

Developed by 2015 Submarine Force Library and Museum STEM –H Teacher Fellow
Paul Mezick, Science Teacher, Daniel Hand High School, Madison, CT

Lesson Name Pure Water

Number of minutes in the Lesson 90

Intended Audience Grades 7-9

Content Standards: Identify state **CCSS content and literacy standards** (when applicable) **and** national curricular standards this lesson is designed to help students attain. Also include **state and district standards** as well as the **Technology Standards** and **CCSS Math Standards** when applicable.

CCSS.ELA-LITERACY.RST.6-8.3

Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

CCSS.ELA-LITERACY.RST.6-8.4

Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context

CCSS.ELA-LITERACY.RST.6-8.9

Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic.

CCSS.ELA-LITERACY.RST.9-10.5

Analyze the structure of the relationships among concepts in a text, including relationships among key terms

CCSS.ELA-LITERACY.RST.9-10.7

Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.

5-PS1-4.

Conduct an investigation to determine whether the mixing of two or more substances results in new substances.

HS-PS1-3.

Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles

HS-PS1-6.

Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.

HS-PS2-6.

Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

Pre-Visit Materials/Activities: Describe the students' prior knowledge or skill related to the learning objective(s) and the content of this lesson, using data from pre-assessment as appropriate. What background knowledge or skills do you want students' to come to the museum prepared with, and what materials will you provide to groups ahead of time so they are prepared for this lesson?

Students should have basic knowledge of phase changes and the relationship between vapor pressure and boiling points. Students should understand the process of distillation as a way to remove solutes from a solution. Students should also have a basic understanding of solubility

Set up Before the Lesson Begins: Describe any preparation that is necessary before the lesson.

PART I:
(optional)

1. Have a model of the experimental design assembled for students to use as an exemplar.

Content Objective(s): Identify specific and measurable learning objectives for this lesson. Remember only one for a 45 minute class, two for a 90 minute class.

In this lesson students will be able to...

1. Explain why smaller molecules and ions can cross this synthetic selectively permeable membrane, but larger molecules cannot.
2. Explain that diffusion results from the random motion of molecules. Diffusion moves substances from regions of higher concentration to regions of lower concentration.
 - a. Diffusion of water across a selectively permeable membrane is called osmosis
3. Explain that reverse osmosis can be achieved by forcing water under pressure through the very tiny pores of a selectively permeable membrane.

Language Objective(s): Distinguish between receptive skills (**listening and reading**) and productive skills (**speaking and writing**). Please **include how you would use them all where appropriate:** Listening, reading, speaking and writing.

Students will work collaboratively in small lab groups, therefore required to implement the following skills:

1. Collective Intelligence:

- a. Students will be able to work respectfully and responsibly with others, exchanging and evaluating ideas to achieve a common objective.
 - i. Student works respectfully and responsibly with others to achieve a common objective by:
 1. exchanging and evaluating ideas critically and respectfully with a keen sense of which ideas will best achieve a common objective
 2. listening carefully to and valuing other members' contributions and synthesizing them with personal knowledge and insightful ideas
 3. showing leadership by employing the expertise of members when equitably dividing the roles/responsibilities.

2. Suspending Judgment:

- a. Students will be able to forgo decision making while considering and finding value in the contributions of other team members in order to grapple with complex issues.
 - i. Student is able to grapple with complex issues by:
 1. actively valuing and seeking contributions from others
 2. synthesizing them with personal knowledge/ideas, as a way of reaching a well-informed decision,
 3. addressing complex issues in a comprehensive manner from various angles/viewpoints.

3. Justifying & Contextualizing

- a. Students will be able to choose and justify the most effective medium to interactively and purposefully share important findings in various contexts as well as adjust style and tone with consideration to audience and purpose.
 - i. Student chooses the most effective medium
 1. to share findings and present them in an interactive, engaging, purposeful manner, choosing more than one medium, when appropriate,
 2. to clearly communicate important findings, adjusting style and tone with clear focus on audience and purpose,
 3. can clearly explain why a medium was chosen in regard to audience and purpose.

Differentiation: Think about:

Students with special needs How will you differentiate this lesson for special education students?

Gifted students- Students can be given specific tasks within a collaborative group that suits their learning style and academic aptitude

Regular education students: Think about how you would differentiate the lesson for all students on all levels:

High- Webb DOK level 3 or 4 (Short-Term Strategic Thinking and Extended Thinking)

Middle- Webb DOK level 2 or 3 (Skills and Concepts and Short-Term Strategic Thinking)

Low- Webb DOK level 1 or 2 (Recall and Reproduction and Skills and Concepts)

*The DOK level should reflect the complexity of the cognitive processes demanded by the task outlined by the objective, rather than its difficulty. Ultimately the DOK level describes the kind of thinking required by a task, not whether or not the task is “difficult”

Sheltered Instruction Observation Protocol (SIOP) Strategies for ELL and regular Ed

Students: Identify the S.I.O.P features that support English Learners and all learners including thorough and accurate explanations on how they will assist English Learners. Identify Sheltered Instruction strategies throughout the lesson.

- Preparation
- Building Background
- Comprehensible Input
- Strategies
- Interaction
- Practice/Application
- Lesson Delivery
- Review/Assessment

Initiation: Briefly describe how you will initiate the lesson. (Set expectations for learning; articulate to learners what they will be doing and learning in this lesson, how they will demonstrate learning, and why this is important)

1. Initiate the lesson by reviewing key concepts in the prior knowledge requirements: **(5 min)**
 - a. Students should have basic knowledge of phase changes and the relationship between vapor pressure and boiling points. Students should understand the process of distillation as a way to remove solutes from a solution.
2. Articulate the collaborative working expectations by reviewing the **Language Objectives (5 min)**
3. Explain the learning activities, their purpose, and the culminating design application and how it relates to the critical function of a submarine. **(5 min)**

Lesson Development: (Add a Time for Each Segment of the Lesson)

Performance Tasks: Describe in outline how you will develop the lesson and what learning activities students will be engaged in order to gain the key knowledge and skills identified in the student learning objective(s).

PART I – Introduction to the process of reverse osmosis (50 min)

INTRODUCTION/DISCUSSION (Teacher initiated):

As you have learned a **solution** is a homogeneous mixture. In such a mixture, a solute is a substance dissolved in another substance, known as a solvent. You also learned that the substances in a solution are not easily separated. However, one way to separate a solution is to use the physical property of boiling point. On heating, the temperature of the liquid increases until the **boiling point** is reached. Additional heating causes the liquid to vaporize accompanied by vigorous bubbling of the liquid. The fact that different substances have different boiling points allows us to separate them. The process of heating a substance until it is vaporized, cooling the vapors, and collecting the condensed liquid is the basis of a commonly used purification technique called **distillation**. Until recently this was the primary method by which submarines obtained fresh water. Conventional filtration is unable to separate a solution, but a special kind of filtration that involves a selectively permeable membrane can be used to separate solutes from a solvent. The process involves the process of diffusion, a concentration gradient, and a selective or semipermeable membrane.

In this activity you will investigate a synthetic selectively permeable membrane. Specifically, you will test the hypothesis that smaller molecules and ions can cross this synthetic selectively permeable membrane, but larger molecules cannot.

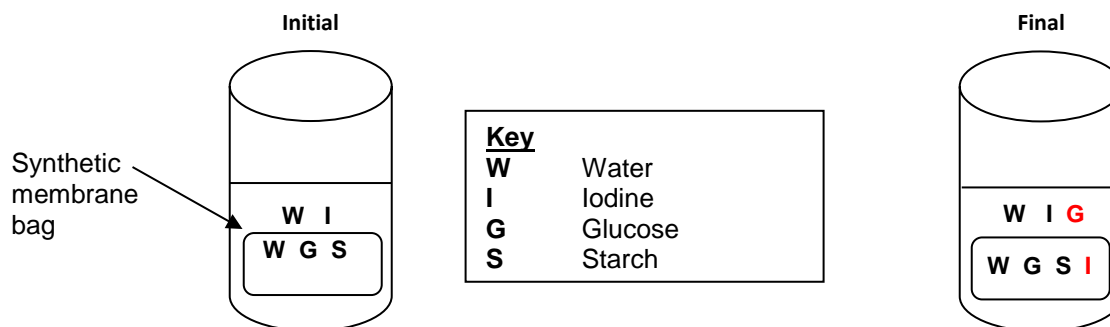
2. Which of the following molecules do you think will diffuse across the selectively permeable membrane used in this investigation?

Molecule or Ion (Molecular Formula)	Will it cross the membrane?	Why or why not?
Iodine (I_3^-)		
Water (H_2O)		
Glucose ($C_6H_{12}O_6$)		
Starch (polysaccharide made up of many molecules of glucose)		

Procedure:

To test your predictions, you will put solutions of starch and glucose in a bag made of the synthetic membrane and put the bag in a beaker of iodine solution. You will allow time for the substances to diffuse across the membrane and then test which of the substances have crossed the membrane.

3. The diagrams below show the locations of each type of molecule or ion at the beginning of the experiment and at the end. Based on your answers to question 2, predict where each type of molecule or ion will be found after diffusion. In the Final State diagram, write the letter for each type of molecule or ion in the places where you think it will be found at the end of the experiment.



To test whether iodine or starch have crossed the synthetic membrane, you will look for color change. A solution of iodine is tan and a solution of starch is clear or milky white; when iodine and starch are together in the same solution, the solution is purple, dark blue or black. To test whether glucose has crossed the synthetic membrane, you will use a glucose test strip to test for glucose in the solution in the beaker. If water can cross the synthetic membrane, water could diffuse into the bag or out of the bag. Your teacher will let you know how you will test for change in volume of water in the bag.

4. For each substance, indicate how you will know whether it crossed the synthetic membrane. What observation will be different, depending on whether or not each substance crossed the membrane?

Substance	Expected Observation (e.g. color of solution in the bag or in the beaker)	
	If this substance crossed the membrane	If this substance did <u>not</u> cross the membrane
Iodine	The inside of the bag will turn bluish-black	The inside of the bag will remain milky white
Starch	The solution in the beaker will turn bluish-black.	The solution in the beaker will remain tan
Glucose	A positive glucose test will occur in the beaker	A negative test will occur in the beaker
Water	An increase in water level inside the bag	No change in water level inside bag or beaker

Procedure:

1. Obtain a piece of dialysis tubing and two pieces of string. Fold the bottom of the piece of tubing up and use a piece of string to tie the folded part tightly to create a bag.
2. Use pipettes or graduated droppers to add 4 mL of glucose solution and 4 mL of starch solution to the tube.
3. Fold tubing at the top of the bag and tie it off tightly. Check to make sure there are no leaks. If scissors are available, trim the strings short.
4. In the table below record your initial observation of the measure you are using to evaluate the movement of water.
5. Add 200 mL of distilled water to a 250 mL beaker. Add about 1 mL iodine to the water in the beaker. .
6. Put the bag in the beaker.
7. Record your observations of the colors of the solution in the bag and the solution in the beaker in the “Initial State” row in the table below.

	In the bag		In the beaker		Measure to evaluate movement of water
	Color	Glucose?	Color	Glucose?	
Initial State	Clear	Yes	Tan	No	200mL in beaker
Final State	Bluish-Black	Yes	Tan	Yes	Increase in bag

After 20-30 minutes, record your observations in the “Final State” row of the table.

8. Complete the following table.

Molecule or Ion (Molecular Formula)	Did this molecule or ion cross the membrane?	How do you know?
Iodine (I_3^-)	Yes	The iodine turned the inside of the bag bluish-black, which indicates that it reacted with the starch
Water (H_2O)	Yes	The volume of water in the bag increased, while the volume of water in the beaker decreased
Glucose ($C_6H_{12}O_6$)	Yes	The glucose tested positive in the beaker
Starch (polysaccharide made up of many molecules of glucose)	No	The color of the water in the beaker remained tan, which indicates that the starch did not cross into the beaker.

9. Based on your results, what characteristic appears to determine which molecules and ions can cross the synthetic selectively permeable membrane?

The size of the molecule determines which ones can pass across the selectively permeable membrane

10. If any of your predictions were different from your results, what do you think is the explanation for any differences between your predictions and your observations?

Some students might not have predicted the movement of water since water already existed in both the beaker and inside the dialysis tubing. It is at this point that students grasp the net movement of particles able to pass through a selectively permeable membrane to be from areas of higher concentration to areas of lower concentration.

Diffusion and Osmosis Questions

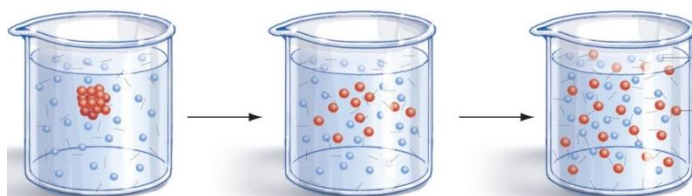
Based on your observations and results answer the following questions.

11. During diffusion, more molecules move

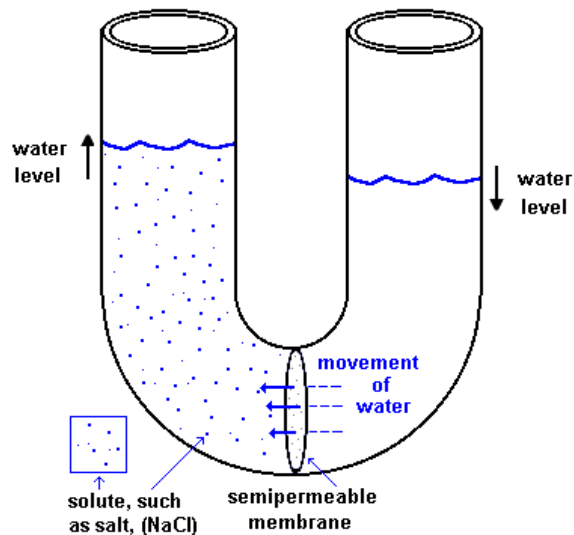
- from regions of higher concentration to regions of lower concentration
- from regions of lower concentration to regions of higher concentration

12. The reason for your response to the previous question

- Crowded molecules want to move to an area with more room.
- Molecules tend to keep moving until they are uniformly distributed and then they stop moving.
- The random motion of molecules results in their uniform distribution in the available space.**



Osmosis is the diffusion of water across a selectively permeable membrane. Na^+ , Cl^- , and the water molecules that are bound to these ions in a solution cannot cross the selectively or semipermeable membrane. Only water molecules that are not bound to ions or other solutes can cross the selectively permeable membrane. During osmosis, diffusion results in movement of free water molecules in both directions across the selectively permeable membrane, but more free water molecules move from the region of higher concentration of free water molecules to the region of lower concentration. This concentration gradient is referred to the **osmotic pressure**. Osmotic pressure is the minimum **pressure** which needs to be applied to a solution to prevent the inward flow of water across a semipermeable membrane.



13. Why is the concentration of free water molecules lower in water with dissolved salt and higher in pure water?

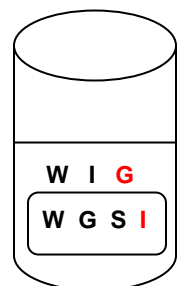
Many of the water molecules are bound to the salt molecules. The higher the concentration of salt, the lower the number of available water molecules

14. Why does osmosis result in a net flow of water from the side of the tube that has pure water to the side of the tube that has water with dissolved salt? Include in your explanation the relative concentrations of free water molecules on the two sides of the tube.

Just like any simple diffusion, the molecules move from a higher concentration to a lower concentration. Since the concentration of free water is greatest on the side without the dissolved salt, the water moves into the side that has the lower concentration of water (highest concentration of salt)

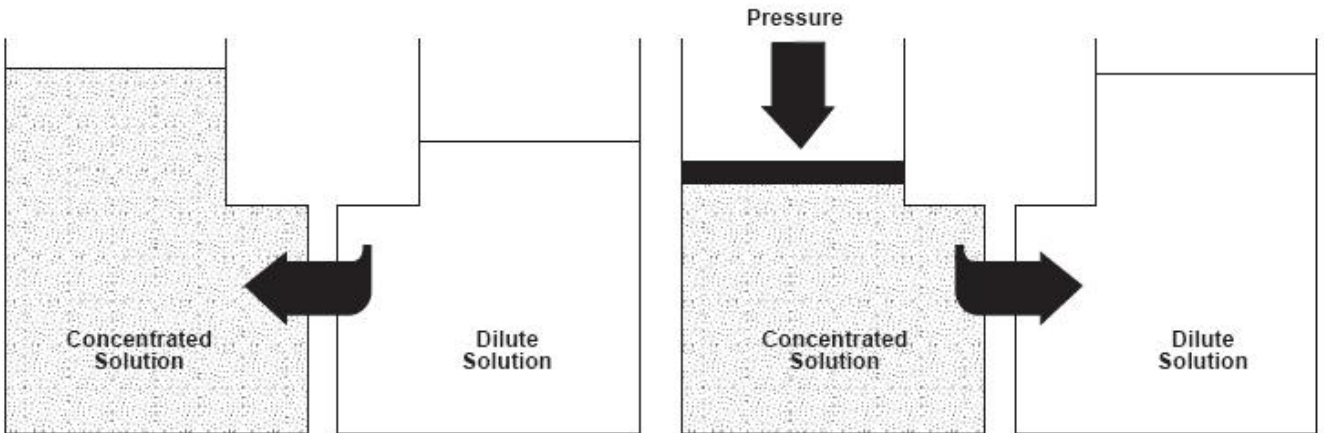
15. In your experiment, the concentration of dissolved substances is higher in the starch and glucose solution in the bag than in the iodine solution in the beaker. Which way would you expect more water to diffuse – into the bag or out of the bag? Explain your reasoning. Include in your explanation the relative concentrations of free water molecules inside and outside the bag.

You would expect the water level to increase inside the bag since the number of free water molecules was greatest in the beaker.



PART II: (30 min)

There is another way to separate water called **reverse osmosis**. Reverse osmosis, often referred to as RO, is an advanced water purification method that was initially developed by the U.S. Navy to produce drinking water from sea water for submarine crews. It is a membrane filtration technology that works by forcing water under pressure through the very tiny pores of a **selectively permeable membrane**. A selectively permeable membrane allows some types of molecules and ions to diffuse across the membrane and prevents other types of molecules and ions from crossing the membrane.



Reverse Osmosis. Digital image. Hitachi. N.p., 2015. Web. 17 July 2015.

<http://www.hitachi.com/environment/showcase/solution/industrial/images/img_desalination/09.jpg>.

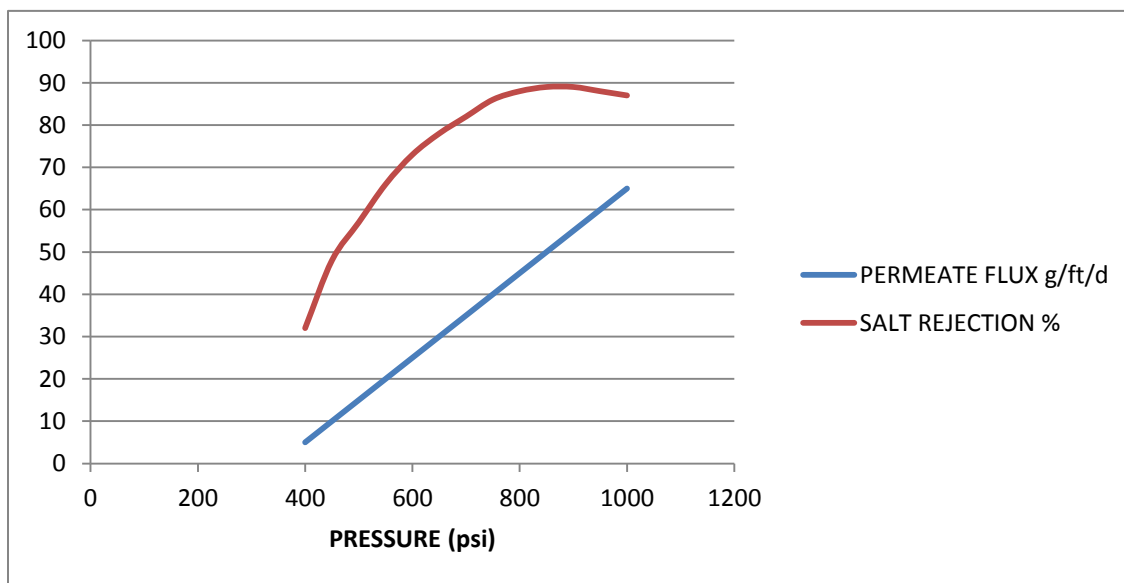
Terminology

- **Feedwater:** The non-purified water coming into the system
- **Recovery:** the percentage of feedwater that emerges from the system as product water or "permeate".
- **Rejection:** the percentage (%) of solids concentration removed from system feedwater by the membrane.
- **Passage:** the opposite of "rejection", passage is the percentage of dissolved constituents contaminants in the feedwater allowed to pass through the membrane. Typically, when the rejection % drop with an increase in pressure some solids are forced through the membrane
- **Permeate:** the purified water produced
- **Flow:** Feed flow is the rate of feedwater introduced to the membrane element, usually measured in gallons per minute (gpm).
- **Flux:** the rate of permeate transported per unit of membrane area, usually measured in gallons per square foot per day (gfd).

16. Construct a multiple line graph for the following data sets. The vertical axis will represent arbitrary units for both permeate flux (gallons/ft²/day) and salt rejection (%).

REVERSE OSMOSIS OF SEAWATER

PRESSURE (psi)	PERMEATE FLUX (gal/ft ² /day)	SALT REJECTION (%)
0	0	
50	0	
100	0	
150	0	
200	0	
250	0	
300	0	
350	0	
400	5	32
450	10	48
500	15	57
550	20	66
600	25	73
650	30	78
700	35	83
750	40	88
800	45	91
850	50	92
900	55	91
950	60	90
1000	65	89



17. Analyze the data and the graph you constructed. Can you infer from the graph the **osmotic pressure** of seawater? Explain your reasoning.

Based on the graph you can infer the osmotic pressure of seawater to be close to 400 psi because permeate is not produced prior to this pressure

18. Analyze the data and the graph you constructed. Can you infer from the graph the optimal operating pressure? Explain your reasoning.

Based on the graph you can infer the optimal operating pressure to be 900 psi because after that the percentage of salt rejected by the membrane begins to decrease

19. At what pressure can you assume the purity / quality of the permeate decreases?

Any permeate above 900 psi will most likely contain contaminants because the amount of permeate is directly related to the increase in pressure, but the percentage of salt rejection decreases after 900 psi

Unlike the example data you graphed above, rejection rates of today's RO membranes can exceed 99 percent, which means that the majority of the **feedwater** salts are rejected by the membrane and pass into the concentrate stream (brine). As the pressure in the system increases to produce more **permeate**, they effectively remove water from the feed stream, leaving less water behind to dilute the increasingly higher concentration of salts, which is often referred to as the brine solution. When the solubility limits are exceeded in the brine, the salts fall out of solution and begin to combine to form scale foulants on the membrane surface. Common scale formers in membrane applications include calcium carbonate, calcium sulfate, barium sulfate, and strontium sulfate. The accumulation of foulants decreases the efficiency of the membrane, and must be periodically cleaned to bring the system back to optimal running efficiency.

Finding the proper balance between acceptable permeate production and reduced membrane fouling is crucial, and why the process math is so important. RO and NF system **recovery rates** are calculated based on the amount of permeate produced divided by the total amount of raw water fed into the system. This calculation is illustrated as $Q_p \div Q_f = Q_c$ described below:

$$Q_p = \text{permeate flow} \quad Q_f = \text{feed flow} \quad Q_c = \text{concentrate flow}$$

20. If a system feed flow (Q_f) is 1,000,000 gallons per day (GPD) and the **permeate** flow is 750,000 GPD, then what would the calculated **recovery rate** be?

750,000 permeate GPD \div 1,000,000 feed GPD = 0.75 or 75 percent

21. What is the volume of the **concentrate** left behind in the previous example?

1,000,000 fed GPD – 750,000 permeate GPD = 250,000 GPD

When salt solubility limits are a concern, the concentration factor must be considered. Most brackish water RO systems operate at recovery rates between 75 and 85 percent, with the limitations based on salt concentrations in the brine stream. Understanding the influence of soluble salts on recovery rates is critical for successful RO plant operation. Dissolved solids must be diluted using conducive recovery rates in order to sustain desirable system performance. When the salt concentrations exceed saturation limits, the salts can drop out of solution and become a solid. The resulting scale will foul membrane surfaces, reducing permeate flow and increasing the dissolved solids in the permeate stream, which decreases the purity of the permeate. Scale fouling restricts water passage through the membranes and forces operators to increase feed pressures to maintain acceptable permeate volumes. This increases energy costs and reduces system efficiency. This calculation for determining concentration factor is illustrated as

$$\text{Concentration factor} = 1 \div (1 - \text{recovery rate})$$

22. Using the example above, what is the concentration factor for producing 250,000 gallons of concentrate?

$$\text{Concentration factor} = 1 \div (1 - 0.75)$$

$$\text{Concentration factor} = 1 \div 0.25 = 4x$$

23. If a system feed flow (Q_f) is 1,000,000 gallons per day (GPD) and the permeate flow is 800,000 GPD, then what would the calculated **recovery rate** be? Calculate the **concentration factor**.

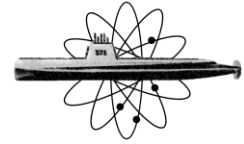
$$800,000 \text{ permeate GPD} \div 1,000,000 \text{ feed GPD} = 0.80 \text{ or } 80 \text{ percent}$$

$$\text{Concentration factor} = 1 \div 0.20 = 5x$$

A seemingly small increase in system recovery from 75 to 80 percent can have a significant impact on the overall level of salts in the concentrate stream. In some cases, even a 1 percent increase in system recovery will exceed the solubility of one or more salts and result in higher fouling rates.

Extension Activity:

One way to illustrate recovery rates and explain concentration factor is to gather 10 one-liter bottles of water and 10 stones to represent salt in the visualization. To illustrate 80 percent recovery, separate eight bottles and drop five stones in each of the remaining two bottles. The eight bottles represent 80 percent permeate and the two remaining bottles represent 20 percent concentrate. Each of the concentrate bottles has five times more salt than the original feed. Repeat the exercise, this time separating nine bottles and putting all of the stones in the remaining tenth bottle. At 90 percent recovery, the stones representing salt have been concentrated 10 times.



Submarine Force Museum Lesson Plan

Teaching and Learning Strategy: Strategies that you used during the lesson, including **modeling, guided practice and independent practice** where applicable.

1. **Teaching Clarity** - Provide explicit criteria on how students can be successful. Present **models** or examples (exemplars) to students so they can see what the end product looks like.
2. **Feedback** - provide whole-group feedback on patterns observed. Students also need to be given opportunities to provide feedback to the teacher to be able to adjust the learning process, materials, and instruction accordingly
3. **Formative Assessment** - assess frequently and routinely where students are in relation to the lesson's learning goals or end product (summative assessment).
 - a. Use of white-boards and response cards can be useful tools for formative assessments
4. **Independence, control and active engagement** – Give students opportunities to plan and organize, monitor their own work, direct their own learning, and to self-reflect.

Monitoring and Adjusting: How do you know the students have learned what you taught them and that they have achieved the objective?

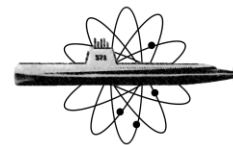
1. Questioning students during classroom discussions to check their understanding of the material being taught Circulating around the
2. Conducting periodic reviews (during lesson) with students to confirm their grasp of learning material and identify gaps in their knowledge and understanding
3. Reviewing student performance data collected and recorded and using these data to make needed adjustments in instruction
4. Paying close attention to who is answering questions during classroom discussion and calling upon non volunteers
5. Asking students to comment or elaborate on one another's answers
6. Initiate more interactions with students, rather than waiting for students to ask for help
7. Have systematic procedures for supervising and encouraging students while they work
8. Asking students to interpret or summarize material presented to them in the lesson

Assessment: How will you ask students to demonstrate mastery of the student learning objectives? Attach a copy of any assessment materials you will use, along with assessment criteria.

1. Evaluate students' understanding by examining performance data and response to performance data questions

Closure: Briefly describe how you will close the lesson and help students understand the purpose of the lesson. (Interact with learners to elicit evidence of student understanding of purpose(s) for learning and mastery of objectives)

One of the most effective methods to assessing student learning in a short-term period of time is to develop a set of assessment questions using response cards, or more traditional use of small white boards. If applicable, visit the Submarine Force Museum exhibits to show application of student learning objectives



Submarine Force Museum Lesson Plan



Post-Visit Materials/Activities: Provide additional materials if they would reinforce a good learning experience

Post-Visit Materials/Activities: Provide additional materials if they would reinforce a good learning experience after leaving the museum.

Technology: Please explain the technology used: why you will use it, how you will use it and how you will assess the results of using this technology.

Key Vocabulary: Words students need to know in order to reach the objectives.

- | | | |
|-----------------------------------|---------------------|--------------|
| 1. Diffusion | 4. Osmotic pressure | 8. Recovery |
| 2. Selectively permeable membrane | 5. Reverse osmosis | 9. Rejection |
| 3. Osmosis | 6. Concentrated | 10. Permeate |
| | 7. Feedwater | |

Extension: What do you have in place in case during the lesson you finish early, run out of time or need to accommodate students who complete the class work before other students, or your technology fails?

Finish Early:

Run out of time:

Technology Fails:

Materials: List the materials you will use in each learning activity.

- 250 ml beaker
- 1% starch solution, corn or potato (4 ml per group) **FLINN CATALOG # S0151**
- 15% glucose solution (4 ml per group) **FLINN CATALOG # G0024**
- Iodine-potassium iodide solution (IKI) (0.8 mL per group) **FLINN CATALOG # 10038**
- 2-3 mL transfer pipets **FLINN CATALOG # AP1718**
- 1" dialysis tubing **FLINN CATALOG # AB1229**
- String
- Glucose test strips **FLINN CATALOG # T0004**
- Distilled water
- Paper Towels
- Scale (accurate to 0.1 g) or a ruler to measure movement of water

Resources: Include any resources you may use such as textbooks and any technological resources.