Submarine Heat Exchange

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Introduction:

The submarine's nuclear reactor is filled with very pure "primary" water. The primary water absorbs heat as it flows through the reactor and then transfers the heat to "secondary" water in another heat exchanger, called a steam generator. Steam in the secondary system turns turbines for both propulsion and electrical power. The expended steam is condensed by transferring heat to seawater in another heat exchanger called a condenser. The activity for students presented here explores the properties of the material used for the heat exchangers. Students are encouraged to record their procedure in a series of photographs, graph their collected data, reevaluate, modify, and adjust their procedure, and cite data in their conclusions.

Standards:

The activity addresses:

- MS-PS3.A (Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present.),
- MS-PS3.B (The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment . Energy is spontaneously transferred out of hotter regions or objects and into colder ones.
- ETS1.A (defining and delimiting an engineering problem); and
- ETS1.B (developing possible solutions) in the Next Generation Science Standards.

History: View either of the short videos produced to describe the *Nautilus'* reactor plant heat exchangers:

Reactor Operations: This video on the reactor operations of nuclear submarines is part of the Covert Submarine Operations Exhibit, located in the Cold War Gallery, Washington Navy Yard. The Cold War Gallery is the latest addition to the National Museum of the United States Navy.

Nuclear Propulsion: "The Nuclear Navy" (1967): This segment of a 1967 Navy documentary explains the basics behind nuclear propulsion. It also shares the history of its development in the years after World War II. Source: Naval History and Heritage Command, Photographic Section UMO-2.

For a more basic explanation of the steam cycle, view the historic explanation by prominent actors in the movie *The Sand Pebbles*; dialog found at the end of the lesson.

Materials (Teacher Notes):

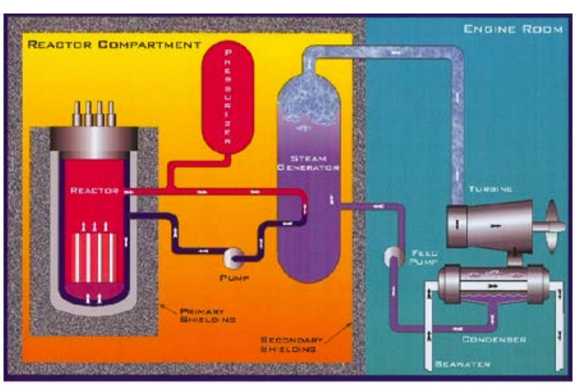
Collecting materials for this experiment requires a bit of ingenuity on the part of the instructor. An assortment of tubes made of different materials is needed. To complete the lab, each lab team will need two thermometers, two #3 stoppers, two #3 2-hole stoppers, a hotplate, a large beaker of water, a source of cool water, and two tubes made from different materials.

Obtaining the tubes is the challenge for most teachers. For a class, half a dozen 15 cm copper tubes, half a dozen aluminum tubes, half a dozen PVC tubes, and half a dozen glass tubes, all of equivalent diameter will be necessary. Tubes made of other materials may also be included as available. Varying thicknesses of the different materials provides another opportunity for experimentation also.

http://www.lowes.com/pd_216096-37672-11397_4294684418__?productId=3053653&Ns=p_product_qty_sales_dollar|1&pl=1&currentURL=%3FNs%3Dp_product_qty_sales_dollar|1&facetInfo=This is a link to Lowes, where an aluminum tube 3/4 inch diameter and 3 feet long costs $9.28, which is affordable.

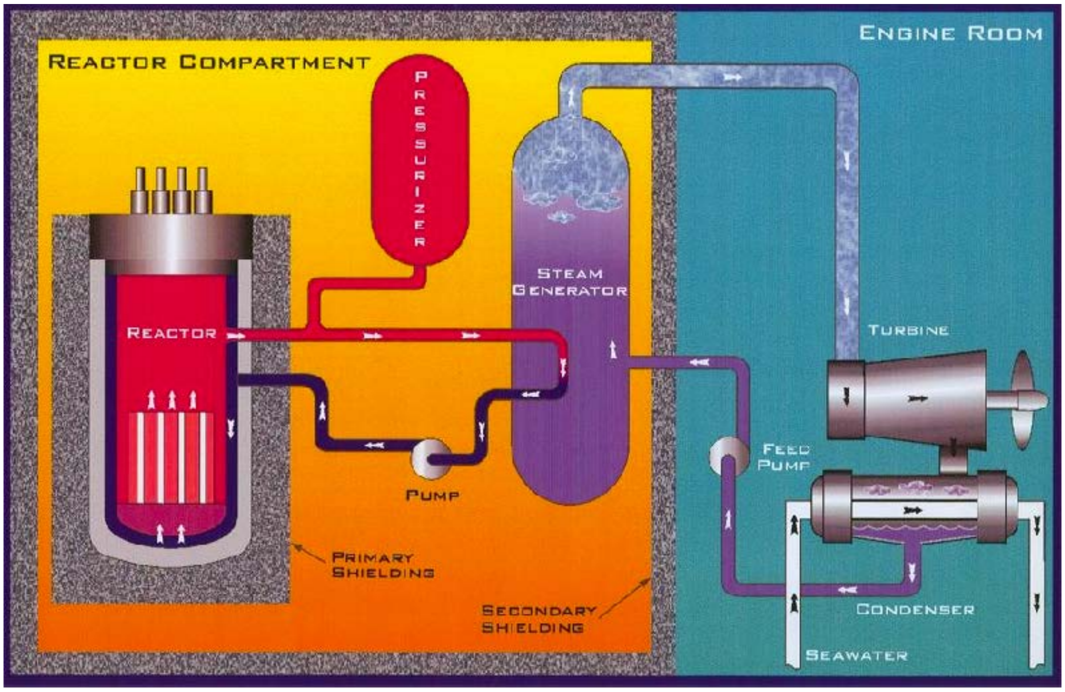
http://www.lowes.com/pd_23792-27953-1-1/4+M+10_0__?productId=3133023&Ntt=copper+tube&pl=1&currentURL=%3FNtt%3Dcopper%2Btube&facetInfo= This one is copper, and 5 feet long, for $15.31 PVC pipe is also available at Lowe's.

Glass tubing is available through most scientific suppliers. Number 3 stoppers will work on a tube of internal diameter ¾" One should be two hole for the top, (one to hold the thermometer or temperature probe, one to keep the pressure from building) one solid for the bottom. The chart for finding stopper sizes is http://www.accurate-prod.com/rubber-stoppers-company/.



<u>Sharing the heat without mixing</u>

Background: The diagram above and below shows the basic design of the nuclear reactor in the submarine *Nautilus.*



In the *Nautilus*, the primary water that runs through the nuclear reactor is kept separate from the secondary water that turns into steam to run the turbine. There are several advantages of this. First, any impurities in the water that runs through the radioactive core will themselves become radioactive. Therefore, extremely pure water is used for this application. The water in the secondary system can be treated to minimize heat exchanger tube corrosion; it is less pure and can contain compounds that minimize wear and corrosion of steam generator materials.

Also, isolation of the nuclear portion of the power generation in a reactor compartment, separate from the steam turbine and condenser spaces, adds a level of safety for the operators.

As the core's primary water is kept separate from the secondary water, and the secondary water is kept separate from the cooling seawater in the condenser, heat is being continually transferred without water mixing. What are the characteristics of the pipes or tubes where this transfer happens? Should these pipes be very thick or very thin? Should they be made of metal or of glass? Today, you will do an experiment to compare some of the material that might be used to transfer this heat, and evaluate their effectiveness.

Materials: (varies by teacher – see Teacher Notes above) To complete the lab, each lab team will need two thermometers, two #3 stoppers, two #3 2-hole stoppers, a hotplate, a large beaker of water, a source of cool water, and two tubes made from different materials.

Procedure (an overview):

> **Safety**: Please remember, hot and cold materials look exactly alike! Allow your tubes to cool before handling them or removing the stoppers. As always, when heating anything in lab, you should wear goggles, aprons, and closed toe shoes.

Obtain two different tubes for holding cool water. Plug the bottom of each with a stopper. Add cool water to each tube. Insert thermometers into one hole of a two-hole stopper, and insert these thermometers into your tubes of cool water. Check that each thermometer is in the water, and not touching the sides of your tubes. Place both tubes in a beaker of hot water on a hotplate. Record the temperature inside each tube at regular intervals over several minutes.

With your partner, examine your materials and agree on your own specific procedure based on this overview. Take a series of photographs that illustrate your procedure.

> **Safety**: Please remember, hot and cold materials look exactly alike! Allow your tubes to cool before handling them or removing the stoppers. As always, when heating anything in lab, you should wear goggles, aprons, and closed toe shoes.

Data, calculations, analysis:

Create a clear, organized and complete data table.

Share your data with the class.

Graph your data to illustrate the differences between your tubes.

Analysis questions:

1. What was the independent and dependent variable in your experiment?
2. Name two variables you controlled in conducting your experiment.
3. Were there any variables you failed to control that could have degraded the quality of your data? Were these significant enough that you feel you need to gather more data to justify reaching a conclusion? If time and your instructor permit, conduct this extra trial.
4. Which of the materials you tested is best suited for transferring heat? Explain your reasoning, citing evidence from the graph.
5. Consider the data from other lab teams in the classroom. Is there one material that seems to be significantly better than others for transferring heat? Cite data to support your claim.
6. Rank the materials used in these tests from most effective to least. Are there any further tests you need to conduct (pun intended!) in order to reach a clear conclusion? If time and your instructor permit, conduct this extra trial.
7. If a different material was especially effective in allowing heat to be transferred, what would its time/temperature graph look like?
8. What differences would you see in your graph if you used less water in your tube? Justify your explanation.
9. What differences would you see in your graph if you used tubes that were very large in diameter? Justify your explanation.
10. Materials have a variety of properties to consider when designing a system like the nuclear power plant that runs *Nautilus*. What other properties might be considered in selecting the right material for this task?

Final product:

- Print and attach your procedure photo-series, with any necessary captions.
- Attach all graphs.
- Attach answers to the analysis questions.

The Sand Pebbles Steam Plant Description

But I wantee new boss, savvy? Teachee all pidgin.
Oh. Engine side not proper?
No, no, the engine's OK. I'll teach you how to run it right. Come here.
Now, main steam stop valve.
May stim stop wowel.
Where?
You find.
No, no.
OK.
OK. If you go that way, then we're going reverse. OK?
Huh?
The generator. Makes juice for the lights.
See?
OK.
This is the boiler. Inside belongs live steam. Savvy?
Strong steam.
- Stim. - Steam.
Stim.
Live stim goes through this pipe.
Live stim goes into the feed pump.
Live stim! Make pump go vroom, vroom, vroom, vroom, vroom...
Live stim, huh?
Live stim... Live stim... Live stim.
Exhaust stim.
Condenser. Makee steam all dead.
You know, sleepy stim.
Live stim, dead stim.
Before, live stim.
Now water. Water belong dead stim.
All same dead stim.
Stim dead. Stim dead!
That's right. That's it.
Now you got it! That's right! That's the way it works!
And that's the throttle.
I'll teach you about that throttle one day.
Go ahead. Grab ahold of it.
Boo!
Nah. There ain't no ghosts in that engine.
Hey, Don’t mess with this teacher! No cell phones in her lab!
http://www.youtube.com/watch?v=q9cbM18bTj4