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Handboiler

HB-100

NGSS Correlations:

Our Handboiler and these lesson ideas will support your students' understanding of these Next Generation Science Standards (NGSS):

Elementary

4-PS3-2

Students can use the Handboiler to make observations to provide evidence that energy can be transferred from place to place light and heat sources.

3-5-ETS1-3

Students can use the Handboiler to plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

Middle School

MS-PS1-4

Students can use the Handboiler to develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.

High School

HS-ESS2-4

Students can use the Handboiler to use as a simple model to describe how the variation in the flow of energy onto and out of Earth system result in changes in climate.

HS-ETS1.B

Developing Possible Solutions. Both physical models (such as Handboilers) and computers can be used in various ways to aid in the engineering process.

Suggested Science Idea(s)

MS-PS1-4

Students can use the Handboiler as a still. The distillation process is achieved by inverting the Handboiler—place the top into ice and water and heat from a hand on the larger chamber.

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An inexpensive, closed-system distillation apparatus

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While discussing vapor pressure with my students this year, I was reminded of a little novelty device known (erroneously) as a "hand boiler" that my daughter Jenna had received for a gift several years ago. For those not familiar with it, the device consists of two blown glass bulbs connected by a glass tube, usually looped around in some ornate fashion (see Fig. 1a). One bulb contains ethanol that has been colored to make it more visible.[1] The system is completely closed with, I believe, most of the air evacuated, so that the ethanol's vapor is more or less the only gas present to supply any pressure.

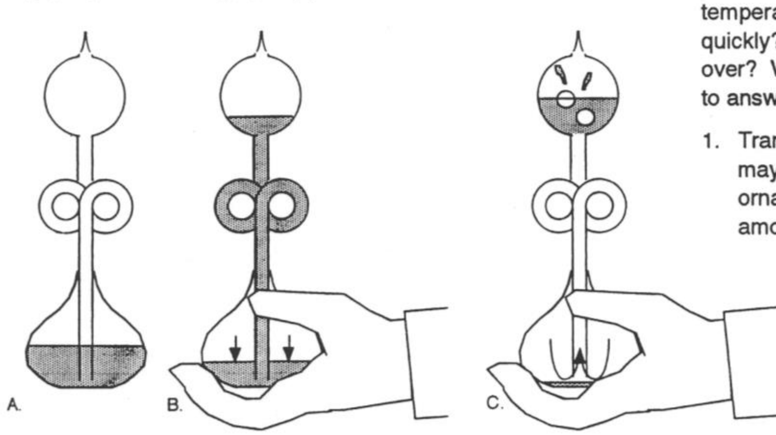

Fig. 1. The "hand-boiler" in typical operation.

As one holds the lower bulb, the warmth causes the vapor pressure to increase enough to push the ethanol through the tube into the upper bulb (see Fig. 1b). Most remarkable is that almost <u>all</u> the ethanol is pushed out of the lower bulb, and when the liquid level in that bulb drops below the level of the extended tube, then the vapor itself is pushed up through the tube. As this vapor bubbles up through the ethanol in the top bulb it gives the appearance of rapid boiling – hence the name (see Fig. 1c).[2] This bubbling lasts for several seconds, until the pressures equilibrate in the two bulbs. At this point, the upper bulb can be warmed to push the ethanol back down into the lower bulb. The process can be repeated several times, but the effect becomes less and less pronounced with each cycle as the ethanol warms up to match the temperature of one's hand. After several cycles, no more bubbling can be achieved, and the device must then be allowed to cool off again before it can be reused.

With all the wonderful tie-ins to vapor pressure and temperature, I was eager to show the hand boiler to my students. I asked Jenna if I could borrow it; but when she went to her room to look for it, it was nowhere to be found. A few weeks later, it turned up; apparently it had fallen behind a trunk, landed on the carpeted floor and fortunately not broken. Even more fortunate was the discovery Jenna made just as she was about to pick it up. She brought it down to show me that although one end contained the regular blue liquid, the other contained a liquid that was colorless. Where had it come from, and how had it gotten there?

I asked her where exactly she had found it, and she explained that it had landed on its side on the floor just below the heat vent. I started to get excited... Perhaps the heat had hit the side with the colored liquid, made it evaporate and then the vapors had condensed in the cooler end, leaving the nonvolatile dye behind. Had she missed that chance observation, had she just picked up the boiler and allowed the two sides to mix, the discovery would have been lost. It certainly would never have occurred to me that any kind of distillation could be performed in this completely closed container. But how long had the distillation taken? If the temperature differential were greater could it be done more quickly? If left long enough would the alcohol distill completely over? We then developed the quick and easy procedure below to answer these questions.

1. Transfer all of the colored ethanol into the lower bulb. This may take some tilting back and forth, depending on how ornately looped the connecting tube is. It's alright if a small amount of colored ethanol remains in the upper bulb, but it will make your distillate slightly tinted.
2. Turn the device upside down. Since the connecting tube extends so far into the lower (now upper) bulb, the liquid does not drain down (See Fig. 2a).
3. Cup the upper bulb in your hand, with the tube extending down between your ring and middle fingers, so that your hand is in good contact with the glass holding the ethanol. Place the empty lower bulb into a cup of water – or better, a salt-ice slurry (see Fig. 3).

Immediately, the upper bulb becomes uncomfortably cold. As the temperature in the lower bulb decreases, some of the vapor condenses and the pressure drops sharply; this causes the pressure in the top bulb to drop, and causes the liquid-vapor equilibrium to shift toward the vapor state. Since evaporation is endothermic, heat is quickly taken from your hand. This is a valuable hands-on experience for students; since heat and high temperatures are often associated with the processes of evaporation and boiling, many students hold the misconception that these processes must be exothermic.

After only 10-15 seconds, a small puddle of colorless liquid can be observed in the lower bulb (making this one of the fastest and easiest distillations on record!). After 4-5 minutes, about half of the ethanol has distilled across, and the ethanol remaining in the upper bulb is noticeably darker than it was at the beginning (see Fig. 2b). Swirling the device (carefully, so as not to break the connecting tube) speeds up the process by increasing the effective surface area and therefore the heat transfer in both the upper and lower bulbs. Finally, after 10-20 minutes, the distillation is complete, and all that is left in the upper bulb is the dry pigment residue (see Fig. 2c).[3] (Surprisingly, some of the dry residues are a completely different color than their solutions. The blue dye, for example leaves a dark orange residue!)

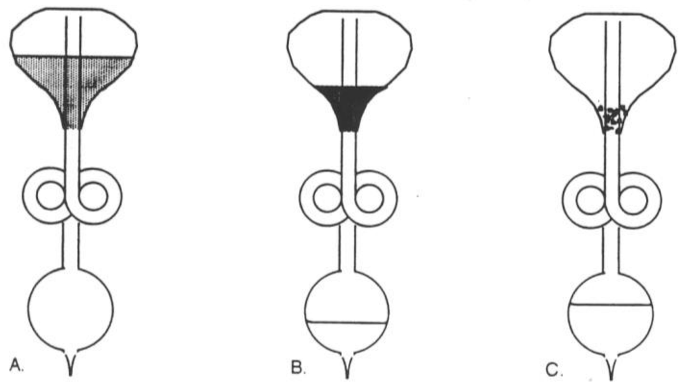

Fig. 2. The "hand-boiler" inverted to make a closed-system distillation apparatus. As the ethanol is distilled from the upper bulb down to the lower bulb, the nonvolatile residue of pigment is left behind.

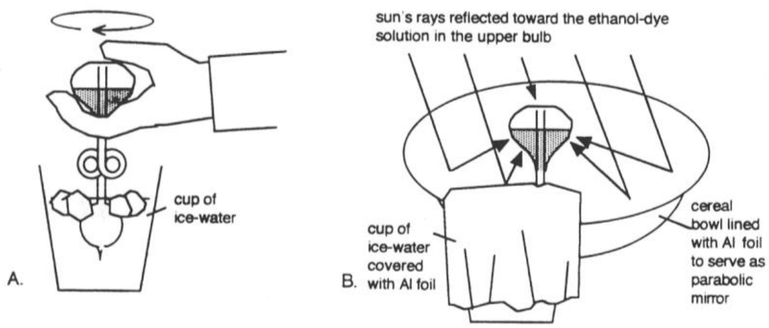

Fig. 3 The distillation apparatus, a) "biothermally driven"; b) solar powered.

Best of all, the process is completely reversible. By simply removing the hand boiler from the ice water and turning it right-side-up, the pigment redissolves in the ethanol and the device is all set to be used again!

Better yet, have some students stop their distillation just before it is complete, with the ethanol distillate on bottom and just a few drops of the dark dye solution on top. Ask the students to predict what would happen to the system if it were removed from the ice water and just left in that upside-down orientation. Most will predict correctly that the distillation will stop since the temperature differential no longer exists. But few will predict that the process will gradually begin to reverse itself! Over the course of the next several days (weeks?), have the students make periodic observations of the two liquid levels. Since the pure ethanol has 100% ethanol molecules at its surface, it will have a greater evaporation rate than the dye solution which has many nonvolatile dye molecules at its surface. Since these dye molecules hinder evaporation from the dye-ethanol solution, but they do not hinder condensation, there will be a very gradual transfer of ethanol molecules from the pure ethanol distillate back into the solution. This is an example of the vapor pressure lowering effect of a non-volatile solute, the dye.

Thus, the "hand boiler" turns out to be a very versatile device. Not only does it demonstrate the effect of temperature on vapor pressure, but with the activities described above, it can be used to illustrate the condensation process, the endothermic nature of evaporation, how a simple distillation works, and the colligative property that solutions have diminished rates of evaporation compared to the pure solvents. All this in a completely reusable system!

Notes

1. The hand-boiler (also known as "passion meter") is available through many science supply catalogs and stores. It ranges in price from $2.50 to $7.00 per item. The connecting tubes come in a variety of shapes and the ethanol comes in a variety of colors. Some hand-boilers come with a warning label: "Caution: Flammable. Contains ethyl alcohol. Do not use near heat or flames. Avoid contact with eyes..." Furthermore, they are rather fragile and not appropriate for young children.
2. Numerous colleagues have pointed out that instead of heating the lower bulb, one can (either with an ice cube or with a few drops of acetone) cool the upper bulb, decreasing the vapor pressure therein, and achieving the exact same effect. Thus, it is not so much the heat as it is the temperature differential that causes the action. This can be illustrated quite easily by warming (or cooling) both bulbs simultaneously and observing no effect at all.
3. Instead of hand-heating for 10-20 minutes, once the students have felt the endothermic nature of the evaporation, have them cover their cups of ice water with aluminum foil, with just the upper liquid-filled bulbs protruding, and place the set-ups on a window sill in direct sunlight for an hour or two. Any reflective surfaces that will direct more of the sun's rays into the upper bulb will make the process go even faster. Try, for instance, lining a bowl with aluminum foil and positioning it in a manner to have it act as a parabolic mirror (see Fig. 3b). A much simpler, though far slower alternative is to set the hand-boiler on its side on the window sill, with the dye-solution bulb in direct sunlight, and the empty bulb in the shade. This requires the least effort, but takes 5-10 minutes to obtain an observable distillate and several hours of strong sunlight to achieve complete distillation. *

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To extend your lesson, consider these Educational Innovations products:

Horizontal Handboiler Demonstration (HB-200)
Transfer liquid back and forth using the heat of your hand! Amazing to see! Fascinates students! Challenge: Can you find a way to obtain clear liquid on one side and solid red dye on the other? Experiment ideas provided.

Drinking Bird (DB-100)
Simply moisten the bird's head with water, place it next to a full glass of water and watch as the bird periodically dunks its head into the glass for a 'drink.' It continues for hours. Great centerpiece for class discussion or laboratory exploration. How does it work? Each bird comes complete with an explanation for teachers and suggested experiments. Whether you are interested in the science behind this fifty-year-old scientific toy or have just fallen in love with its adorable face, it makes a great addition to the classroom or a great gift!

Amazing Ice Melting Blocks (BLK-100)
This is one of the most striking science demonstrations we have seen in a long time. Place an ice cube on each of these two identical looking black blocks at room temperature. One ice cube instantly begins to melt and is totally gone in about 90 seconds. The other ice cube shows no evidence of melting whatsoever. Great for showing the difference in heat conductivity in different materials. This demo is simple enough for elementary students, yet also challenges high school and university level students and educators. A truly beautiful demonstration!

Radiometer (RAD-105)

Originally, designed by William Crooke in the 1860's, the radiometer still fascinates both young and old. Whenever light shines on the four diamond shaped vanes the paddle wheel spins at up to 3,000 rpm. Great for illustrating the conversion of light energy into mechanical energy. Each vane is black on one side and white on the other. Because the black surface absorbs energy better than the white reflective side, the molecules of air move faster near the black surface. Molecules of heated air moving faster on one side of the vane than the other cause it to spin. Suggested experiments included.