How Do Submariners Breathe Underwater, For 90 Days?

Developed by Mary Harris, Chemistry Teacher, Robert E. Fitch High School
Groton CT, http://www.groton.k12.ct.us/Domain/98
2014 Submarine Force Museum & Historic Ship *Nautilus*
STEM-H Fellowship

Introduction: Since the advent of nuclear-powered submarines with their ability to travel long periods submerged without surfacing, while generating vast amounts of electricity for shipboard use, replenishment of oxygen in the closed atmosphere and removal of air impurities has been a critical requirement and a complex technological and engineering task. (see http://usnavymuseum.org/Education_LP0008.asp for a lesson plan on submarine power). Sometimes, it may be difficult to surface to use "outside air" for life support.

(Top left) USS *Skate* (SSN 578) was the first submarine to surface at the North Pole on 11 August 1958, after USS *Nautilus* (SSN 571) transited beneath the North Pole on 3 August 1958 . Newer U.S. Navy submarines (top right) have been modified for greater ability to operate and surface through ice. Note the absence of ice at the North Pole in summer 1958. See the link to a mathematical extension activity below, for details on USS *Nautilus'* transit.

Background: Living in a sealed environment with 100+ other humans for days, weeks, or months created many new atmosphere control problems for the U.S. Navy to solve. The transition from diesel-powered subs to nuclear-powered fast attack submarines like USS *Nautilus* (SSN 571) www.ussnautilus.org and fleet ballistic missile submarines like USS *George Washington* (SSBN 598) http://www.usnavymuseum.org/Ex1_Submarines.asp lead to new technology and engineering necessary for a safe undersea life. Read the short article "No More Loose Fillings and Slow Embalming, How Naval Science Helped Submariners Breath Easy" at http://www.navy.mil/navydata/cno/n87/usw/issue_10/breathe.html .

How Do Submariners Breathe Underwater, For 90 Days?

1. Using the electricity generated aboard a submarine, a basic first step to provide oxygen is to make pure water from sea water: desalinization. This is done by an evaporator/distiller or reverse osmosis process: (http://adventure.howstuffworks.com/survival/wilderness/convert-salt-water1.htm). The pure water (H_2O) is then used to create an oxygen supply, using the electrolysis method.

Demonstration: View the demo of electrolysis of water on Youtube, or as conducted by your teacher: (http://www.youtube.com/watch?v=0X604USY6hs).

2. Write a balanced chemical equation for the electrolysis reaction.

3. What happens to the products of electrolysis?

4. Write an equation for sailors breathing-in oxygen; what do they exhale?

Student activity: Exhale through a straw into a flask containing lime water.

Write an equation for the lime water reaction with your exhaled "air".

What explains the change in appearance of the lime water?

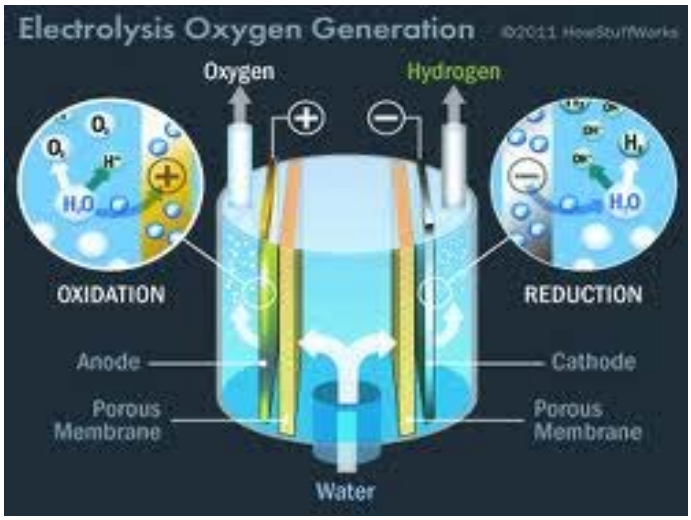
Extension: Are there parts of a submarine (besides the sailors) that may be giving off gases or impurities (plastics, insulators, paints, air conditioning)? How does cooking food impact the air quality on a submarine? What gases might be present?

Review the following explanations, describing the methods and equipment for replenishing and purifying air on submarines (Courtesy of MM1(SS) Rami Dia, U.S. Navy).

Atmosphere Control Equipment:

- Electrolytic Oxygen Generators
- CO_2 Scrubbers
- CO-H_2 Burners

Electrolytic Oxygen Generators



Using pure water, a mixture of potassium hydroxide, and 350-1050 amperes of electricity, a grouping of electrolytic cells shown in the above drawing provide more than sufficient breathable oxygen for a submarine crew. The electrolytic cells are enclosed within the electrolytic oxygen generator cabinet shown on the right. "Excess" produced oxygen can be stored in large oxygen flasks external to the submarine pressure hull for later use. The hydrogen produced is safely disposed-of. A newer unit, the Low Pressure Electrolyzer, using state-of-the-art proton exchange membrane electrolysis cells is now being used in newer submarines. For more information see http://www.treadwellcorp.com/about-who-we-are.php .

CO_2 Scrubbers

A "scrubber" is used to remove CO_2 gas continuously on a submarine. What chemical process is used to remove this compound? MEA is the acronym for mono-ethanol amine, the strong base used in the CO_2 scrubbers on a submarine. MEA has the formula $NH_2C_2H_4OH$. MEA absorbs the CO_2 from the air. The MEA is then heated to drive out the gas, and the latter is compressed and ejected overboard. See the diagram and photo below.

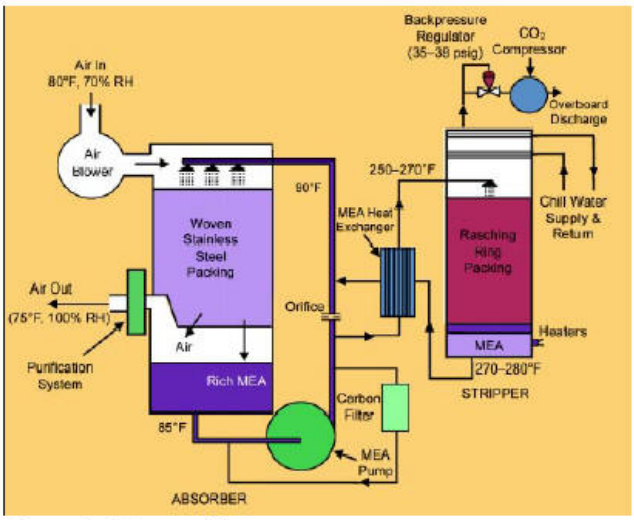
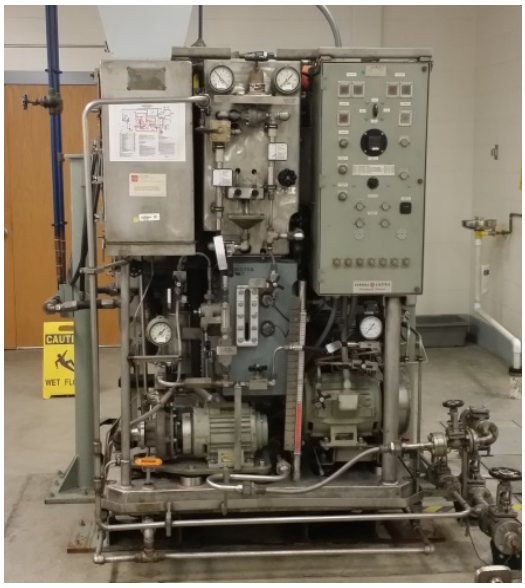


Figure 2: CO_2 scrubber.



Scrubber diagram and equipment photograph; Photo courtesy MM1(SS) Rami Dia

CO-H_2 Burners

To maintain a safe and breathable atmosphere, carbon monoxide and hydrogen are subjected to controlled-burning. Photo courtesy of MM1(SS) Rami Dia.

- Catalyst bed- hopkalite and lithium bicarbonate
- Heated to 500^{o}F
- CO→CO_2 which is then removed by the scrubbers
- H_2→H_2O
- Afterfilter- Lithium Bicarbonate
- Lithium Bicarbonate- LiOH

Mathematics Extension Activity: Across the Pole

(http://www.ussnautilus.org/education/stemlessonplans.shtml)

Navigation During *"Operation Sunshine".* Use data from the historic 1958 under-ice voyage of USS *Nautilus* (SSN571) beneath the North Pole to calculate distance, speed, and time, employing s = d/t (speed equals distance divided by time) and its transformations.

Lung Operations: The chemistry which happens in the lungs is very complex. It involves more than just Oxygen gas (O_2) binding to hemoglobin.

Gas exchange takes place in the alveoli (plural), which are the tiny sac-like structures in the lungs at the end of the airways. The blood is pumped from the heart to the capillaries on the surface of these alveoli.

Inhaling involves the reaction of the Hemoglobin (Hb) in the red blood cells to with the Oxygen gas (O_2) from the air to form Oxy-hemoglobin (Hb-O_2). Once the red cells are delivered to the internal cells of the body, the Oxygen is released by Carbon dioxide (and H+), which are in high concentration.

Hb-O_2 (s) + CO_2 (g) --> Hb-CO_2 (s) + O_2 (g)

Some of the Oxygen gas is not replaced. The Oxy-hemoglobin becomes Deoxy-hemoglobin

Hb-O_2 (s) --> Hb (s) + O_2 (g)

The blood is then pumped back to the lungs where the reverse reactions take place.

Hb-CO_2 (s) + O_2 (g) --> Hb-O_2 (s) + CO_2 (g)

Hb (s) + O_2 (g) --> Hb-O_2 (s)

The Carbon dioxide is then exhaled from the lungs.

You should notice that the Oxygen and the Carbon dioxide do not bind to the hemoglobin at the same site.

NOTE: In addition, the pH of the blood is regulating these gas exchanges. The change of pH is do to a reversible reaction of Carbon dioxide with water.

H_2O (l) + CO2 (g) <==> H_2CO_3 (aq)
and
H_2CO_3 (aq) <==> H+ (aq) + HCO_3- (aq)

SOURCES:

http://www.chm.bris.ac.uk/motm/hemoglobi...
http://www.chemistry.wustl.edu/~edudev/L...