# Separation By Distillation

## Summary

**KEY CONCEPTS**

Boiling point, condensation, distillation

**CREDITS**

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## Introduction

Do you like cooking? If you have helped in the kitchen at home, you have probably heated up lots of liquids, like water, milk, and soup. Did you notice that once the solution boils, a lot of steam develops; and have you ever wondered what the steam is made of? What happens to all the substances, such as sugar or salt, that are dissolved in the solution you are boiling? Do they boil off, too, or do they stay behind in the solution? In this activity, you will build a distillation device that allows you to sample the steam that you generate while boiling a fruit juice! How do you think it will taste?

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## Background

What do you need to make a solution? First, you need water, or a *solvent*, and then you need a substance, such as sugar or salt, to dissolve, also called the *solute*. The solvent and solute become one solution—a *homogeneous* mixture—in which you cannot see the difference between them anymore. Most solutions are actually mixtures of many different substances. But what if you want to separate the individual components from a liquid mixture? There is a process called *distillation* that allows you to do just that. It is used in many real-world applications, such as making medicine, perfumes, or in the food industry.

Distillation exploits the differences in the volatility of the mixture's components, which means that every compound has a different boiling point and starts to vaporize (change from its liquid to gaseous phase) at a different temperature. When distilling, you heat up the mixture so that the component with the lowest boiling point evaporates first, leaving the other solutes behind. The vaporized component in the gas phase can then be collected in a different container by condensation and is called *distillate*. This means that the vapor is cooled down so the gas becomes a liquid again. By changing the distillation temperature, you can separate many different substances according to their different volatilities. If you have a mixture that includes a non-volatile solute, then this compound will always stay behind in the solution.

Knowing now how distillation works, what do you think will happen to the fruit juice once you heat it up? Make your own distillation device and find out!

## Materials

- Stove (always work with an adult helper when using the stove)
- Deep cooking pot with sloped (optional: and transparent) lid
- Ceramic bowl
- Small ceramic plate or ceramic coffee cup
- 3 Glasses
- Apple juice or cranberry juice (about 0.5L)
- Liquid measuring cup
- Ice
- Oven mitts
- Optional: Broth
- Optional: Cooking thermometer
- Optional: Vinegar

## Preparation

1) Place the small ceramic plate in the center of the cooking pot. Depending on how deep your cooking pot is, you can also place a ceramic coffee cup in the center of the deep pot.

2) Place a ceramic bowl on top of the small plate or coffee cup.

3) Put your pot on the stove.

## Instructions

1) Measure out and pour 1 cup of the colored fruit juice in a glass. Have a look at its color and take a sip to taste it. *Is it very sweet? How does the color look; is it very intense?* Keep the rest of the juice for comparison at the end.

2) Pour an extra cup of colored fruit juice in the bottom of the pot (your small ceramic plate or ceramic coffee cup will now be standing in the juice).

3) Together with your adult helper, turn on the stove to medium heat and bring the juice to a boil. It should be a moderate rather than a rolling boil. *Can you see the steam developing once your juice starts boiling? How does the steam feel if you put your hand in it (be careful and do not keep your hands in the steam too long)?*

4) Now place the cover on the pot, upside down, so that the tip of the sloping lid is facing toward the bowl placed inside the pot. *What happens to the steam once you close the lid?*

5) Put ice in the cover of the pot. You might have to replace the ice in the lid as it melts. *If you use a transparent lid, can you see droplets forming on the inward facing side of the lid? Where do they come from and what happens to the droplets?*

6) Allow the juice to boil for 20-30 minutes. *Do you see any changes in the amount of juice inside the pot?*

7) After 20-30 minutes, turn the burner off. Allow the pot to cool for a few minutes.

8) Put on oven mitts and carefully remove the cover from the pot. *What do you notice about the empty bowl that you placed under the lid?*

9) Still wearing hot mitts, lift the bowl off the small ceramic plate or coffee cup and set it down on a heat-resistant surface.

10) Remove the small plate or coffee cup. *Looking at the remaining juice in the pot, is there more or less juice left than the amount you poured in?*

11) After it cools, pour the remaining juice from the pot into a glass. *Did the juice change during boiling? What is different?*

12) Pour the cooled distillate (the condensed steam), which is now the liquid inside the small bowl, into a glass. *How does the distillate look?*

13) Now take the glass from the beginning with the original colored juice and place it next to the remaining juice and distillate. Compare their appearance. *How do they differ? Did you expect these results? Why do you think the juice changed the way it did? How much fruit juice is left compared to what you poured into the pot?*

14) Because you used clean kitchen utensils and edible fruit juice in this experiment, go ahead and take a sip of each of the solutions. Let the liquids cool to room temperature before tasting them. *How do the three different liquids compare in taste? Which one is the sweetest, which on is the least sweet? How does the condensed steam taste? Why is there a difference?*

15) Finally, re-combine the distillate and the remaining fruit juice again by pouring the distillate into the remaining fruit juice. *Do the volumes add up to what you put in at the beginning? How do the*

*appearance and taste of this solution compare to the original fruit juice?*

**Extra:** Repeat this activity with a salty solution, such as broth, instead of the sweet fruit juice. *Do you think the results will be similar? What happens to the salt in the broth when you are boiling it?*

**Extra:** Try to do this experiment again with household vinegar. Vinegar is a mixture of about 4-6% acetic acid and water. *Can you separate these two liquids by distillation? How does your distillate taste in this case?*

**Extra:** You might know that the boiling temperature of pure water is 100ºC (212ºF) at normal atmospheric pressure. Adding a solute, such as sugar, salt, or other compounds to water will change the boiling point of the resulting solution. Try heating up your three liquids (original juice, distillate, and remaining juice) and measure their boiling points with a thermometer. *Are they very different? How does the boiling point change with increasing solute concentration?*

## Observations and Results

Juices are usually very sweet. This is because fruits contain a lot of fruit sugar, called fructose. However, more than 80% of most fruits consist of water, so basically the apple or cranberry juice is a mixture of water and sugar. Once you reach the boiling point of the juice, it will start to evaporate and you will see steam coming out of the pot, which is pretty hot. If you close the pot with a lid, the steam rises up to the lid and because the lid is much colder than the steam (especially after you put the ice on top), the vapor cools down rapidly and it condenses, becoming a liquid again that you can see in the form of droplets inside the lid. These droplets fall and are collected in the bowl that you have placed in the pot. As the juice boiled, you probably noticed that the amount of water in the bowl increased, whereas the amount of apple juice in the pot decreased. This is because the steam, which was part of the juice, was collected in a separate container. If combined, the distillate and the remaining juice should add up to a similar volume of juice that you had in the beginning.

When you compared the three different solutions at the end (original juice, distillate, and remaining juice), the first thing you probably saw was that the color of the remaining juice became much darker and the distillate had no color at all and looked like pure water. And it actually is pure water; it shouldn't have had any sweetness at all when you tasted it, whereas the remaining juice should have tasted much sweeter than the original juice. The reason for this is that sugar is a non-volatile compound, which means that when you boil any sugary liquid, the sugar will stay behind in the solution and will not be transferred into the gas phase. The water component of the mixture, however, starts to evaporate at about 100ºC (212ºF), resulting in a steam consisting of pure water. Salt is also a non-volatile substance and, if you repeated the experiment with broth, your distillate also should have been pure water. If you compared the boiling points of all three solutions at the end, you might have noticed that you can increase the boiling point of water by adding solutes; the higher the amount of solutes, the higher the boiling point will be.

Vinegar, on the other hand—or a mixture of 4-6% acetic acid and water—is not easily separable by distillation. This is because the boiling points of water (100ºC) and vinegar (about 100.6ºC) and are too close together to result in a full separation of both components. You should have noticed that the distillate still tasted like vinegar.

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## Cleanup

1) Put all the used dishes in the dishwasher. You can drink the original juice and pour the distillate and the remaining juice from after boiling into the sink.

## Additional Resources

- Distillation, at Youtube
- How Oil Refining Works, from Science, How stuff works
- Science Activity for All Ages!, from Science Buddies

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