

## Scrubbers and pH

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**Introduction:** A submarine spends many days below the surface and needs a system for removing CO<sub>2</sub> from the atmosphere. A “scrubber” is used to remove the CO<sub>2</sub> continually. What chemical process is used to remove this compound? MEA is the acronym for mono-ethanol amine, the strong base used in the CO<sub>2</sub> scrubbers on a submarine. MEA has the formula NH<sub>2</sub>C<sub>2</sub>H<sub>4</sub>OH. MEA absorbs the CO<sub>2</sub> from the air. The MEA is then heated to drive out the gas, and the latter is compressed and ejected overboard.

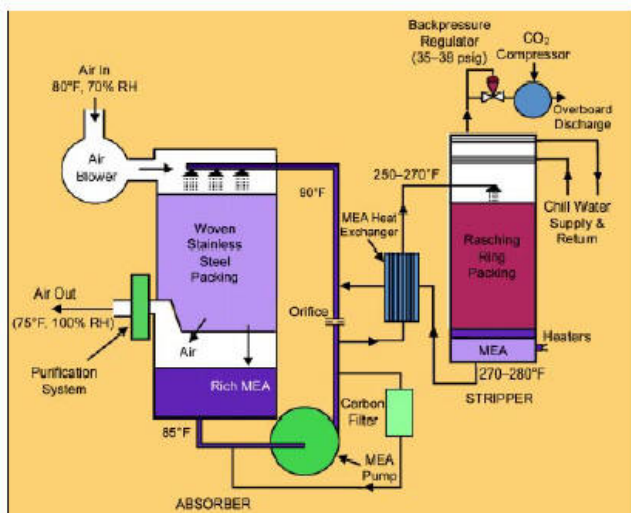
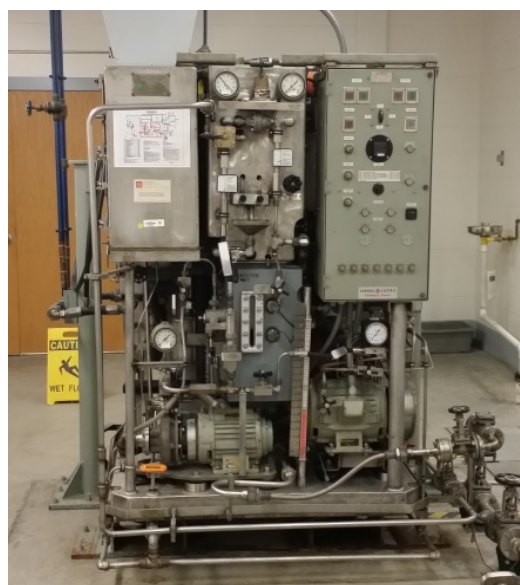


Figure 2: CO<sub>2</sub> scrubber.



Scrubber diagram, Walsh, at website below

Photo courtesy MM1 Rami Dia

**Background:** Living in a sealed environment with 100+ other humans, not only must CO<sub>2</sub> be removed, other contaminants like CO, H<sub>2</sub> and refrigerants required removal and O<sub>2</sub> must be replenished. The transition from diesel-powered subs to nuclear-powered fast attack submarines like USS *Nautilus* (SSN 571) [www.usnautilus.org](http://www.usnautilus.org) and fleet ballistic missile submarines like USS *George Washington* (SSBN 598) [http://www.usnavymuseum.org/Ex1\\_Submarines.asp](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 Breathe Easy” at [http://www.navy.mil/navydata/cno/n87/usw/issue\\_10/breathe.html](http://www.navy.mil/navydata/cno/n87/usw/issue_10/breathe.html) .

## CO<sub>2</sub> Scrubber Operation and Problemsolving

The MEA is purchased and stored in concentrated form, as 15.8 M solution. It requires dilution to 4.0 M for use.

1. A scrubber holds approximately 225 liters of dilute MEA when it operates. What volume of concentrated MEA and distilled water must be used to initially fill the system?
2. How many moles of MEA are present in the system at the start of operation?

Sailors test the MEA periodically to determine if its concentration is still high enough to efficiently operate the scrubber. Bromophenol blue indicator C<sub>19</sub>H<sub>10</sub>Br<sub>4</sub>O<sub>5</sub>S is used in a titration of MEA with 0.50 M nitric acid. This indicator is blue in basic solution, and begins to turn yellow when the pH goes below 4.6.

3. A 100. mL sample of MEA that has been in use is is titrated with nitric acid. The indicator changes the solution yellow after the addition of 690 mL of nitric acid. What is the concentration of the used MEA?
4. This solution of MEA is a weak base even when it is concentrated and it is a dilute base in use. How could a solution be both? Differentiate these terms to clarify this.

Because the concentration of the MEA has dropped below the 4.0 M target, additional concentrated MEA needs to be added to the system. A chemistry teacher would remove a quantity of the dilute base, add an equal volume of the concentrated base, and reestablish the solution with the desired volume and concentration. The Navy takes a different approach. They add an additional volume of concentrated MEA, allow the system to mix, and re-titrate to see if they hit the desired molarity. Each method has advantages and disadvantages.

5. Describe the advantages and disadvantages of each of these strategies for maintaining the correct concentration of MEA. Scientific and practical considerations should both be considered!

6. A scrubber contains 240 liters of 3.75 M MEA. A sailor adds 1.0 liters of concentrate to that. What will the concentration of MEA be after his addition? Has he hit the target zone of  $4.0 \pm 1$  M?
  
7. Show calculations that demonstrate the changes in concentration with the addition of 1.0 liter aliquots up to a total of 6.0 liters.
  
  
  
  
  
  
  
  
  
  
8. A chemistry teacher who stowed away (BTW, really silly, never happen!) decides to adjust the system using the chemists' method. What volume of pH 3.75M MEA would need to be replaced with concentrate to reestablish that 4.0 M desired concentration in a total volume of 240 liters?
  
  
  
  
  
  
  
  
  
  
9. This solution of MEA is a weak base even when it is concentrated and it is a dilute base in use. How could a solution be both weak and concentrated? Differentiate these terms to clarify this.
  
  
  
  
  
  
  
  
  
  
10. Why can't the sailors just check the pH of the solution instead of titrating it?

**Extension:** A resource for more information about scrubbers can be found at:

<http://www93.homepage.villanova.edu/michael.b.walsh/CO2Scrubber.htm>