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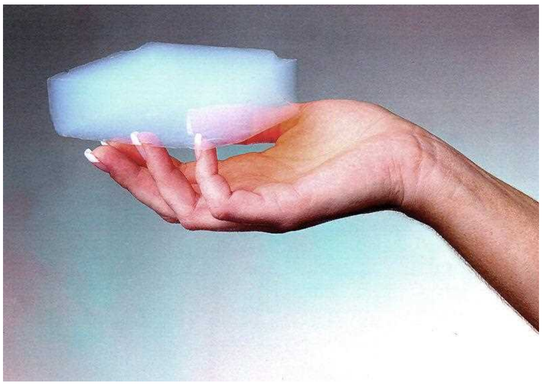

Frozen smoke prevents global warming

Global warming is one of the major problems facing humanity today. According to the IPCC's 2018 report, if the global average temperature keeps rising at the same speed, temperature increases will reach 1.5 degrees Celsius by 2050 [1]. It is important to reduce energy consumption in order to reduce carbon dioxide emissions, which is the main cause of global warming. Not surprisingly, air conditioning accounts for a non-negligible portion of energy consumption. Indeed, air conditioning accounts for roughly 33% of the University of Tokyo's all electricity consumption [2]. Global warming itself encourages the use of air conditioners, which in turn promotes energy consumption. In order to reduce energy consumption, it is necessary to save energy on air conditioning. Using highly insulating materials inside buildings' walls or windows is a promised way to reduce the cost of air conditioning. Aerogel, also known as "frozen smoke" from its pale, transparent appearance, could be the solution to this problem.

In 1931, Kistler at Stanford University tested a hypothesis that the liquid in jelly can be replaced by air, and he succeeded in producing such a substance called aerogel [3]. The jelly can be any jelly, from silicone gel to coffee jelly, which you can buy at a supermarket. Silicone gel is the most common choice. A typical aerogel is pale, transparent and more than 95 % of its volume is air, and its density is only about 0.02 g/cm^3 [4]. It shows very high thermal insulation ability, with a thermal conductivity (a value that indicates how easily heat is transmitted) that is only about 1/3 that of glass wool, which is often used as a heat insulator in buildings. Furthermore, since aerogel is highly permeable, it can be used as windows with very high thermal insulation performance. In this way, aerogel has excellent properties as a thermal insulator for buildings.

How can we replace the liquid in the jelly with air? The easiest way is just to leave the jelly in the air and let it dry naturally. However, this does not work. As the liquid in the jelly evaporates, some areas of the jelly still contain liquid, and others are replaced by gas. A force called capillary force acts on the boundary between the gas region and the liquid region. This localized force exerts the gel skeleton and deforms the whole structure. When all the liquid evaporates, jelly becomes xerogel, which is a jelly shrunk to about one-tenth of its original size. Therefore, natural drying will not work. The solution lies in a technique called supercritical drying. In general, materials change between three phases, solid, liquid, and gas, depending on exposed pressure and temperature. The change across these phases is called a phase transition. In a region where the temperature and pressure are sufficiently high, there exists a state where there is no distinction between liquid and gas, called supercritical fluid. Since no phase transition occurs in the change from liquid to supercritical fluid and from supercritical fluid to gas, you can change from liquid to gas without causing a phase transition by going through supercritical fluid. Using this technique, we can change the liquid in the jelly to gas without changing the structure. First, replace the liquid in jelly with a solvent by just dipping. Next, put the jelly into a pressurized liquid of carbon dioxide. Now we increase the temperature of the carbon dioxide to make it a supercritical fluid, and then decrease pressure to make it a gas. In this way, the liquid of jelly can be replaced by gas, and aerogel is produced [4].

Aerogel's high insulation property and pale appearance come from physics. The heat-insulating property can be explained by the narrowness of the mesh structure. The collision of gas molecules scatters heat. The mesh structure of the gel is shorter than the mean free path, which is the average distance that gas molecules collide. This makes it difficult for the gas inside the aerogel to transfer heat, giving its high thermal insulation ability. The pale appearance of aerogel is due to a phenomenon called Rayleigh scattering, the same mechanism that makes the sky blue. Rayleigh scattering is a phenomenon in which the scattering intensity of light is inversely proportional to the fourth power of its wavelength when the size of the particle is smaller than the wavelength. The skeleton of the gel is smaller than the wavelength of light, so lights with shorter wavelength such as blue light, the more strongly it is scattered, resulting in a bluish appearance.

Although aerogel has very high thermal insulation and transparency, it has some drawbacks. Though aerogel can withstand intense pressure, it is vulnerable to localized impact and breaks easily. Also, the cost of supercritical drying makes aerogel so expensive that 10cc aerogel costs one dollar. For this reason, it is rarely used as an insulating material in houses for now. However, various researches have been actively conducting to enhance durability and reduce manufacturing costs. Nowadays, in addition to being used as a heat insulator, there is also research on using it as a direct carbon dioxide absorber [5]. Furthermore, because of its transparency, a device that cools an object without using electricity has been proposed by using the object's thermal radiation (a phenomenon in which heat is lost by emitting electromagnetic waves) [6]. I hope that with future technological development, the "frozen smoke" will cool the earth.

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[4] Aerogel.Org » How Is Aerogel Made? http://www.aerogel.org/?p=4. Accessed 27 May 2021.
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