

Replacing Food Refrigeration with Food Storage Under High Pressure: A CO₂-Saver?

Geoff Graham

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Food must be refrigerated, but refrigeration emits massive amounts of CO₂. Storing food under high pressure could replace refrigeration and greatly lower CO₂ emissions, but the pressures needed are too high. Molecular biology might lower those pressures by 50-fold.

The need to reduce CO₂ emissions

Society must use less fossil fuel in order to limit CO₂ emissions. Every passing year that we exceed our emissions targets increases the danger that rising temperatures will irreversibly harm our biosphere.

Unfortunately, restrictions on fossil fuel production drive up the cost of energy; hence, times of energy shortage are also times of wealth shortage. This causes hardship and undermines public support for fossil fuel restrictions. Worse, it threatens us with a replay of the 1970s and 1980s, when capital shortages weakened efforts to transition to non-hydrocarbon energy. The big corporations that were supposed to be incentivized to invest in non-fossil fuel energy instead had too great a need for capital in other parts of their organizations. They were like starving elephants: big, but weak.

If we cannot quickly produce adequate non-hydrocarbon energy, could we instead reduce our demand for energy? And could we do it without curtailing goods and services? I believe that we can, and in this and several coming postings at this website, I will suggest ways to do that.

The cold chain and its replacements

Food should be kept cold from the time it is butchered/harvested until shortly before it is consumed. The set of arrangements to refrigerate food are collectively called the “cold chain.” About 1% of society’s CO₂ emissions result from maintaining cold chains. This percentage seems likely to increase because the environment is warming. Moreover, as of 2012, only 10% of the world’s perishable food was refrigerated, and 30% of the world's food supply was lost as a result. The lost food amounts to about 200 million tons, all of which required CO₂ emission to grow and harvest.

There are many traditional (canning, salting, smoking, drying) and novel (cold plasma, ultrasound, pulsed electric fields) alternatives to refrigeration. However, the most promising alternative is treatment and storage of food under high hydrostatic pressure.

The Alvin incident

In 1968, edible food was recovered from the research submarine Alvin, which had been sunk for 10 months in the ocean at a depth of 1540 meters. Sandwiches, bouillon, and apples, which had been maintained at a temperature of 3-4 °C and a pressure of 15 megapascals (148 atmospheres), were practically untouched by decay when retrieved. However, when they were later kept under refrigeration at atmospheric pressure, they were spoiled in a few weeks. Hence, high hydrostatic pressures can contribute to food preservation.

Advantages and disadvantages of high-pressure food storage

The main advantage of high pressure as a method of storing food is that it costs relatively little energy. One study concluded that the cost in energy to preserve fruit juice for a period of 2 weeks was 1/26 the cost of refrigeration.

High pressure also preserves flavors and nutrients that canning or other heat treatments would destroy. In addition, pressure rises quickly and evenly through most foods. In this, pressure treatment has an advantage over heating, drying, cold plasma, and so on.

The main disadvantage of high-pressure food storage is that enormous pressures are usually required. Bacterial spores stoutly resist high hydrostatic pressure, and pressures as high as 1200 megapascals (11,843 atmospheres or 174,045 pounds per square inch) may be needed to kill them. The deep-sea bacterium *Shewanella* is a normal component of the surface flora of fish and contributes to fish spoilage but

also resists very high pressures. Further, although some strains of bacteria are very sensitive to high pressure, closely related strains may resist much higher pressures, suggesting that pressure-sensitive strains might become more resistant to pressure under selection.

The equipment needed to subject foods to high pressure is expensive. In poorer parts of the world, the food throughput of affordable pressurization equipment is likely to be meager. Moreover, it would be difficult if not impossible to transport large quantities of food around a country in containers holding food at thousands of atmospheres of pressure.

It is true that use of pulsed pressures can mitigate some of these problems. Pulses of high pressure reduce the microbial content of foods by many orders of magnitude. However, the microbes are not eliminated and eventually grow back. For pressure to replace refrigeration in the storage and transport of food, it will probably have to be applied continuously.

The causes and prevention of food spoilage

The two most important causes of food spoilage are microbial action and the activity of enzymes that are endogenous to the food. These—along with unwanted humidity, damage by oxygen, and the action of light—account for most food deterioration.

Enzymes are proteins that transform one molecule or macromolecule into another. Some endogenous enzymes have a measurable effect on bulk substances present in food. Enzymes cause the ripening process in fruits and vegetables. They cause texture, color, and flavor changes. For example, as a banana turns from green to yellow to brown, not only does the color change, but there is also a change in the fruit's texture. The enzymes of respiration (oxygen use by tissues) are major contributors to food spoilage.

Both microbes and enzymes can be inactivated by sufficiently high pressures but, as noted above, the pressures needed are impractically large. Fortunately, molecular biology may be able to reduce the pressures needed, perhaps by as much as 50-fold.

Biological stresses have additive effects

Life can exist only where environmental conditions permit it to. Moreover, among permissive conditions, only some conditions are optimal, allowing organisms to grow and reproduce unimpeded. We can define a “stress” as any deviation from optimal conditions for a given organism that imposes significant

difficulties that the organism must overcome. Stresses might include temperatures that are so low or so high that the organism must struggle to thrive, non-optimal pH values of the environment, very high or very low environmental salinity, the presence of chemical toxins or harmful radiation, scarcity of nutrients, etc.

In most cases, biological stresses are loosely additive. For example, if an environment is too acidic and too saline, a given microbe will be unable to survive and grow, even if it could survive and grow at the same acidity and benign salinity, or at the same salinity but a benign acidity.

Combinations of stresses that show this additive effect include heat+high pressure, gamma rays+high pressure, gamma rays+heat, high pressure+alternating electric current and high pressure+ultrasound. More examples include heat+potassium sorbate, heat+sodium benzoate, heat+acidity+potassium sorbate, heat+acidity+sodium benzoate, acidity+propionate, high pressure+acidity, and various combinations of antibiotics.

In at least some cases, combinations of stresses also have an additive effect in suppressing enzyme activity. Such combinations include high pressure+CO₂ gas, high pressure+CO₂+heat, and high pressure+citric acid.

These results suggest that combining high hydrostatic pressure with one or more additional stresses might reduce the pressure needed to preserve food. If such a reduction were large enough, preservation of food by high pressure might become practical. However, stressors that could permeate the food and not adversely affect its taste, texture, and smell would be required.

Proteins and peptides

The most promising food additives to maximize the killing effects of high pressure are proteins and peptides. Proteins and peptides are chains of amino acids. Chains of between 2 to about 50 amino acids are usually referred to as peptides, while longer chains are termed proteins. Although the presence of some proteins or peptides in food might give food an unpleasant taste, foods such as meat and eggs are protein-rich but appetizing. Thus, protein or peptide additives to food might not spoil the food's taste, smell, or texture. A number of classes of proteins or peptides are good candidates to inactivate microbes in food.

Lysozyme is an enzyme present in a wide assortment of living things, including egg whites and milk; hence, lysozyme does not necessarily spoil the taste of foods. Lysozyme degrades the cell walls of bacteria. However, inactivated lysozyme, which cannot degrade bacterial cell walls, nevertheless kills bacteria, indicating that it has some poorly understood second antibacterial activity. Since some lysozymes are components of foods, their use is more likely to gain regulatory

approval. The combination of high pressure and lysozyme kills most tested bacteria. Gram-positive bacteria are more resistant to high pressure than are Gram-negative bacteria but are more sensitive to lysozyme.

Common crop plants (e.g., corn) produce several antimicrobial enzymes, some of which target the fungi that parasitize crops. ***Chitinase*** degrades the cell walls of fungi. ***Ribosome-inactivating protein*** inhibits fungal ribosomes but not the ribosomes of the host plant. ***Zeamatin*** seems to make permeable the cell walls of fungi. Because these enzymes are present in common foods, they are more likely to be approved by regulators.

Bacteriophages are viruses that invade and lyse bacteria. Most bacteriophages infect only a single species of bacterium and, in some cases, only a subset of strains within that species. In order to escape from a parasitized bacterium whose resources have been exhausted, bacteriophages produce ***lysins***. Lysins are enzymes that are released within the infected bacteria and degrade the bacterial walls from the inside.

Lysins can also degrade bacterial cell walls from the outside. Gram-positive bacteria are more susceptible to this than are Gram-negative bacteria because Gram-negative bacteria are shielded by an outer membrane. Lysins are extremely effective killers of susceptible Gram-positive bacteria. Gram-positive bacteria on average resist higher pressures than do Gram-negative bacteria, and lysins are a potent remedy for this extra resistance.

Bacteriocins are toxins that bacteria use to kill similar or closely related bacterial strains. Because they are toxic to a limited range of bacteria, many bacteriocins might be used to preserve foods without the danger of killing the consumer's intestinal bacteria.

Peptides, as mentioned above, are chains of between 2 and 50 or so amino acids. ***Antimicrobial peptides*** are a huge class of peptides that exist in nature, created by most cellular organisms. Thousands have already been described and many thousands more exist. Antimicrobial peptides are known that can kill viruses, bacteria, fungi, trypanosomes, malaria parasites, and so on.

In one way, antimicrobial peptides are good candidates for use as food preservatives because they are quickly degraded by proteases within the human body. However, antimicrobial peptides have one potentially serious drawback. Antimicrobial peptides are an important part of the innate immune systems of humans and animals. If antimicrobial peptides are misused or overused in the way that classical antibiotics have been, microbial pathogens may become resistant to them and may also become resistant to natural human defenses. This will happen if

resistance to one antimicrobial peptide confers resistance to an entire class of related peptides.

A small number of antimicrobial peptides have already been approved as food additives.

Biochemicals

Many, probably most, microorganisms produce biochemical signals with which they communicate with other members of their species, with members of other species, or (in the case of large fungal colonies) with themselves. These signals can prevent spores from germinating, can attract or repel growth along a signal gradient, and can suppress unwanted activities such as toxin production.

It is not clear whether these biochemical signals would affect the taste and odor of food. Some of them are unstable or volatile and might be destroyed or driven off by a short period of heating before food was served. However, even if this is unrealistic, these signals act by activating receptors on the target microbe; if peptide mimics could be devised that activated the same receptors, they might be useful in preserving foods.

Spices are pungent biochemicals extracted from plants. Essential oils are oils extracted from plants. Both tend to inhibit or kill microbial parasites. In many cases, combinations of these substances have roughly additive antimicrobial activity and are made more effective when present with other stresses such as salt, nitrate ions, acidity, or high pressure. Spices and essential oils are more effective when used together.

So far, research on the preservative uses of spices and essential oils has concentrated on substances derived from plants that are widely consumed and are Generally Recognized As Safe (GRAS). This avoids regulatory scrutiny, and regulatory scrutiny of non-GRAS essential oils is merited because some essential oils are clearly unsafe. A review published in 2004 noted that over 3000 essential oils are known, of which about 300 are economically important. However, most of these essential oils are mixtures of chemical species, and the number of distinct pure oils involved is probably much less than 3000. If society is serious about using high pressure to preserve foods, we may have to search for safe, flavorless essential oils from among inedible plants.

Retarding enzyme action

As mentioned above, action of endogenous enzymes can spoil food even in the absence of microbial action. Although high hydrostatic pressure can inactivate such enzymes, the pressures required are often enormous. They can be higher than 900 megapascals (130,500 pounds per square inch).

It may be possible to genetically engineer the endogenous enzymes of interest to become much more vulnerable to relatively low pressures. There may be multiple ways to do this, but the classic method is to create a hydrophobic pocket deep within the enzyme of interest. The 20 amino acid types present in proteins include 8 that are hydrophobic (water-repellant), 6 that are hydrophilic (water-attracting) and 6 that are neutral. Although proteins are chains of amino acids, properly folded proteins generally consist of a hydrophobic core surrounded by a hydrophilic shell which interacts with water and ions in living tissue or aqueous solution. If the amino acid sequence of a natural protein is altered such that a hydrophobic cavity exists deep within the protein, hydrostatic pressure may cause the protein to unfold in order to minimize its total volume. This, of course, will inactivate the protein. With effort and ingenuity, it might be possible to lower the required pressure to about 5 atmospheres. Ingenuity might be needed because cells can recognize and remove disordered proteins and the modified enzymes might trigger this removal system even at normal pressures.

Pressure-dependent enzymes

It might also be possible to discover or create enzymes that function only at high hydrostatic pressures. This could allow genetic engineers or food processors to add antimicrobial enzymes to pressurized food that would otherwise be too harsh because they would injure the consumer or the consumer's intestinal microflora or the engineered food organism.

Pressure-dependent variants of known enzymes could probably be created de novo, with effort, but there may be an easier way. Some enzymes from deep sea organisms can not only withstand high pressures but depend on such pressures.

It might be possible to use these deep-sea enzymes directly in food. However, a more likely prospect is that they could guide protein engineers in the modification of existing, well-characterized enzymes to pressure-dependence.

Sources of high hydrostatic pressure

Some coastal communities might be able to store food in the deep sea. As with the submarine Alvin mentioned above, people on islands or continental seacoasts

with access to deep, cold ocean water might be able to use that water to preserve food.

In addition, one method of storing renewable energy involves lifting very heavy weights against the Earth's gravity and allowing the weights to return to the ground while turning an electricity [generator](#). If there were times when one or more of those heavy weights were lying on the ground, the weights might provide the pressure needed to inactivate the microbes and enzymes within foods. This ability to perform this service might increase the value of energy storage machinery and make the economics of renewable energy storage more favorable. When energy reserves were high, an electric compressor could be used to pressurize food; when energy reserves were low, the heavy weights could be used.

References

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