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#24 How Much Air Is In Foamed Polystyrene Products?

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I. INTRODUCTION

Description

In this experiment students are challenged to come up with a good estimate of the amount of air in foamed polystyrene products. It is ultimately a gas evolution experiment and as such has students measure the gas generated when foamed polystyrene is degassed and dissolved or dispersed in an organic solvent. The volume of the air is measured by water displacement with the twist that the organic solvent utilized is mostly water immiscible and floats on the water but has a vapor pressure significantly greater than water at room temperature and pressure. Gas laws calculations can be utilized in determining the amount of air present in the sample. The vapor of the organic solvent contributes to the total gas pressure so it must be considered in the calculations.

Foamed polystyrene products such as insulated cups, packing peanuts, ice chests and other packing containers are usually made from polystyrene resin that contains a blowing agent (usually pentane, CO_2, or butane). Alternatively, the blowing agent may be injected into the extruder and then into the die. The resin with the blowing agent unblown is more dense than the expanded products. Since the volume of materials transported from the polystyrene resin manufacturer to the polystyrene finisher is less, the compact materials are transported more cheaply. At the finishing product site, the resin with blowing agent is "prepuffed," stored to allow equilibration of the expanded material and then processed into cups, sheets or other products. In the final process, some additional expansion as well as molding occurs. The blowing agent gradually diffuses out and is replaced by air. When the amount of air incorporated into these foamed products is high relative to the amount of polystyrene used, the insulating abilities of the products are higher and the profitability will be greater because more product will be produced with less polystyrene resin.

At some finishing operations, problems with poor expansion in the "prepuff" and/or storage-equilibration stage might be compensated for by using more "prepuffed" material in the final expansion and molding or finishing stage. Products produced under these conditions would contain more polystyrene and less air, therefore determining the amount of air in the finished product is important.

A polystyrene resin with the blowing agent in it can be puffed in hot air or boiling water as a prelaboratory demonstration to introduce this experiment. One producer of the resin is Nova Chem. Alternatively, the polystyrene resin with blowing agent can be made available to students for individual experimentation. The two stage expansion of the resin is almost illustrated since the beads first change density and color and expand but after about five minutes are clearly much larger than when they first expand. Use of a heat gun illustrates that, upon further heating, the foamed polystyrene melts and collapses. (Foamed polystyrene materials can also be used in

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"shrinking plastic" experiments.)

Student Audience

This investigation is appropriate for high school chemistry classes and college level general, organic and polymer chemistry or chemical technology courses.

Goals for the Experiment

By completing this investigation students will:

- gain experience in measuring the generation of a gas (air) quantitatively,
- determine the volume of air in the sample (which requires applying the gas laws, particularly the law of partial pressures and using organic vapor–pressure nomographs), and
- use both hydrophobic and hydrophilic materials, as well as solvents of different densities, to illustrating the behavior of those materials with foamed polystyrene.

Recommended Placement in the Curriculum

This investigation would be appropriate when discussing:

- gas laws,
- hydrophobic and hydrophilic interactions, and
- processing of foamed polymers.

II. STUDENT HANDOUT

How Much Air Is In Foamed Polystyrene Products?

Scenario

As a small manufacturer of foamed polystyrene cups and sheets, your company wonders if there is a problem with a recent shipment of resin. The production foreman says that more “prepuff” material seems to be required in the cup and sheet process than typical quality control data indicates. She adds that no other changes have been noted in the processing conditions. If that is the case, your plant is currently putting more plastic material into each article than it did before. This will hurt the profit margin. As the company’s chemical technician, you wonder if there is a quick way to determine the amount of air in the finished polystyrene and, after consulting the local technical college chemistry instructor, you try the following procedure.

Background

Foamed polystyrene products are an integral part of our modern world. (Specifically, foamed polystyrene is noted for its insulating ability.) Upon close examination, some foamed and molded polystyrene articles (for example, cups and ice chests) are made of individual balls or beads pressed closely together. Since it is more economical to ship the polystyrene resin (beads) before puffing or blowing and molding, the individual manufacturers are responsible for the two stage process used to foam the polystyrene. In the first stage the polystyrene resin beads are partially puffed or blown with heat. After an equilibration, the partially puffed or blown beads are puffed or blown again and molded.

Safety, Handling, and Disposal

- Safety goggles are required.
- Ethyl acetate is a flammable solvent. Avoid use of open flames or other sources of ignition when ethyl acetate is used.
- Review the MSDS of any chemical used in the experiment.
- Dispose of used reagent according to your teacher’s instructions. Collect used solvent and polymer in the bucket provided. Do not dump the waste water and ethyl acetate polymer solution down the drain. Dumping the experiment down the drain could plug the drain with polystyrene.

Materials

- goggles
- 100-mL graduated cylinder
- beaker or cut off 2-liter bottle (at least as tall as the graduated cylinder)
- (optional) detergent
- foamed polystyrene material to test
- Beral pipet
- ethyl acetate
- 10-mL graduated cylinder
- balance (± 0.001 g)
- water
- paper towels
- thermometer

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Procedure

1. If the foamed polystyrene pieces to be analyzed are too large to fit into the 100-mL graduated cylinder, cut or break the pieces. Nearly fill the dry cylinder with as much of the polystyrene product as possible. Carefully shake the foamed polystyrene pieces out of the cylinder being careful not to break the cylinder. Determine and record the mass of the foamed polystyrene.
2. Return the foamed polystyrene pieces to the cylinder and fill the cylinder with water. Be sure to keep all the polystyrene sample in the cylinder. Fill the cylinder to the top with water keeping all the foamed polystyrene submerged. This may be a bit difficult since the foamed polystyrene floats. A drop of detergent added to the water in the cylinder may lessen the air bubbles clinging to the sides of the foamed polystyrene pieces.
3. Fill the tall bottle or beaker about 3/4 full of water.
4. Wet a piece of paper towel and place it on top of the water and polystyrene filled cylinder. Using the wet paper towel to keep everything in the cylinder, quickly invert the cylinder and submerge the top in the large beaker or cut off 2-liter bottle. Try to have as small an air pocket in the top of the cylinder (when it is inverted) as possible. A diagram of the experimental assembly at this point is provided in Figure 1. Remove the wet paper towel once the top of the cylinder is submerged.

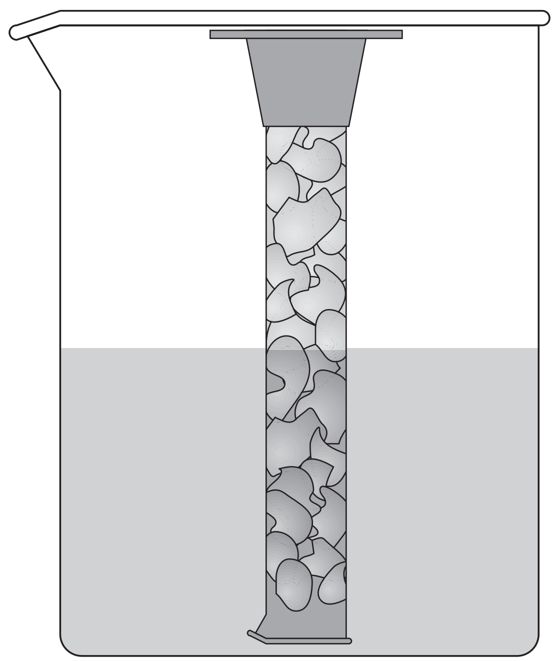

Figure 1: Fill the graduated cylinder with foamed polystyrene and invert it into a large beaker.

If there is a measurable amount of air in the cylinder at this point, you need to determine the volume of air. To do this, the liquid level in the cylinder and outside the cylinder (that is, in the beaker) must be at the same height. When the liquid level inside and outside the cylinder is at the same height, the air (gas) in the cylinder is at the same pressure as outside the cylinder, atmospheric pressure. You may need to alter the position of the cylinder and/or add more water to the beaker.

5. Pour a little more than 2 mL of ethyl acetate into the 10-mL graduated cylinder. Pull up 2 mL of ethyl acetate into the Beral pipet.
6. If the beaker or cut off 2-liter bottle was nearly filled with water to measure the air in the cylinder, some water may need to be poured out before proceeding. To do this, keep the cylinder inverted and allow no air to enter as you pour a little of the water out of the large beaker.
7. Position the Beral pipet such that the ethyl acetate is in the tube and bottom of the bulb. Place the end of the pipet into the large beaker such that the end is under the 100 mL graduated cylinder. The inverted cylinder may need to be lifted a little for this operation, but do not allow air to enter the inverted cylinder. See Figure 2.

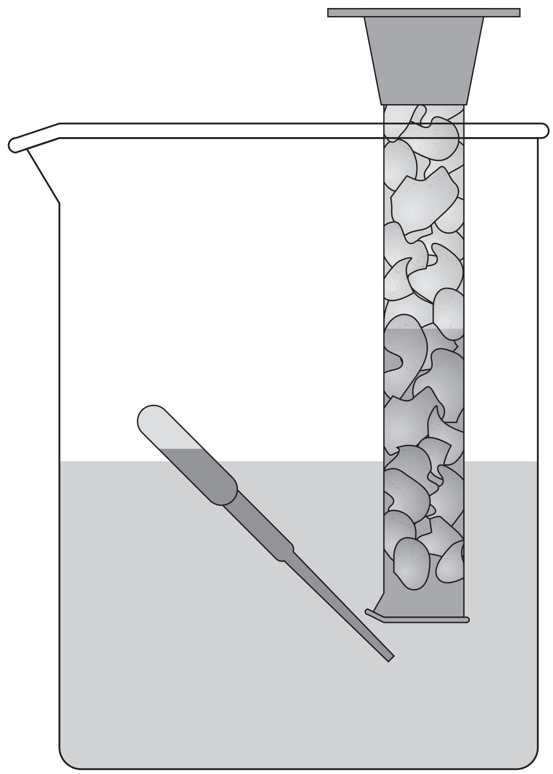

Figure 2: Place the delivery tube into the open end of the cylinder.

8. Squeeze the ethyl acetate out of the pipet and into the cylinder. Do not squeeze out air. Describe all the changes which occur.
9. When no more changes are observable, the volume of gas liberated can be measured. Again, the level of the liquid inside the cylinder must be at the same height as the water outside the cylinder in order for the gas inside the cylinder to be at atmospheric pressure. Be sure to use the height of the liquid in the cylinder, not the height of the polystyrene.
10. Measure room temperature.
11. When the cylinder is removed from the water, the ethyl acetate-polystyrene layer will float on the top of the water in the beaker. Dump the entire contents of the beaker in the waste bucket in the laboratory. **Do not dump the water and ethyl acetate with polystyrene down the drain. The drain will become plugged with plastic.**

12. In determining the volume of air in the foamed polystyrene, recall that the gas volume was measured over ethyl acetate at room temperature. The vapor pressure of ethyl acetate at room temperature is significant; its volatility is why an opened bottle of ethyl acetate can be detected by smell in the laboratory. As a first approximation, the boiling point of esters on a vapor pressure distillation nomograph can be consulted for the vapor pressure of ethyl acetate at room temperature and pressure.
13. Express the volume of air in the foamed polystyrene product per gram of polystyrene analyzed.

Questions

1. How “good” a determination of the amount of air in foamed polystyrene is this?
2. What would you need to know to express the volume of air as percent air in the foamed polystyrene product?
3. Describe another way to determine the air in foamed polystyrene products.
4. Why is, for example, pentane now used as the blowing agent rather the CFCs (chlorofluorocarbons) used previously?

Optional Experiment

Blowing Of Pentane Impregnated Polystyrene Resin

Materials

- 400-mL beaker
- (optional) food color
- water
- spatula
- pentane impregnated polystyrene resin
- hot plate

or, for alternate procedure,

- 125-mL Erlenmeyer Flask
- spatula
- pentane impregnated polystyrene resin
- loose fitting foil cap for the 125-mL flask or a stopper with a hole
- heat gun or hair dryer
- clamp, clamp holder and stand to hold the 125-mL flask

Procedure

1. Put about 200 mL of water in the 400-mL beaker. Place the beaker on the hot plate and allow the water to come to a boil. After the water reaches a boil, the heat may be turned down but the temperature should be maintained near the boiling point. (Food color may be added to the water for better visibility of what happens to the very small resin pieces.)
2. Use the spatula to place a small pea size amount of pentane impregnated polystyrene resin in the hot water. Record all of the physical changes observed.

3. After 5 to 10 minutes, turn off the heat and allow the beaker contents to cool. Dispose the polystyrene beads in the solid waste disposal, trash, or polystyrene recycling bin (if available), and dump only the water down the drain. **Again, do not dump plastic down the drain.**

Alternate Procedure

1. Clamp the 125-mL Erlenmeyer flask on the stand. Add a spatula tip, small pea sized amount of pentane impregnated polystyrene resin pellets into the empty flask. Place a loose foil cover on the flask, or place a stopper with a hole on the flask. (The purpose of the cover is to prevent the resin from flying out.)
2. Heat the dry resin in the flask with a heat gun or hair dryer, being careful to move (rotate) the hot air stream around the flask. **Do not heat only one spot of the flask making a very hot spot. Do not char the polystyrene onto the flask. When melting begins stop heating.** Record all the physical changes that you observe.
3. Allow the flask to cool. Discard the polystyrene into the solid waste disposal or trash, or, if possible, recycle it.

Question

1. What are the various physical changes observed in the above procedures?

Reference

Gordon, J.B. "Expandable foam molding," *The Modern Plastics Encyclopedia*; McGraw-Hill, 1985-1986, pp. 233-240.

III. INSTRUCTOR NOTES

How Much Air Is In Foamed Polystyrene Products?

Purpose

The purpose of this investigation is to determine how much air is in a foamed polystyrene material. In doing this, the hydrophobic nature of polystyrene will also be illustrated.

Time Required

One hour is sufficient for two determinations of the foamed polystyrene. The air is released quickly but students will need some time to figure out how to manipulate the cylinder and Beral pipet in the determination. Additional time is necessary for doing the calculations. The optional experiment of puffing or blowing the blowing agent impregnated polystyrene resin adds about thirty minutes to the experiment.

Group Size

Individual work is possible, however students might feel more comfortable working in pairs, such that one student is responsible for keeping the cylinder top submerged while the other student positions the open end of the Beral pipet with the ethyl acetate. Groups of more than two would have too much standing around.

Materials

- goggles
- 100-mL graduated cylinder
- tall beaker or cut off 2-liter bottle
- foamed polystyrene material to test (A variety of samples of foamed polystyrene products would add interest to this experiment. For example. foamed polystyrene coffee cups might be compared with packing peanuts, solid packing materials and foamed ice chests.)
- Beral pipet
- 10-mL graduated cylinder
- 2 mL ethyl acetate for each determination
- balance (± 0.001 g)
- water
- paper towels

Burners with an open flames should not be used in the first part of the experiment due to the use of ethyl acetate, a flammable solvent.

<u>Materials for Optional Investigations</u>

- 400-mL beaker
- (optional) food color
- water
- spatula
- hot plate (Burners with an open flames should not be used due to the use of ethyl acetate, a flammable solvent, in the first part of the experiment.)
- pentane impregnated polystyrene resin [Nova Chem (1-800-926-7479 for customer service) sells this resin under the trade name Dylite®. It comes in 1000 pound cartons which must be shipped as a hazardous material due to the flammability of the pentane. For a small sample, contact

Jennifer L. Autry, Technical Service Specialist, Dylite Advanced Styrenics Technology, NOVA Chemicals Inc., 400 Frankfort Road, Monaca, PA 15061; 724-770-5537; (FAX) 724-770-2489; autryje@novachem.com. You may also be able to locate a local user willing to provide a small sample.]

or, for alternate procedure

- 125-mL Erlenmeyer Flask
- spatula
- pentane impregnated polystyrene resin
- loose fitting foil cap for the 125-mL flask or a stopper with a hole
- heat gun or hair dryer
- clamp, clamp holder and stand to hold the 125-mL flask

Safety

- Students must wear safety goggles.
- Ethyl acetate is a flammable solvent. No open flames or other sources of ignition should be present when it is used. Use in a well ventilated area.
- Review the MSDS of any chemical used in the experiment.
- Dispose of used reagent according to local ordinances. Provide a bucket or other container to collect used solvent and polymer. Do not dump the waste water and ethyl acetate polymer solution down the drain. Dumping the experiment down the drain could plug the drain with polystyrene.

Points to Cover in Pre-Laboratory

- The idea of collecting a gas in a closed space and measuring it, should be discussed. In this case, the gas (air) is not released until the hydrophobic solvent ethyl acetate is added to the cylinder. The hydrophobic materials, ethyl acetate and polystyrene dissolve in each other, allowing the air trapped in the foamed polystyrene to be released and collected in the top of the cylinder.
- The volume measurement must be made at a constant (atmospheric) pressure so the water levels inside the cylinder and outside the cylinder must be level when the volume is determined. Students are responsible for subtracting initial air from the final air. The size of the corrections to the volume of air due to water vapor and ethyl acetate vapor should be discussed. The correction for water vapor is relatively small (included in classic textbook gas collection problems) but the contribution of ethyl acetate vapor is significant.
- The flammability of ethyl acetate should be mentioned even though it is not heated in this laboratory investigation.

Procedural Tips and Suggestions

- Working in pairs may allow for more comfort in measuring the gas, allowing one student to manipulate the cylinder and another to manipulate the end of the Beral pipet with the ethyl acetate.
- As an extension, students might try to determine the amount of air in the polystyrene by determining its volume foamed. Students could then heat their samples in an oven, a little above “shrinky plastic” temperatures. After allowing their samples to cool the “shrunk” defoamed volume could be determined. The length of time in the oven might be varied and the air volume by difference compared to that determined by directly measuring the gas released when the foamed product is defoamed by a solvent.
- The vapor pressure for ethyl acetate is 75 mm Hg at 20 °C, 94 mm Hg at 25 °C, and 100 mm Hg

at 27 °C. A vapor pressure–temperature nomograph can be found in "The Chemist's Companion" listed in the references.

- You may wish to put "The Encyclopedia of Modern Plastics" reference article in the library on reserve for your students.
- You may prefer to do the optional parts of the activity as a demonstration.

Sample Results

Using a foamed polystyrene coffee cup as the source material.

Data: volume of foamed polystyrene by water displacement: 4.4 mL
(note: very small air bubble present)
volume of gas measured after introduction of ethyl acetate: 3.6 mL
temperature: 20 °C
atmospheric pressure: 756 mm Hg
vapor pressure of ethyl acetate at 20 °C: 75 mm Hg

Calculations: P(air) = P(atm) – P(ethyl acetate) = 756 – 75 = 681 mm Hg
volume air = (3.6 mL) x (681 mm Hg/760 mm Hg) = 3.2 mL

%-by volume air = (3.2 mL/4.4 mL) x 100% = 73% air by volume

Note: Other samples of foamed polystyrene will probably have greater or lesser percentages of air by volume depending on their intended use. Coffee cups, for example, need to not leak and need to insulate.

Plausible Answers to Questions

1. How "good" a determination of the amount of air in foamed polystyrene is this?

A: Answers will vary depending on the ability to measure the initial volume of air in the cylinder. If detergent is used (so few bubbles cling to the foamed polystyrene pieces) and the top of the cylinder could be read to one place past the decimal (0.1 mL) rather than to the nearest milliliter, students may get reproducible and fairly accurate results. If students have difficulty manipulating the cylinder and Beral pipet containing the ethyl acetate under water, the results could be quite variable.

2. What would you need to know to express the volume of air as the percent air in the foamed polystyrene product?

A: Since the volume of air in the product was determined, the volume of the foamed polystyrene used would need to be determined. If the density of the foamed polystyrene product were known, the volume could be calculated since the mass of the product was measured prior to addition of the ethyl acetate. If the density is not known, the volume could be determined by water displacement.

3. Describe another way to determine the air in foamed polystyrene products.

A: The mass and volume of the foamed polystyrene could be measured, the mass on a balance and the volume by water displacement. The polystyrene sample could then be defoamed with a solvent such as ethyl acetate or acetone, the defoaming solvent evaporated, and the final volume again determined by water displacement. The difference in volume would be the volume of air in the sample. The mass should be determined to be constant. Alternatively, the foamed materials could be heated in an oven to allow the polystyrene to melt, cool, and again allow for a determination of the unfoamed volume by water displacement.

4. Why is, for example, pentane now used as the blowing agent rather the CFCs (chlorofluorocarbons) used previously?

A: CFCs have been implicated in the loss of the protective ozone layer from the upper atmosphere. The United States, along with other countries, has legislated against the use of CFCs as blowing agents.

Plausible Answer to Optional Question

1. What are the various physical changes observed in the above procedures?

A: At first the small beads changed appearance from nearly transparent and very small to a little larger and opaque. About 5 minutes later, the average size of the beads was significantly larger than that observed in the initial expansion. The delayed final expansion presumably is important in the second stage of molded foamed polystyrene manufacture and the first observed expansion is related to the first stage, the pre-puff stage. (Swelling of the polymer may also play a role in the observed behavior)

Extensions and Variations

- One extension, defoaming the foamed polystyrene with oven heat was previously mentioned as an answer to Question #3. It might be possible to structure the lab to allow students to try this. Is some residual air still trapped in samples treated with oven heat?

References

Gordon, A.J. and Ford, R.A. *The Chemist' Companion, A Handbook of Practical Data, Techniques, and References*, John Wiley & Sons, New York, 1992, p 34.

Gordon, J.B. "Expandable foam molding," *The Modern Plastics Encyclopedia*; McGraw-Hill, New York, NY, 1985-1986, pp. 233-240.

Lide, D.R. *Handbook of Organic Solvents*, "232. Ethyl Acetate," CRC Press, Inc., Boca Raton, 1995, p 207.