A Solar Ammonia Absorption Icemaker

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Above: Steven Vanek with his machine which uses solar thermal energy to make ice.

Everywhere in our world, refrigeration is a major energy user. In poor areas, "off-grid" refrigeration is a critically important need. Both of these considerations point the way toward refrigeration using renewable energy, as part of a sustainable way of life. Solar-powered refrigeration is a real and exciting possibility.

Working with the S.T.E.V.E.N. Foundation (Solar Technology and Energy for Vital Economic Needs), we developed a simple ice making system using ammonia as a refrigerant. A prototype of this system is currently operating at SIFAT (Servants in Faith and Technology), a leadership and technology training center in Lineville, Alabama. An icemaker like this could be used to refrigerate vaccines, meat, dairy products, or vegetables. We hope this refrigeration system will be a cost-effective way to address the worldwide need for refrigeration. This icemaker uses free solar energy, few moving parts, and no batteries!

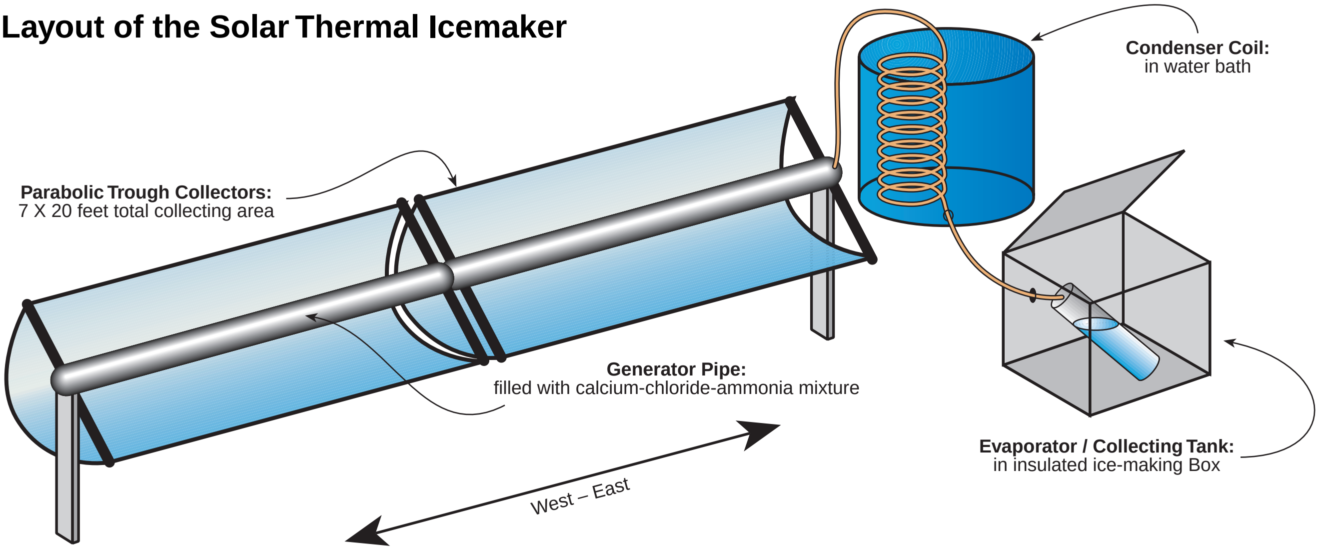
Types of Refrigeration

Refrigeration may seem complicated, but it can be reduced to a simple strategy: By some means, coax a refrigerant, a material that evaporates and boils at a low temperature, into a pure liquid state. Then, let's say you need some cold (thermodynamics would say you need to absorb some heat). Letting the refrigerant evaporate absorbs heat, just as your evaporating sweat absorbs body heat on a hot summer day. Since refrigerants boil at a low temperature, they continue to evaporate profusely — thus refrigerating — even when the milk or vaccines or whatever is already cool. That's all there is to it. The rest is details.

One of these details is how the liquid refrigerant is produced. Mechanically driven refrigerators, such as typical electric kitchen fridges, use a compressor to force the refrigerant freon into a liquid state.

Heat-driven refrigerators, like propane-fueled units and our icemaker, boil the refrigerant out of an absorbent material and condense the gaseous refrigerant to a liquid. This is called generation, and it's very similar to

Layout of the Solar Thermal Icemaker



the way grain alcohol is purified through distillation. After the generation process, the liquefied refrigerant evaporates as it is re-absorbed by an absorbent material. Absorbent materials are materials which have a strong chemical attraction for the refrigerant.

This process can be clarified using an analogy: it is like squeezing out a sponge (the absorbent material) soaked with the refrigerant. Instead of actually squeezing the sponge, heat is used. Then, when the sponge cools and becomes "thirsty" again, it reabsorbs the refrigerant in gas form. As it is absorbed, the refrigerant evaporates and absorbs heat: refrigeration!

In an ammonia absorption refrigerator, ammonia is the refrigerant. Continuously cycling ammonia refrigerators, such as commercial propane-fueled systems, generally use water as the absorbent, and provide continuous cooling action.

The S.T.E.V.E.N. Solar Icemaker

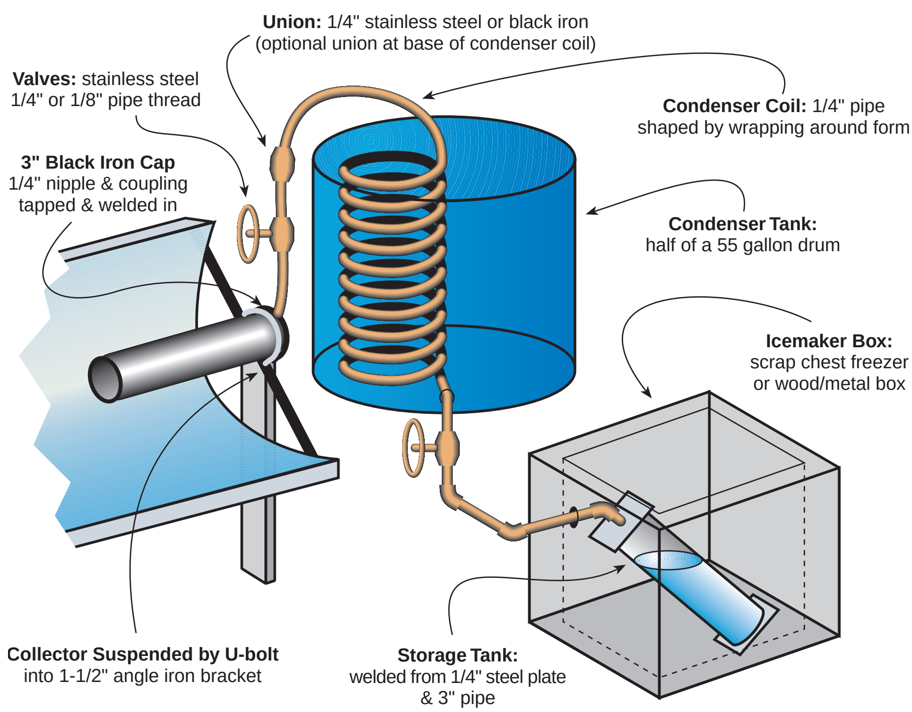
We call our current design an icemaker. It's not a true refrigerator because the refrigeration happens in intermittent cycles, which fit the cycle of available solar energy from day to night. Intermittent absorption systems can use a salt instead of water as the absorbent material. This has distinct advantages in that the salt doesn't evaporate with the water during heating, a problem encountered with water as the absorber.

Our intermittent absorption solar icemaker uses calcium chloride salt as the absorber and pure ammonia as the refrigerant. These materials are comparatively easy to obtain. Ammonia is available on order from gas suppliers and calcium chloride can be bought in the winter as an ice melter.

The plumbing of the icemaker can be divided into three parts: a generator for heating the salt-ammonia mixture, a condenser coil, and an evaporator, where distilled ammonia collects during generation. Ammonia flows back and forth between the generator and evaporator.

Plumbing Detail

All plumbing is ungalvanized steel (black iron) unless indicated



Above: Detail of the condenser bath, containing the condenser coil, and the icemaker box below.

The generator is a three-inch non-galvanized steel pipe positioned at the focus of a parabolic trough collector. The generator is oriented east-west, so that only seasonal and not daily tracking of the collector is required. During construction, calcium chloride is placed in the generator, which is then capped closed. Pure (anhydrous) ammonia obtained in a pressurized tank is allowed to evaporate through a valve into the generator and is absorbed by the salt molecules, forming a calcium chloride-ammonia solution ($CaCl_2$ - $8NH_3$).

The generator is connected to a condenser made from a coiled 21 foot length of non-galvanized, quarter-inch pipe (rated at 2000 psi). The coil is immersed in a water bath for cooling. The condenser pipe descends to the evaporator/collecting tank, situated in an insulated box where ice is produced.

Operation

The icemaker operates in a day/night cycle, generating distilled ammonia during the daytime and reabsorbing it at night. Ammonia boils out of the generator as a hot gas at about 200 psi pressure. The gas condenses in the condenser coil and drips down into the storage tank where, ideally, 3/4 of the absorbed ammonia collects by the end of the day (at 250 degrees Fahrenheit, six of the eight ammonia molecules bound to each salt molecule are available).

As the generator cools, the night cycle begins. The calcium chloride reabsorbs ammonia gas, pulling it back through the condenser coil as it evaporates out of the tank in the insulated box. The evaporation of the ammonia removes large quantities of heat from the collector tank and the water surrounding it. How much heat a given refrigerant will absorb depends on its "heat of vaporization," — the amount of energy required to evaporate a certain amount of that refrigerant. Few materials come close to the heat of vaporization of water. We lucky humans get to use water as our evaporative refrigerant in sweat. Ammonia comes close with a heat of vaporization 3/5 that of water.

Above: About ten pounds of ice are created in one cycle of ammonia evaporation / condensation.

During the night cycle, all of the liquefied ammonia evaporates from the tank. Water in bags around the tank turns to ice. In the morning the ice is removed and replaced with new water for the next cycle. The ice harvesting and water replacement are the only tasks of the operator. The ice can either be sold as a commercial product, or used in a cooler or old-style ice-box refrigerator.

Under good sun, the collector gathers enough energy to complete a generating cycle in far less than a day, about three hours. This allows the icemaker to work well on hazy or partly cloudy days. Once generating has finished, the collector can be covered from the sun. The generator will cool enough to induce the night cycle and start the ice making process during the day.

Solar Ice Maker: Materials and Costs

Quan	*Material*	*Cost*
4	Sheets galvanized metal, 26 ga.	$100
1	3" Black Iron Pipe, 21' length	$75
120	Sq. Ft. Mirror Plastic @$0.50/sq. ft.	$60
2	1/4" Stainless Steel Valves	$50
	Evaporator/Tank (4" pipe)	$40
	Freezer Box (free if scavenged)	$40
1	Sheet 3/4" plywood	$20
6	2x4s, 10 ft long	$20
	Miscellaneous 1/4" plumbing	$20
2	3" caps	$15
1	1/4" Black Iron Pipe, 21' length	$15
4	78" long 1.5" angle iron supports	$15
	Other hardware	$15
15	Lbs. Ammonia @ $1/lb	$15
10	Lbs. Calcium Chloride @ $1/lb	$10
	Total	$510

Future Design

A refrigerator, which is able to absorb heat at any time from its contents, is more convenient than our current intermittent icemaker. To enable constant operation, a future design will include several generator pipes in staggered operation as well as a reservoir for distilled ammonia. Staggered operation will allow the refrigerator to always have one or more of the generators “thirsty” and ready to absorb ammonia, even during the day when generation is simultaneously happening. Generation will constantly replenish the supply of ammonia in the storage reservoir. We are currently in the first stages of making these modifications to the icemaker.

Caution: Safety First!

Working with pure ammonia can be dangerous if safety precautions are not taken. Pure ammonia is poisonous if inhaled in high enough concentrations, causing burning eyes, nose, and throat, blindness, and worse. Since water combines readily with ammonia, a supply of water (garden hose or other) should always be on hand in the event of a large leak. Our current unit is a prototype. We will not place it inside a dwelling until certain of its safety. Unlike some poisonous gases, ammonia has the advantage that the tiniest amount is readily detectable by its strong odor. It doesn’t sneak up on you!

For the longevity of the system, materials in contact with ammonia in the icemaker must resist corrosion. Our unit is built with non-galvanized steel plumbing and stainless steel valves, since these two metals are not corroded by ammonia. In addition, during operation the pressure in the system can go over 200 psi. All the plumbing must be able to withstand these pressures without leaks or ruptures.

Would-be solar icemaker builders are cautioned to seek technical assistance when experimenting with ammonia absorption systems.

Conclusion

The S.T.E.V.E.N. icemaker has both advantages and disadvantages. On the down side, it’s somewhat bulky and non-portable, and requires some special plumbing parts. It requires a poisonous gas, albeit one which is eco- and ozone- friendly in low concentrations, so precautions must be taken. In its favor, it has few moving parts to wear out and is simple to operate. It takes advantage of the natural day/night cycle of solar energy, and eliminates the need for batteries, storing “solar cold” in the form of ice.

Access

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