Advanced Water Treatment
(DESALINATION)

EENV 5330 **معالجة مياه متقدمة**

PART 1

PART 1

Introduction

- ❑ **Global water availability & problems**
- ❑ Water availability and problems in Gaza Strip
- ❑ Terminology
- ❑ Overview of desalination technologies
- ❑ Source water quality & constituents
- ❑ Minerals (brackish & seawater)

❖ Global water availability & problems

- Approximately 97.5 percent of the water on our planet is located in the oceans and therefore is classified as seawater.

- Of the 2.5 percent of the planet's freshwater, approximately 70 percent is in the form of polar ice and snow and 30 percent is groundwater, river and lake water, and air moisture.

WATER

2.5 %

freshwater

97.5 %
oceans(seawater)

70 %

polar ice and snow

30%

groundwater,

river and lake water

❖ Global water availability & problems

- Over the past 30 years, desalination has made great strides in many arid regions of the world, such as the Middle East and the Mediterranean.

- At present, desalination plants operate in more than 120 countries worldwide.

- Some desert states, such as Saudi Arabia and the United Arab Emirates, rely on desalinated water for over 70 percent of their water supply.

❖ Global water availability & problems

- The brackish water quantity on the planet is fairly limited (0.5 percent), and most of the large and easily accessible brackish water aquifers worldwide are already in use.
- A significant portion of the new capacity growth is expected to come from the development of seawater desalination plants.
- While brackish water sources, especially brackish aquifers, are finite in terms of capacity and rate of recharging, the ocean has two unique and distinctive features – it is droughtproof and practically limitless.

Global water availability & problems

- Over 50 percent of the world's population lives in urban centers bordering the ocean.
  - Therefore, seawater desalination provides the logical solution for a sustainable, long-term management of the growing water demand pressures in coastal areas.

- Brackish desalination is also expected to increase in capacity, especially in inland areas with still untapped brackish water aquifers.

❖ Global water availability & problems

- A clear recent trend in seawater desalination is the construction of larger-capacity plants, which deliver an increasingly greater portion of the freshwater supply of coastal cities around the globe.

❖ Water availability and problems in Gaza Strip

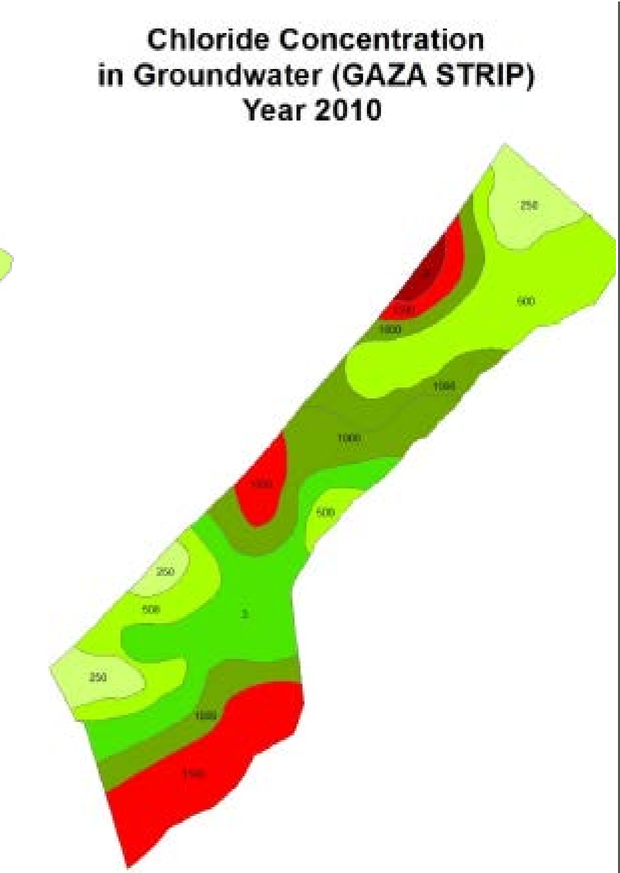
•As noted by the CMWU (2010), the supply of fresh water to the population of approximately 1.6 million in Gaza at the present time relies almost totally on the underlying groundwater (the aquifer).

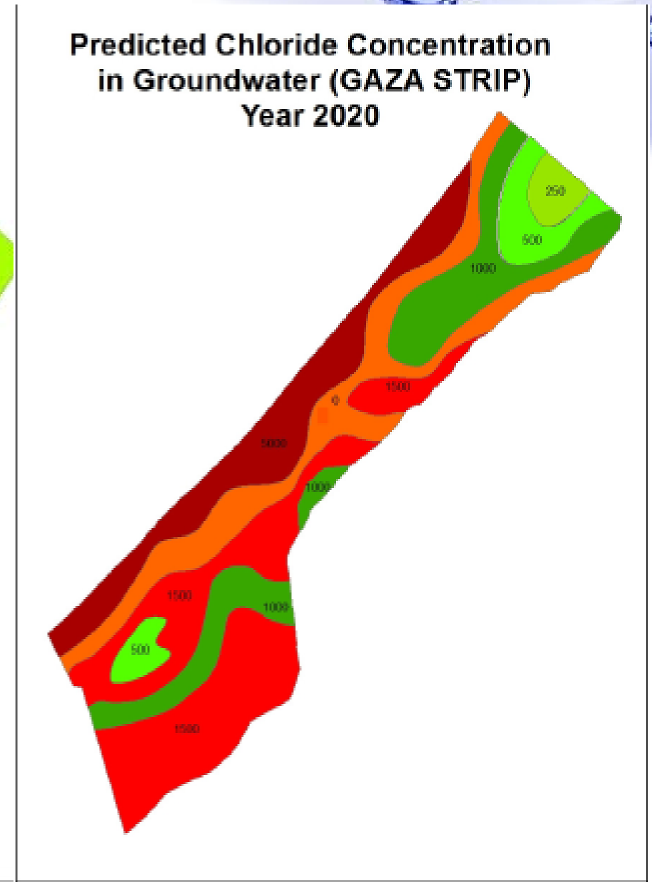
•5 Minor volumes of fresh water (4.7 million cubic metres/year, recently) are imported from Israel, and it has not been possible to date to increase those flows.

• Further very small volumes arise from several scattered desalination facilities in Gaza (Hilles and Al-Najar, 2011), but these are currently insignificant at the strategic level.

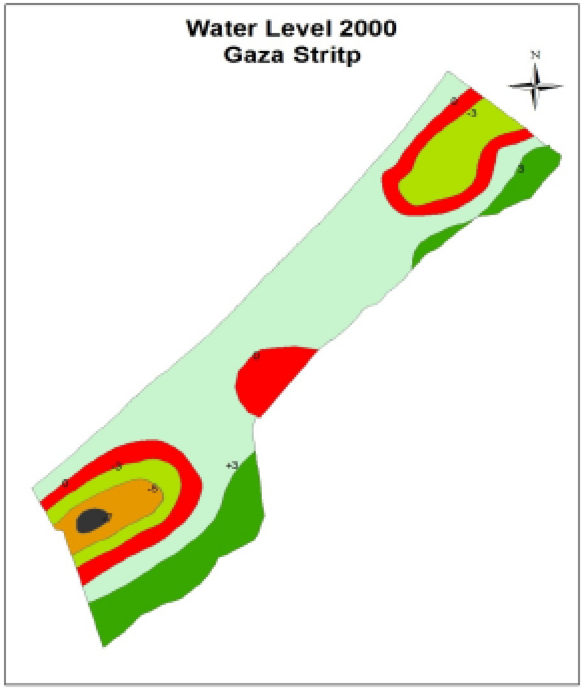
- The annual sustainable yield of the aquifer within the geographical boundary of Gaza is widely quoted as 55 million cubic metres (MCM). Recent rates of pumping from the aquifer are estimated at 170 MCM/year (this estimate, for 2010).
- The abstraction rates have increased markedly over the last three decades, due to a combination of inadequate available water imports to Gaza; the expanding population; and the drilling and use of unlicensed wells (especially to provide irrigation for agricultural activities). The over-abstraction has caused saline intrusion.
- A second problem also exists, this being driven primarily by contamination of the shallow groundwater from activities at the surface or near-surface of the land in Gaza.

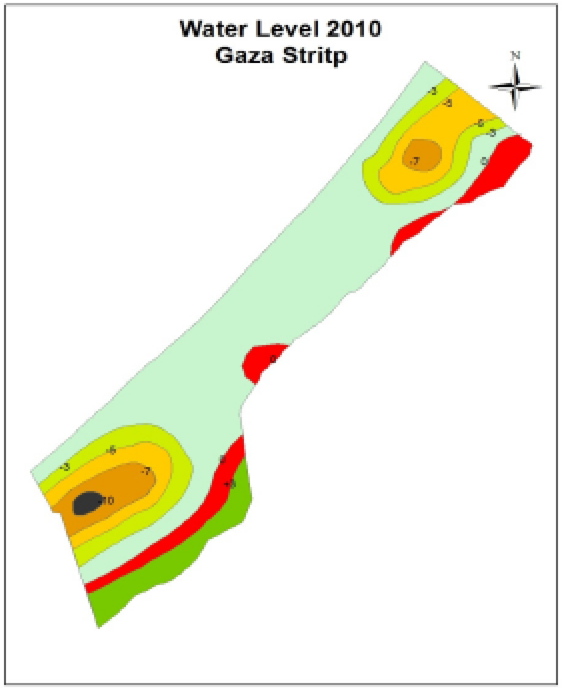
Levels of chloride (denoting salinity) in the groundwater within the borders of Gaza, for the years 2000 and 2010, plus predicted data for 2020.
(Data from the Palestinian Water Authority, Gaza).

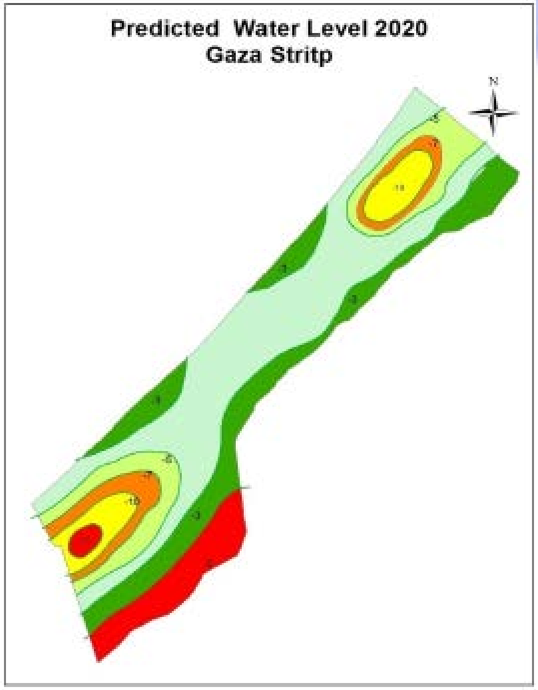




The depth to the groundwater table within the borders of Gaza, for the years 2000 and 2010, plus predicted data for 2020. (Data from the Palestinian Water Authority, Gaza).







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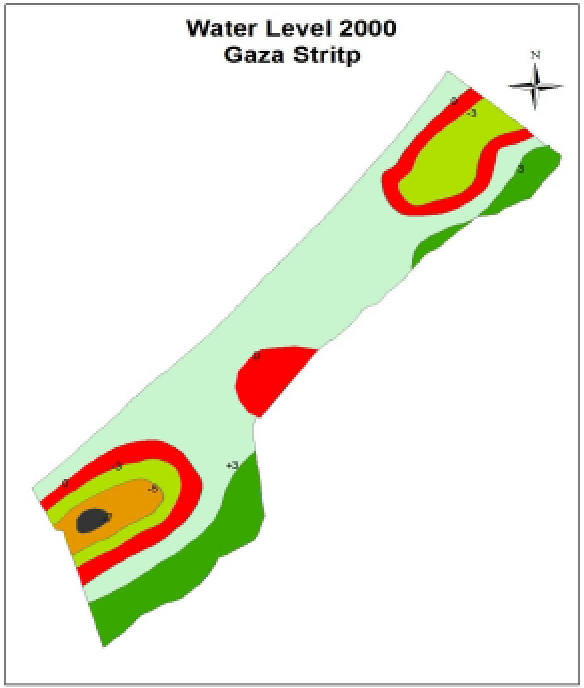
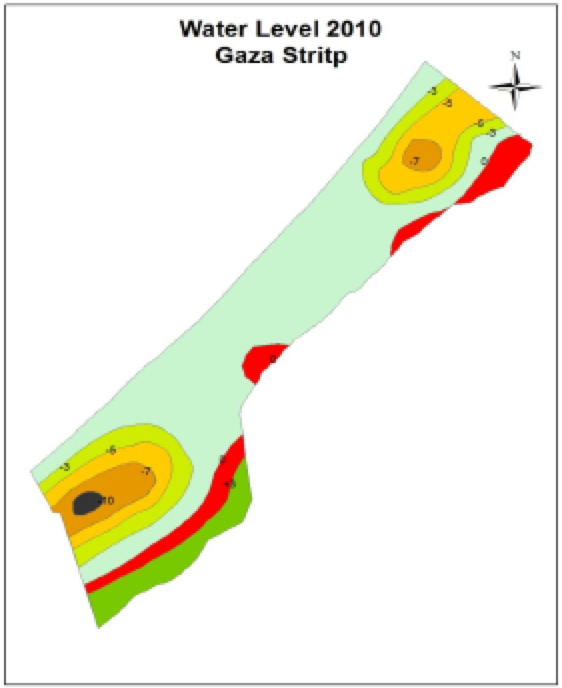
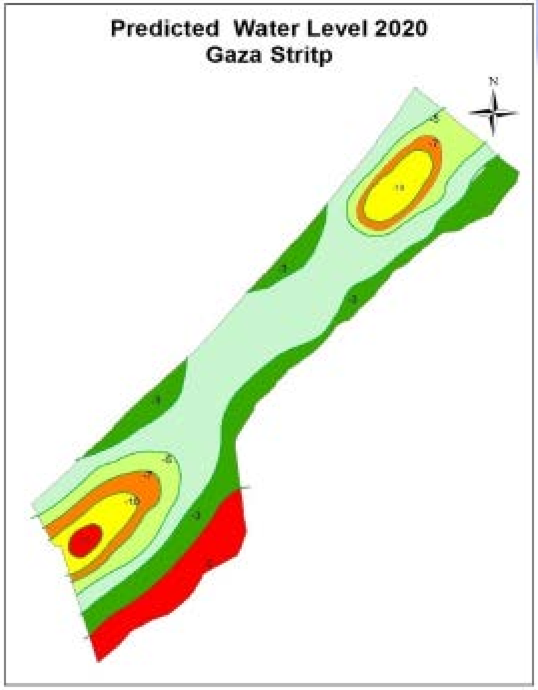






❖ Terminology (TDS)

- Total Dissolved Solids **(TDS),** the concentration of which is expressed in milligrams per liter (mg/L) or parts per thousand (ppt).
- (US EPA) under the Safe Drinking Water Act, have established a maximum TDS concentration of 500 mg/L as a potable water standard.
- This TDS level can be used as a classification limit to define potable (fresh) water.

❖ Terminology (TDS)

- TDS concentration higher than 500 mg/L and not higher than 15,000 mg/L (15 ppt) is classified as brackish.

- TDS concentrations higher than 15,000 mg/L are generally classified as seawater.
  - **For example:** : The TDS concentration of the Pacific Ocean seawater can actually range from 33,000 to 36,000 mg/L at various locations and depths along the coast.

❖ Overview Of Desalination Technologies

❑ Two general types of water treatment technologies:

- Thermal Evaporation (distillation).
- Reverse Osmosis (RO) membrane separation.

- In Thermal Distillation: freshwater is separated from the saline source by evaporation.
- In Reverse Osmosis Desalination: freshwater is produced from saline source water by pressure-driven transport through semipermeable membranes.

❖ **Overview Of Desalination Technologies**

- Besides thermal distillation and RO membrane separation, two other mainstream desalination technologies widely applied at present are electrodialysis (ED) and ion exchange(IX).

- **Electrodialysis** is electrically driven desalination in which salt ions are removed out of the source water through exposure to direct electric current.

- **IX** is the selective removal of salt ions from water by adsorption onto ion-selective resin media.

❖ Overview Of Desalination Technologies

Separation Process	Range of Source Water TDS Concentration for Cost-Effective Application, mg/L
Distillation	20,000–100,000
Reverse osmosis separation	50–46,000
Electrodialysis	200–3000
Ion exchange	1–800

Table1.1 Desalination Process Applicability

❖ Overview Of Desalination Technologies

- Currently, approximately 60 % of the world's desalination systems are RO membrane separation plants and 34 % are thermal desalination facilities.

- At present, ED and IX-based technologies contribute less than 6 % of the total installed desalination plant capacity worldwide.

❖ **Source water quality & constituents**

❑ The constituents contained in source water used for desalination can be classified in four main groups:

- (1) dissolved minerals and gases.
- (2) colloids and suspended solids.
- (3) organics.
- (4) microorganisms.

❖ **Minerals (brackish & seawater)**

❑ Mineral Content of Seawater

- A commonly used measure of the content of dissolved minerals is the concentration of total dissolved solids (salinity).

- Table 2.1 shows key ion content and total dissolved solids(TDS) concentrations of typical Pacific Ocean water

Parameter	TDS Concentration, mg/L		TDS Concentration, meq/L	
	Raw Water	Permeate	Raw Water	Permeate
Cations				
Calcium	403	0.6	20.1	0.03
Magnesium	1298	1.3	106.2	0.11
Sodium	10,693	88.0	464.9	3.82
Potassium	387	4.3	12.9	0.14
Boron	4.6	0.8	1.5	0.26
Bromide	74	0.7	0.9	0.01
Total Cations	**12,859.6**	**95.7**	**606.5**	**4.37**
Anions				
Bicarbonate	142	2.2	2.24	0.03
Sulfate	2710	7.1	56.6	0.16
Chloride	19,287	145.0	542.6	4.24
Fluoride	1.4	0.0	0.06	0.00
Nitrate	0.00	0.0	0.0	0.00
Total Anions	**22,140.4**	**154.3**	**601.5**	**4.43**
TDS	**35,000.0**	**250.0**	**1208.0**	**8.80**

Table2.1 Typical Pacific Ocean Water Quality

PART 1

The Milliequivalents & TDS

- The milligrams-per-liter parameter indicates the ratio of ion weight to solution volume.

- The milliequivalent-per-liter designation reflects the capacity of ions to react with one another.

PART 1

The Milliequivalents & TDS

- The main reason why the TDS concentration is often measured in milliequivalents per liter instead of in milligrams per liter is to check the accuracy of the measurement for the water for which analysis is completed.

- When added together, the milliequivalent-per-liter concentrations of cations (positively charged ions) contained in the water should approximately equal the total milliequivalent-per-liter concentrations of anions (negatively charged ions) in the solution.

PART 1

The Milliequivalents & TDS

- These two values are usually not exactly equal, since other ions beside those listed in Table are present in the water.

- If the difference between total cation and anion content exceeds 5 to 10 percent, then the accuracy of the laboratory analysis is inadequate or other ions are present in the water which may not have been reported or which are not typically contained in saline water of the particular type of source.

PART 1

The Milliequivalents

- The atomic or formula weight of an ion divided by its valence (number of positive or negative charges) is called the equivalent weight (eq) of the ion.

- One-thousandth of this weight is termed a milliequivalent (meq).

The Calculation procedure

- Calculate the molecular weight for each ion in g/mol.

- Indicate the valence of each ion.

- Calculate the equivalent weight of the ion {(molecular wt g/l)/ valence eq/mol)}.

- Finally, the concentration in milliequivalent-per-liter is equal to {(conc. mg/l)/ equivalent wt mg/meq)}.

Example

PART 1

- A brackish desalination plant has feed and permeates characterization as followed, Calculate the ions concentrations in milliequivalent-per-liter for each of them.

Parameter	Feed (mg/l)	Permeate (mg/l)	Molecular wt g/mol
Cations			
Sodium (Na^{+1})	1150	80	22.989
Potassium (K^{+1})	22	1	39.09
Calsuim (Ca^{+2})	100	8	40.08
Magnesium (Mg^{+2})	191	4	24.3
Total cations	**1463**	**93**	
Anions			
Sulphate (SO_4^{-2})	212	40	96
Chloride (Cl^{-1})	2100	85	35.45
Fluoride (F^{-1})	2	0.02	18.99
Nitrate ($^{-2}$)	94	53	
Total anions	**2408**	**178**	
Total dissolved solids (TDS)	**3871**	**271**	

PART 1

Solution

- For Sodium (Na^{+1}), the molecular wt= 22.989 g/mol and the valence is 1, therefore, the equivalent wt. of the sodium **= 22.989/1 = 22.989 mg/meq**.

- The concentration of sodium in the feed in milliequivalent-per-liter = **1150/22.989 = 50.02**

- The concentration of sodium in the permeate in milliequivalent-per-liter = **80/22.989= 3.48**

<u>H.Work:</u> *Do the rest of calculations for all parameters.*

TDS & EC

- TDS concentration is often monitored continuously by measurement of the electrical conductivity (EC) of the water.

- Electrical conductivity (also known as specific conductance) is a measure of a solution's ability to conduct electricity.

- Conductivity is expressed in microsiemens per meter (µS/m). The ratio between TDS and EC in source water is site specific and usually varies in a range between 0.67 and 0.70.

TDS & EC

- For example, seawater with a TDS concentration of 35,000 mg/L would typically have a conductivity of 50,000 to 52,000 µS/m.

- The ratio between TDS and EC depends on the content of sodium chloride in the water and on the temperature.

- If the TDS is made of 100 percent sodium chloride, the TDS/EC ratio is typically 0.5. This ratio increases as the content of sodium chloride decrease.

TDS & Osmotic pressure

PART 1

- TDS concentration has direct influence on the osmotic pressure and therefore on the feed pressure.

- Every 100 mg/l of TDS required 0.07 bar osmotic pressure approximately.

Example

- Determination of required osmotic pressure for TDS removal of example one, bearing in mind that every 100 mg/l of TDS 0.07 bar is needed.

- **Solution:**
  TDS concentration is 3871 mg/l, therefore:

  Required osmotic pressure = **(3871 mg/L X0.07 bar)/100 mg/L = 2.71 bar**

❖ Minerals (brackish & seawater)

❑ Mineral Content of Brackish Water

Seawater Source	Typical TDS Concentration, mg/L	Temperature, °C
Pacific and Atlantic Oceans	35,000	9–26 (avg 18)
Caribbean Sea	36,000	16–35 (avg 26)
Mediterranean Sea	38,000	16–35 (avg 26)
Gulf of Oman and Indian Ocean	40,000	22–35 (avg 30)
Red Sea	41,000	24–32 (avg 28)
Persian Gulf	45,000	16–35 (avg 26)

Table2.2: Seawater TDS and Temperature of Various Ocean Water Sources

Parameter	Orange County, California	Rio Grande, Texas	Tularosa, New Mexico	Cape Hatteras, North Carolina
Cations, mg/L				
Calcium	140.0	163.0	420.0	545.0
Magnesium	10.0	51.0	163.0	1398.0
Sodium	300.0	292.0	114.0	4961.0
Potassium	35.0	0.0	2.30	99.0
Boron	0.8	0.0	0.14	1.2
Bromide	7.4	4.5	0.70	12.5
Total Cations	**493.2**	**510.5**	**700.14**	**7016.7**
Anions, mg/L				
Bicarbonate	275.0	275.0	270.0	223.0
Sulfate	350.0	336.0	1370.0	173.0
Chloride	350.0	492.0	170.0	6523.0
Fluoride	0.8	0.08	0.0	1.3
Silica	10.0	35.0	22.0	22.0
Nitrate	1.0	1.5	10.0	1.0
Total Anions	**986.8**	**1139.58**	**1842.0**	**6943.3**
TDS mg/L	**1480.0**	**1650.0**	**2542**	**13,960.0**

Table2.3 Brackish Water Quality of Several Sources

❖ Particulate Membrane Foulants

- Particulate foulants are organic and inorganic particles contained in the source water, such as fine debris, plankton, detritus, and silt. These solids cannot pass through RO membranes.
- All suspended solids which naturally occur in insoluble form, if not removed by pretreatment, would be retained on the feed side of the RO membranes.
- Particulate foulants in raw source seawater vary in size. However, most of them, including picophytoplankton, are larger than 0.1 µm **(0.0001 mm)**. Usually over 90 percent of particulate foulants are larger than 1 µm **(0.001 mm).**

µm (micrometer)= 0.001 mm

PART 1

Silt Density Index (SDI)

- Silt density index (SDI) is a parameter that provides an indication of the particulate fouling potential of source water.

- If RO system is operated at a constant transmembrane pressure, particulate membrane fouling will result in a decline of system productivity (membrane flux) over time.

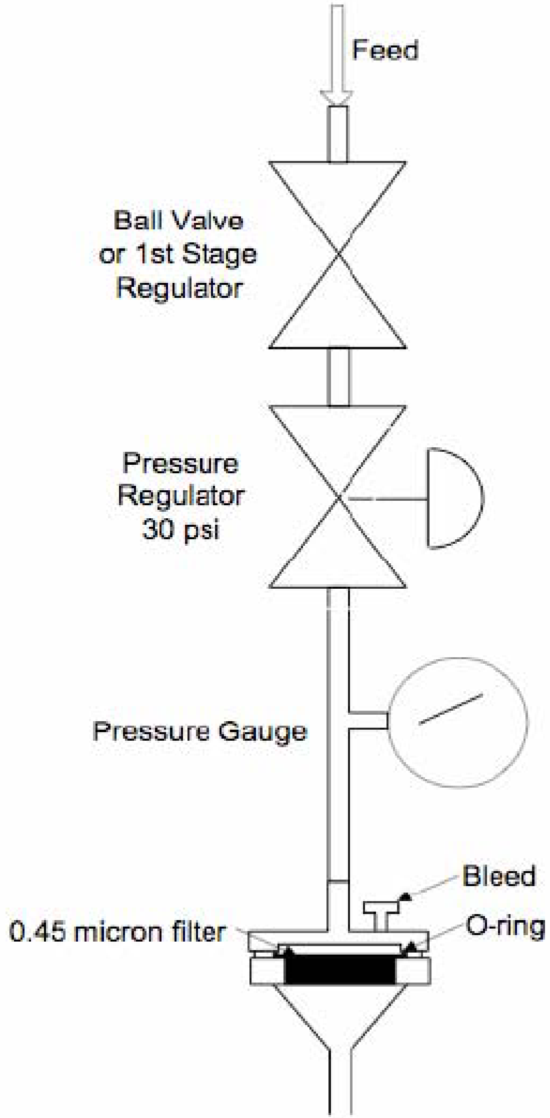
- SDI gives an indication of the rate of flux decline through a filter of standard size and diameter operated at constant pressure for a given period of time.

PART 1

Silt Density Index (SDI)

- A standard SDI_{15} test procedure is described in ASTM Standard D4189-07 (American Water Works Association, 2007) and is based on the measurement of the time in seconds it takes to collect a 500-mL sample through a paper filter of size 0.45 µm and diameter 45 mm both at the start of the test (t_0 = 0 min) and after the source water has flowed through the filter under a driving filtration pressure of 2.1 bar (30 lb/in^2) for 15 min (t_{15} = 15 min).

Figure 1. SDI Apparatus



Silt Density Index (SDI)

- The two sample durations (t_0 and t_{15}) are applied to a formula (Eq. 2.1), and the resulting SDI_{15} value indicates the particulate fouling potential of the source water:

$$SDI_{15} = \frac{1 - (\frac{t_0}{t_n})}{n} x100$$

PART 1

Example

- Determine the SDI_{15} of a seawater sample that took four minutes initially at 2.1 bar to accumulate 500 ml.

- **Solution:**

$$SDI_{15} = \frac{1 - \left(\frac{240}{900}\right)}{15} x100 = 4.88$$

Description of the silt density index test

The silt density index test described in ASTM 4189-07 is performed using a .45 micron, 47mm diameter filter. The water to be tested is supplied to the filter at a constant pressure of 30 psi. The test involves measuring the time it takes to collect a 500 ml sample through the filter at the start of the test and comparing it with the time it takes to collect a 500ml sample after water has flowed through the filter (at 30psi) for 15 minutes. The sample times are applied to the formula below to obtain the SDI15 value.

SDI Calculation

$$SDI_T = \frac{\% P_{30}}{T} = \frac{\left[1 - \frac{t_i}{t_f}\right] 100}{T}$$

where $\%P30$ = *percent @ 30 psi feed pressure (see note 1)*
T = *total elapsed flow time (see note 1)*
t_i = *initial time required to collect 500 ml sample.*
t_f = *time required to collect 500 ml sample after test time T. (see note 1)*

Note 1. The value *%P30* is commonly referred to as the "plugging factor". *%P30* (plugging factor) should not exceed 75%. If you obtain values higher than 75%, the test should be conducted using a shorter time for T, that is 5 or 10 minute measurements for T*f*. If *%P30* exceeds 75% on a 5 minute test, you have water that needs further treatment before a meaningful SDI result can be obtained.

PART 1

Silt Density Index (SDI)

- It should be pointed out that while the standard SDI test requires a test run time of 15 min between the first and second measurements, the test can also be run for 5 or 10 min, depending on the solids concentration.

- Based on this formula, the maximum value of SDI_{15} is 6.7; this condition would occur if the time to collect 500 mL after 15 min of filtration were infinite.

PART 1

Silt Density Index (SDI)

- Typically, source water with an SDI_{15} lower than 4 is considered to have adequately low RO membrane particulate fouling potential, and its use in membrane desalination is expected to result in a reasonably slow flux decline over time. Source water with SDI_{15} lower than 2 is considered to have a very low fouling potential and to be of good quality.

Mineral Membrane-Scaling Foulants

- Ions of calcium, magnesium, barium, strontium, sulfate, and carbonate can form insoluble salts, which could precipitate on the RO membrane surface.
- The mineral scales that typically form during desalination are those of calcium carbonate, calcium and magnesium sulfate, and barium and strontium sulfate.
- For brackish water: Calcium carbonate is the most commonly encountered mineral foulants
- For SWRO: Calcium sulfate and magnesium hydroxide are the most frequent causes scaling.

Mineral Membrane-Scaling Foulants

- Scale formation can be prevented by the addition of an antiscalant or dispersant to the source water
- High salinity increases the solubility of all salts. Therefore, the higher the salinity of the water, the less likely a mineral scale is to form on the membrane surface
- Therefore, mineral scaling is a frequent problem in brackish water desalination systems, since water has relatively low ionic strength.
- Although the source seawater’s temperature usually has a limited influence on scale formation, when this temperature exceeds 35 ^{o}C, calcium carbonate scale will form at an accelerated rate.

Parameters for mineral Scale

PART 1

- Commonly used parameters which can be used to predict source water's potential to form mineral scale of calcium carbonate are the Langelier Saturation Index (LSI) and the Stiff–Davis Saturation Index (SDSI).

- These indices are functions of the source seawater's pH, calcium concentration, alkalinity, temperature, and TDS concentration or ionic strength.

Langelier Saturation Index (LSI)

•For LSI > 0, water is super saturated and tends to precipitate a scale layer of $CaCO_3$.

•For LSI = 0, water is saturated (in equilibrium) with $CaCO_3$. A scale layer of $CaCO_3$ is neither precipitated nor dissolved.

•For LSI < 0, water is under saturated and tends to dissolve solid $CaCO_3$

PART 1

Langelier Saturation Index (LSI)

- The Langelier Saturation Index can be calculated using the following equation:

$$LSI = pH - pH_s$$

Where pH = the actual pH of the saline source water,

$pH_s = (9.30 + A + B) - (C + D)$

$A = [\log(TDS - 1]/10$, TDS in mg/L

$B = -13.2 \times \log(\text{temperature} + 273) + 34.55$, temperature in °C

$C = \log[Ca^{2+}] - 0.4$, $[Ca^{2+}]$ in mg/L as $CaCO_3$

$D = \log(\text{alkalinity})$, alkalinity in mg/L as $CaCO_3$

PART 1

Example

- Calculate the LSI for the example no.1 feed (pH = 7) assuming that concentration of $CaCO_3$ is 240 mg/l and temperature is 25°C.

- **Solution:**

TDS = 3871 mg/l, Calcium =100 mg/l

Calculate A, B, C, and D and LSI ,

pHs = 7.2 , LSI=-0.20