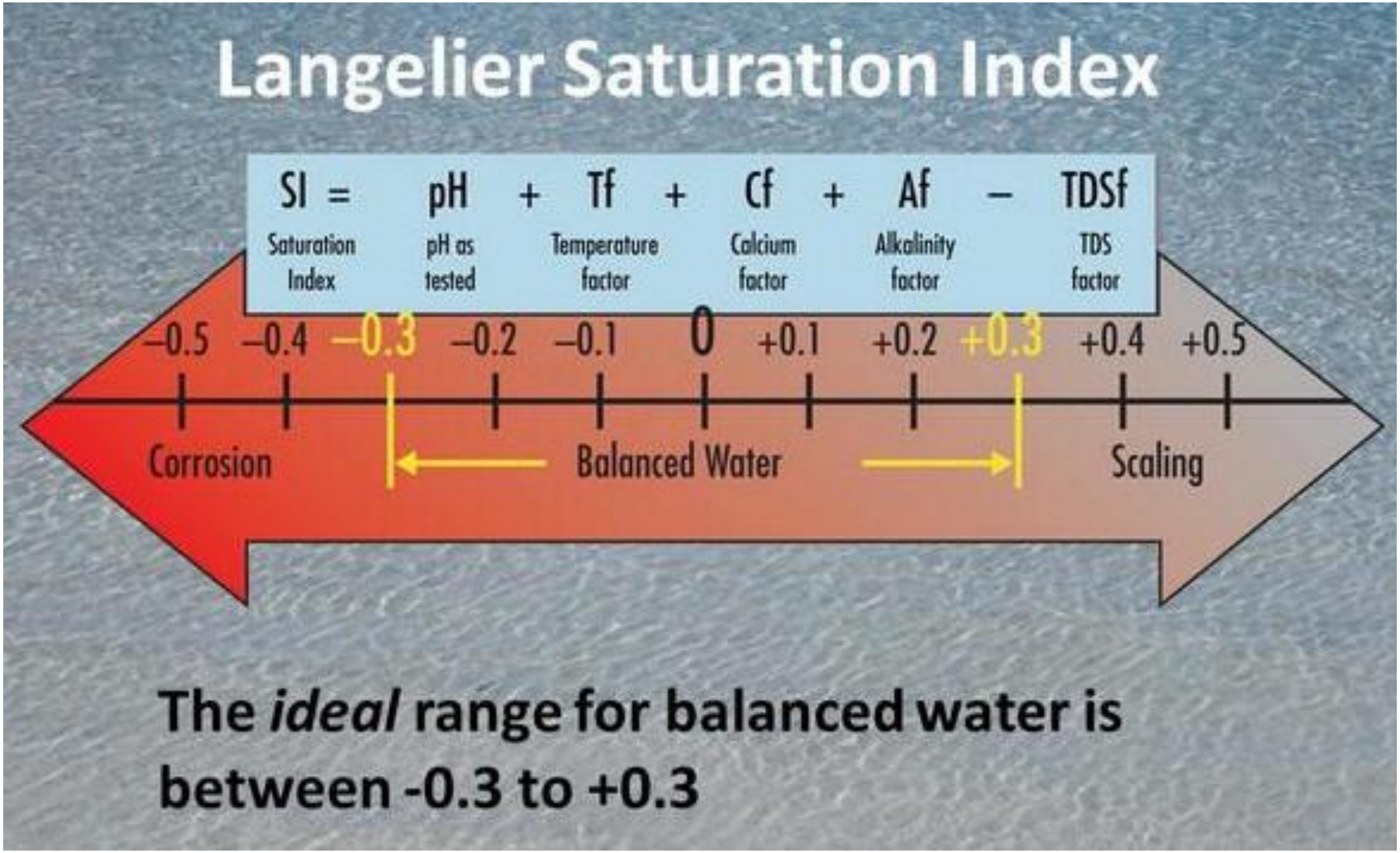
2.6 Design

- The following formula is used to calculate the Langelier /Saturation Index:

Langelier Index = pH + Tf + Cf + Af - 12.1*

* 12.1 (TDSf) is a constant used in the calculation of the Langelier/Saturation Index

2.6 Design



Langelier Saturation Index
SI = pH + Tf + Cf + Af – TDSf
Saturation Index
pH as tested
Temperature factor
Calcium factor
Alkalinity factor
TDS factor
–0.5 –0.4 –0.3 –0.2 –0.1 0 +0.1 +0.2 +0.3 +0.4 +0.5
Corrosion
Balanced Water
Scaling
The *ideal* range for balanced water is between -0.3 to +0.3

2.6 Design

- With these data, ED and EDR plants can be designed to remove from 50 to 99 percent of source water contaminants or dissolved solids.
- Source water salinities of less than 100 mg/L up to 12,000 mg/L TDS can be successfully treated to produce finished water of less than 10mg/L TDS.
- An antiscalant (1-5mg/L) can be added into the concentrate stream to control calcium scaling, and acid (HCl) is continuously feed into the electrode flow and into the concentrate stream to maintain the Langelier Saturation Index (LSI) at +1.8 for calcium carbonate control.

3. Maintenance

- Operating &Maintenance procedures are scheduled to check control settings and operating parameters, supported with detection systems that recognize operation levels or critical conditions.

3. Maintenance

- It could be necessary to clean the membranes periodically.
- **Cleaning** is a means of removing **mineral scale, organic matter, biological growth (slime), colloidal particles, or insoluble constituents** which build up on the surface of the membrane.
- To prevent scaling and fouling, ED and EDR units are equipped with a **clean-in-place (CIP)** system to allow periodic flushing of the membrane stack and piping with an acid solution.

3. Maintenance

- In EDR systems, electrode clean-in-place (ECIP) is a routine preventive-maintenance procedure to remove scale or fouling from the electrode system.
- The chemical solution circulated through the stack depends on the type of contamination.
- The following chemical solutions used in the CIP process are the only chemicals that should be used for stack cleaning.

3. Maintenance

- Hydrochloric acid solution. Periodic cleaning with a **2 to 5 % HCl** acid solution is the most frequently used method to **remove scale and biofouling**.
- NaCl solution. **A 3 to 5 percent NaCl** solution **removes organic foulants**, which are present in many surface waters, from the membranes.
- The solution should be at least 3 percent NaCl and have a pH between 8.0 and 10.0, adjusted with NaOH. A pH greater than 11 can damage the anion membrane.
- This solution should then be circulated through the system. **After the NaCl application, the operator should flush the membranes with HCl to remove excess salt.**

3. Maintenance

- Chlorine solution. **A 10- to 50 mg/L chlorine** solution **disinfects** the membranes and hydraulic piping.
- The **use of chlorine is one of the advantages** of ED/EDR membranes compared to RO membranes.
- They can **operate on waters with up to 0.5 mg/L** chlorine to control the biological nature of feed water, and can be **shock-chlorinated up to 30 mg/L** for maximum cleaning efficiency if required.
- Additionally, ED/EDR presents some other advantages, for example it is possible to repair and disassembly the stack and if it is necessary, it easy to manually clean the membranes or replaced them.

3. Maintenance

- In these cases, **stacks should not be allowed to remain dry for long periods** of time because membranes may become damaged.
- Generally, disassembly requires that each piece be removed separately, with the exception of the top electrode, which can be replaced without the removal of any of the membranes.
- The stack should be **rebuilt** in the order it was disassembled; **incorrect assembly** can reduce performance or cause scaling.

3. Maintenance

- Besides the cleaning procedure, the most frequent manual operation is to check the **intermembrane voltage** to prevent "**hot spots**" or **current leakage**.

- The intermembrane voltage has to be similar along the entire stack, and operators had to check it frequently.

- Excess current can melt or **"burn**" the membranes and spacers.

3. Maintenance

- **<u>Normal design</u>** practices limit this voltage to **<u>80% of the current that would cause burning</u>.**
- The limits is determined by water temperature, conductivity of the source water, membrane stack size, and the internal manifold that splits flow into concentrate and dilute streams.
- When operators find increases of current in a located point, they had to check the voltage along some days to prevent a "hot spot".

4. EDR vs RO

1. The EDR system does not require high feed water quality and is less sensitive to pretreatment problem in comparison with an RO system.

   EDR system is able to operate with Silt Density Index (SDI) average of 12 compared to 3 for the RO system.

4. EDR vs RO

2. The EDR system is capable of operating with a continuous free chlorine residual of up to 1 ppm.

   The RO system will require a dechlorination process to protect RO membrane from degradation by free chlorine oxidation.

   The EDR ability to operate with chlorine residual minimizes biological fouling of the membrane in a more reliable system.

4. EDR vs RO

3. The EDR system has a nominal initial brackish water recovery in the range of 80%-90%.

   The RO system normally has a water recovery in a much lower range, 65%-75%.

   The high EDR water recovery reduces this project's feed water usage and wastewater discharge cost.

4. EDR vs RO

4. The EDR membrane is not attacked by bacteria or affected by high temperatures.

Therefore no special storage solutions are necessary for long term storage.

The RO system requires special storage solutions and controlled storage temperatures.

The EDR membrane can be cleaned with acid and brine flush while the RO membrane requires special and expensive cleaning chemicals.

It is important to determine if these chemicals can be discharged to the environment without further treatment.

4. EDR vs RO

5. The EDR rugged thick membrane technology has ensured membrane life of 7 to 10 years.

   The RO membrane is designed for 3-5 years due to the membrane sensitivity to various operating factors.

6. The reversal feature of the EDR system controls membrane scaling with no chemical addition.

   The RO system requires the addition of acid and an antiscalant agent.

   The resulting waste from the RO system is highly acidic requiring caustic neutralization and may not be discharged to the environment.

4. EDR vs RO

7. The EDR membrane can be manually cleaned without damaging the membrane properties. This is due to the "plate and frame" configuration.

   The RO membrane has a HFF and spiral wound configuration, it can not be cleaned manually, and therefore it must be replaced.

Questions

- Answer with Yes or No, and correct the false ones:

1. In ED stack, at the cathode, pairs of water molecules dissociate to produce two hydrogen gas (H_2) only.
2. The use of chlorine is one of the disadvantages of ED/EDR membranes compared to RO membranes.
3. In ED process, normal design practices limit this voltage to 40% of the current that would cause burning of the membranes.
4. The EDR system requires high feed water quality in comparison with an RO system.
5. The EDR system has a nominal initial brackish water recovery in the range of 65%-75%.

Questions

- Complete the following statements:

1. In ED process, when ------- of the electrodes is reversed, chemical reactions at the electrodes are reversed.
2. Electrical energy required in ED is-------- proportional to the amount of salts that have to be removed.
3. The ideal range for the Langelier or Saturation Index is

   ------- to ------.

4. Langelier or Saturation Index values higher than +0.3 (i.e., +0.6) are indicative of ---------- tendencies.
5. The ED membranes can tolerate up to ------ mg/L Chlorine.

Questions

6. In ED process, if the membranes are subjected to excess current , this may cause a phenomenon called---------.
7. The EDR membrane can be --------- cleaned, while RO membranes must be replaced.

Answer the following questions:

- 1. Compare between ED and RO from the different aspects.
- 2. What are the parameters by which Langelier or Saturation Index can be calculated.