NOTE

Preparation and Potential Applications of Evacuated Closed-Cell Plastic Foams

DOUGLAS M. JEWETT
Division of Nuclear Medicine
University of Michigan Medical School
Ann Arbor, MI 48109-0552

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INTRODUCTION

Self-expanding, closed-cell plastic foams would have wide applicability as seals and cushions provided that such foams could be manufactured simply. Self-expanding polystyrene foam objects can be prepared by heating polystyrene microspheres containing blowing agents above their softening point [1,2]. This paper which describes a completely different approach, uses an evacuated closed-cell flexible foam as the intermediate. The method is, in principle, applicable to large monolithic foam objects (raising the possibility of interesting structural applications), as well as, seals and cushions. The diffusion of gases in and out of closed-cell foams has practical consequences for their fabrication and application as insulation; the theory has been developed [3]. One consequence of such diffusion is that it is possible, by placing a plastic foam object in a vacuum chamber for a sufficiently long time, to obtain an evacuated foam. Some experiments which demonstrate the preparation and useful properties of some evacuated foams are described.

PREPARATION OF EVACUATED FOAMS

Segments of a closed-cell, foamed polyethylene "rope" (Dow Etha-

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foam: 10 mm and 20 mm diameters) were placed in a chamber that was rapidly evacuated to a pressure of 5–10 mm Hg. During the evacuation the segments of foam initially expanded in diameter by several percent because of the pressure differential, but rapidly relaxed to approximately their original dimensions as gas diffused out. No further changes were apparent while the vacuum was maintained for 72 h. When the chamber was filled with air, or other gas (1 atm), the segments immediately collapsed to about 20% of their original volume. However, over the course of a week or more, depending on the ambient gas, the segments expanded again to very nearly their original dimensions. Figure 1 shows the dimensional recovery in air of two cylindrical

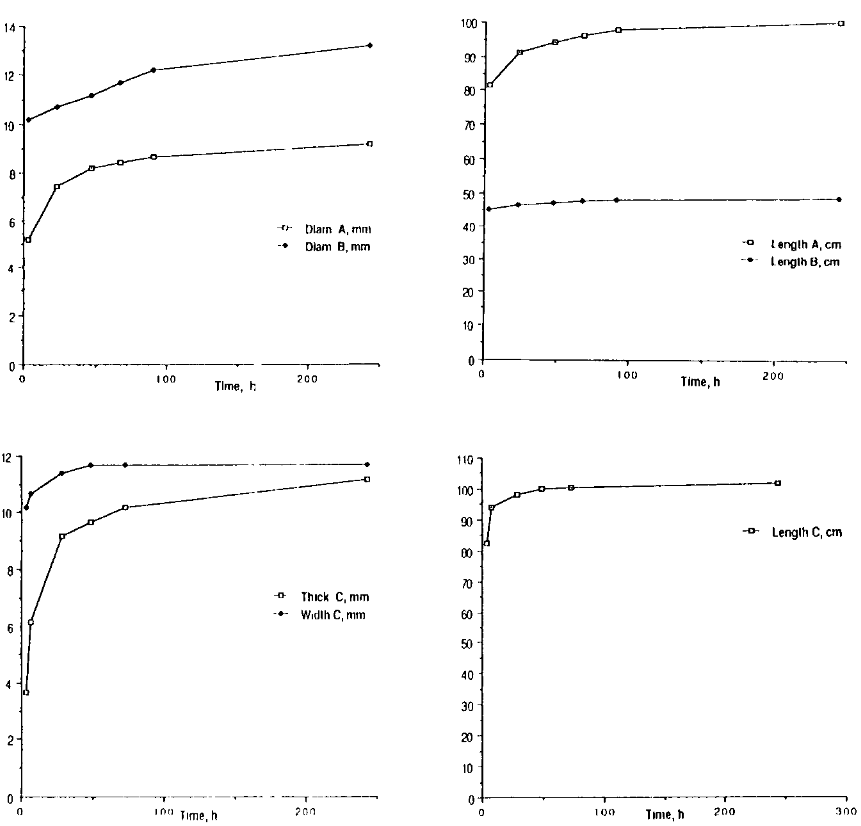

Figure 1. Dimensional recovery in air of evacuated, collapsed elastomeric foams. Specimen A: 10 mm diam. × 100 cm polyethylene foam rope; Specimen B: 20 mm diam. × 50 cm polyethylene foam rope; Specimen C: 11 mm × 12 mm × 100 cm rectangular vinyl foam strip.

polyethylene foam segments and a vinyl foam of rectangular cross section. Of interest is the marked dimensional anisotropy in the collapse and recovery of the foam samples.

The rate of dimensional recovery varied markedly with the ambient gas, requiring several days for oxygen or nitrogen; but only hours for helium, hydrogen, light hydrocarbons, ammonia, and carbon dioxide—with Freon-11, only a few minutes were required. The apparent weight changes of polyethylene foams exchanged with a variety of gases were as follows (%, relative to the original air-filled foam): hydrogen, −2.4; helium, −2.0; methane, −1.0; ammonia, −0.9; evacuated and collapsed, −0.5; oxygen, +0.3; carbon dioxide, +1.4; propane, +1.5; butane, +4.7; Freon 22, +6.5; Freon 12, +8.3. For foams where the diffusivity of the exchanged gas was high, the weights changed rapidly during weighing.

When the same procedures were performed with a more rigid foam (expanded closed-cell polystyrene), the dimensional changes were much less marked. However, by weighing such foams that had been exposed to a vacuum and then to different ambient gases, it was demonstrated that the same process of evacuation and gas exchange had occurred.

POTENTIAL APPLICATIONS OF EVACUATED FOAMS

There are several technological implications of this set of observations. First, the installation of thermal insulation, seals, and cushions in existing structures can be simplified, provided that time is available to allow for dimensional recovery of evacuated, collapsed foams. A poorly fitting storm window was, in fact, the original motivation for these investigations. The anisotropy with respect to dimensional change of a foam object can be predicted. It should be possible to design shapes and cross sections that will collapse and expand in predictable ways. The marked cross sectional change of foam ropes and strips relative to the change in length simplifies their use in the sealing of cracks and linear spaces in existing structures.

A simple, general approach to incorporating foam seals as integral parts of structures is indicated in Figure 2. In this case the expanded foam holds the window in place, but allows it to be removed if necessary by cutting through the seal with a thin blade.

More generally, there are a large number of assembly problems, exemplified by a model ship in a bottle, where it would be desirable to have a structural element move or expand after assembly of a system. The use of closed-cell foams as structural aneroids confers reversibility. Provided that the assembled structure can be placed in a vacuum

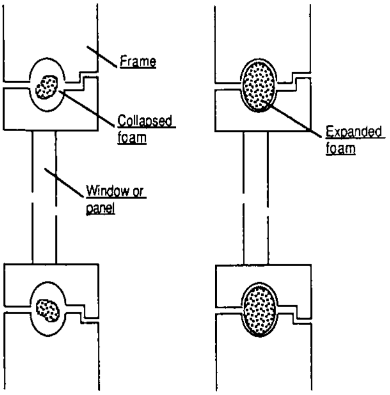

Figure 2. Self-expanding foam seal for window or panel.

chamber, the foam elements can be evacuated and collapsed *in situ* to permit disassembly. An interesting class of possible applications exists with respect to reentering space vehicles. Closed-cell plastic foamed structural elements would retain their shape in the vacuum of space while becoming evacuated over the course of a few days. Upon reentering the atmosphere, the foams would collapse in a controlled way.

POTENTIAL APPLICATIONS OF GAS-EXCHANGED FOAMS

While evacuation is not a necessary step in the preparation of a gas-exchanged foam, it provides an efficient means of achieving such exchange. Foamed objects offer an efficient means of dispersing gaseous chemicals in temporal or spatial patterns not economically accessible in other ways. Foamed pellets containing a fumigant, such as methyl bromide, could be poured through openings in buildings. Environmental tracers such as tritium or sulfur hexafluoride could be dispersed from aircraft. As an experiment, polyethylene foam rope segments were evacuated, exchanged with ethylene and place in bags with carnations or green bananas. The fruits and flowers so treated showed enhanced senescence or ripening.

An area of potential economic significance is the modification of evacuated foams by treatment with reactive gases. It is known, for example, that polyethylene can be treated with fluorine gas to convert it to a fluoropolymer resembling Teflon. Direct fluorination of closed-cell foamed objects would be capable of producing materials not accessible by conventional routes. Evacuation of the foams would allow faster, more efficient use of fluorine or other reactive gases. In preliminary experiments in which evacuated polyethylene foams were exposed to 10% fluorine in helium, the fluorine was taken up and HF was evolved as expected. Foams treated by one cycle of evacuation showed only a slight increase in weight and were still flammable, indicating that cyclic evacuation and fluorine diffusion would be necessary for substantial fluorination.

The differential gas permeability of polymeric closed-cell foams offers a novel way of separating gases. Each foam cell element provides a separate permeable membrane, so that high spatial efficiencies may be possible in spite of less than ideal geometry and speed. As a demonstration, a 4 × 100 cm glass tube was filled with 3 mm expanded polystyrene beads, sealed with stoppers and evacuated for 72 h. Then a mixture of 35% CO_2 in N_2 was introduced at one end to a pressure of 1 atm. A sample drawn immediately from the other end of the tube contained only 10% CO_2.

Evacuated polyethylene foam rope segments maintained under water for several days in an open vessel gradually recovered their original dimensions. The ability of evacuated foams to extract oxygen or other dissolved gases from water may find application in submarine vessels or habitats.

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BIOGRAPHICAL NOTE:

Douglas Jewett is an Assistant Professor with the Division of Nuclear Medicine, University of Michigan, where he is responsible for developing new processes and machines for labeling radiopharmaceuticals with short-lived, positron-emitting isotopes.