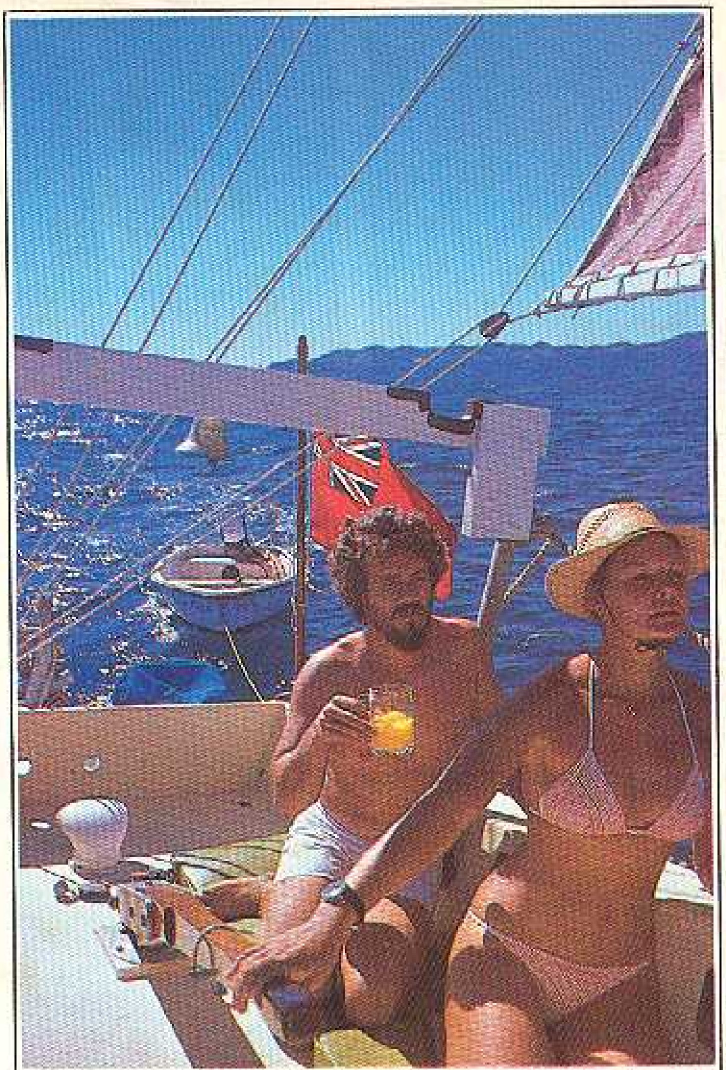


KEEPING COOL

by JOHN CAMPBELL

Part 1. How refrigeration systems work, and a look at the different types available.

MARINE refrigeration has progressed greatly in the last few years. After several years of living aboard without refrigeration, or relying on buying ice, we finally succumbed to luxury living about a year ago, and installed refrigeration. It has transformed the culinary department. We can be away from shops for a couple of weeks, be it on passage or just coastal cruising; yet still have fresh meat and salads. If we catch a large fish we no longer have to waste most of it, instead we can enjoy it over several days. On top of all that, there is nothing to beat a cold drink on a hot day, while sitting in the cockpit watching the world go by.

Let's start off by taking a look at the basic physics of what makes the thing get cold. This will give us a better understanding of the different systems that are available, as we look at them in detail. Finally I will explain why we chose our system, and how it has all worked out in practice.

First let's lay to rest the most common misconception. A refrigerator does *not* make cold, it actually removes heat from whatever is supposed to be getting cold, and transfers that heat somewhere else.

How is this done? Well, apart from a few oddball systems, most rely on the compression and subsequent expansion of a gas.

How does this transfer heat? When a gas is compressed, all the gas molecules that are moving around at high speed are forced closer together. As their motion is restricted, the extra energy is given up as heat. Heat is produced until the gas stabilises at the new pressure.

Similarly, when a compressed gas is allowed to expand, the molecules can suddenly move around more. This requires extra energy which they get by drawing heat from their surroundings. That is why the can on a compressed gas foghorn mists over with condensation in use. The can becomes colder as the expanding gas removes heat from it. Moisture from the atmosphere condenses on the cool can and can even ice-up the nozzle.

Before we see how this phenomenon is used in the refrigerator, we must consider another form of heat, called latent heat. This is the energy involved in changing the state of a substance; solid to liquid and so on. When we boil a kettle of water (for example), it may take five minutes for the water to reach boiling point. If the kettle is left on the heat, the water will never get any hotter, but it will turn into steam. It may take as long as an hour for the kettle to boil dry, and for all the water to be turned into steam.

All that extra heat applied to the water in the kettle is the latent heat of evaporation. We do not need to quantify it, but it is fairly obvious, from the time involved, that a great deal more heat is required to turn a liquid into vapour (water into steam), than was required to bring that liquid to boiling point in the first place.

Latent heat has a second form, the latent heat of fusion. This is the heat that must be applied to a solid to turn it into a liquid, without raising its temperature. Maybe they should have called it the latent heat of melting!

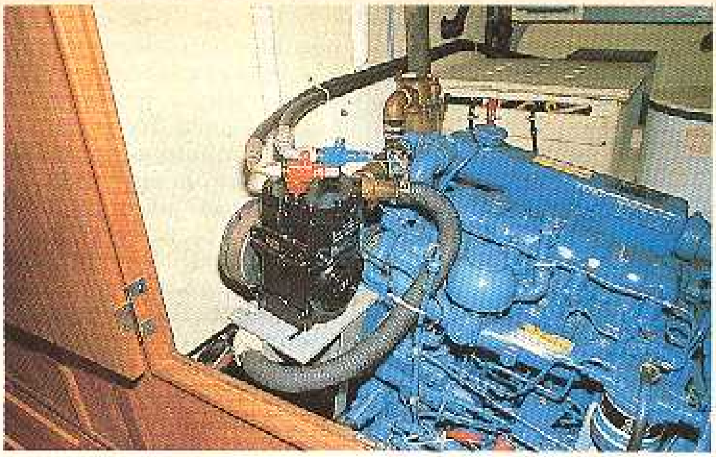
An icecube cools the drink it is sitting in by taking up heat from its surroundings (the drink). This heat is used as the latent heat of fusion, to melt the ice. Again, it takes a lot more heat to melt the ice than it does to subsequently increase the temperature of the resulting water. That is why when the last of the icecube melts, the drink warms up rapidly.

Let's see now how all this relates to a typical refrigeration system. Almost all of the systems suitable for yachts rely on a gas with a dreadfully complicated chemical name, but commonly called Freon. Incidentally, there are several types of Freon. It is important to use only the type for which the system was designed, and not to mix grades. Freon is a gas at normal temperatures, but it is easily liquified by compressing it.

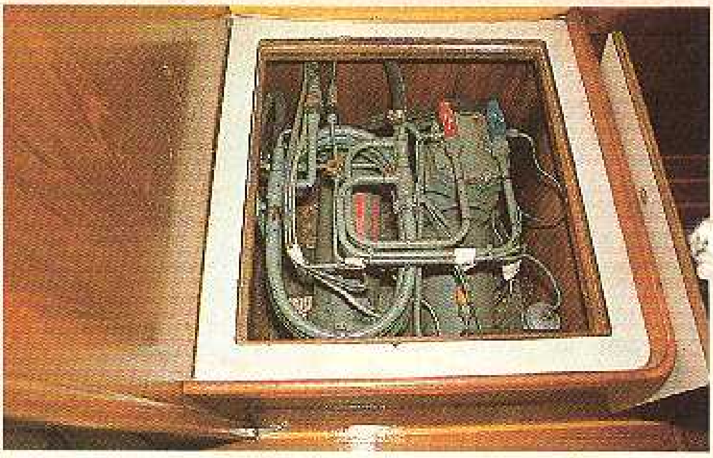
All of the systems that we will be looking at use some kind of compressor.

There are some other systems such as those powered by propane, butane and even paraffin. These are rarely successful in seagoing applications except perhaps on multihulls or power boats that travel along nearly upright. Compressor type systems seem to be better able to perform under a greater variety of conditions.

As the the compressor compresses the Freon, the Freon becomes hot. The hot compressed gas is cooled more or less to room temperature by passing it through some kind of heat exchanger. This can either be air cooled, similar to

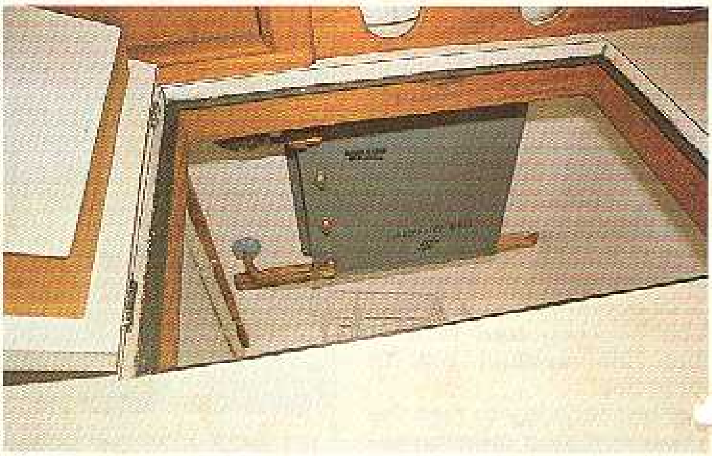


Engine mounted compressor. Silver disc at front is magnetic clutch belt-drive off crankshaft. Pipes lead to heat exchanger using engine cooling water.



110v DC unit. Coil on left is the heat exchanger. Water is pumped through the outer tube while the hot Freon flows through the inner tube.

Typical hold-over plate in a freezer marked for 0°F. This indicates a strong salt solution inside the plate. Note pipe entering box is well sealed to cut heat transfer.



Typical hold-over plate in a fridge. Marked for 26°F it has a weaker salt solution that will freeze at a somewhat higher temperature. Note drain pickup tube in LH corner.

a car radiator, or water cooled, or a combination of both. In any event, as the Freon cools it becomes a liquid, the latent heat of evaporation is removed, and passed to the air or seawater by the heat exchanger.

The liquid Freon, still under pressure, is allowed to escape through a small hole into the cooling part of the system. On more complicated systems this hole is variable in size, on smaller systems it is fixed. Either way, this unit is called the expansion valve.

As the liquid Freon passes through the expansion valve, into a region of lower pressure (remember the compressor is 'sucking' as well as 'blowing'), it wants to turn back into a gas. That requires heat, the latent heat of evaporation again. The liquid draws heat from the tube enclosing it, which becomes cold to the touch.

The gas now wants to expand to fill the space. That also requires heat, so the expanding gas continues to draw heat from the surrounding tube, which continues to get colder.

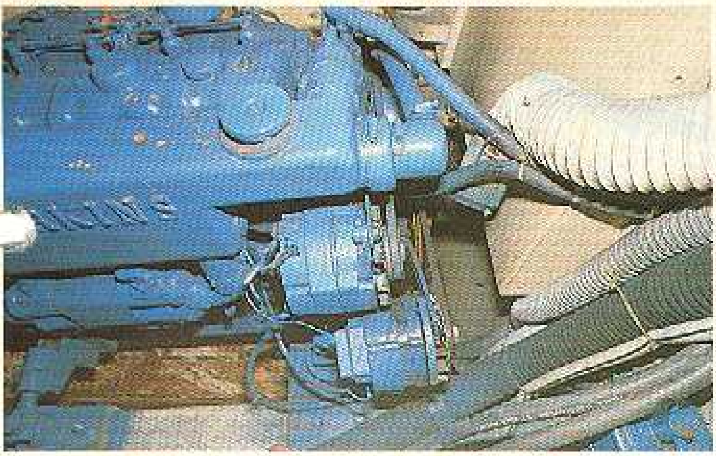
Some systems use this returning cold gas to help cool the high pressure hot gas leaving the compressor, augmenting the heat exchanger. Eventually the gas is drawn back into the compressor, and the cycle is repeated continuously.

Some marine systems work like a domestic refrigerator, where electric power for the compressor is continously applied. The temperature is sensed by a thermostat, and the compressor runs whenever the temperature rises to a certain point.

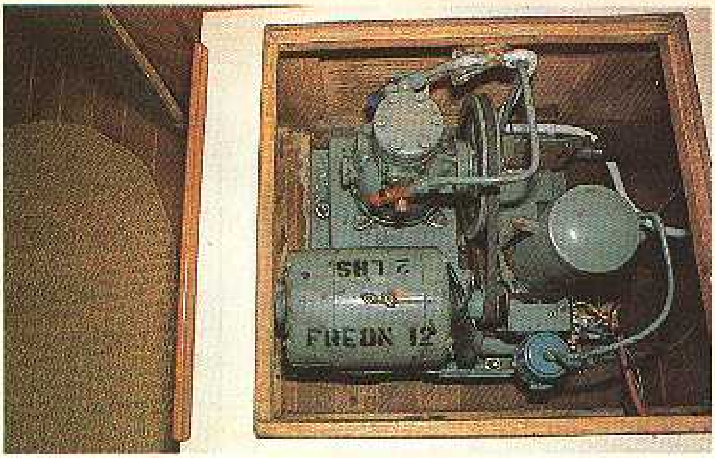
Other systems employ what are termed 'hold over plates'. These plates are cooled by running the compressor at intervals, usually once or twice a day. The holdover, or cold plates as they are sometimes called, continue to remove heat from the surroundings until the compressor runs again.

The plates are really in essence tanks filled with a liquid. This liquid has the grandoise name of a 'Eutectic Solution'. In actual fact the solution is usually no more than a solution of salt water. The salt lowers the freezing point of the water to below 0°C. There is a tube running through the solution, through which the cold Freon passes. The compressor is run until the brine solution is frozen solid. As this salty ice melts, it is our old friend, the latent heat of fusion which is the heat that is drawn out of the surroundings, cooling them until the compressor runs again.

Which sort of system one choose depends largely on what is used to drive the compressor. The compressor may be driven directly off the engine, or by electricity. If driven by electricity, it may be 12 or 24 volts DC off the battery or it

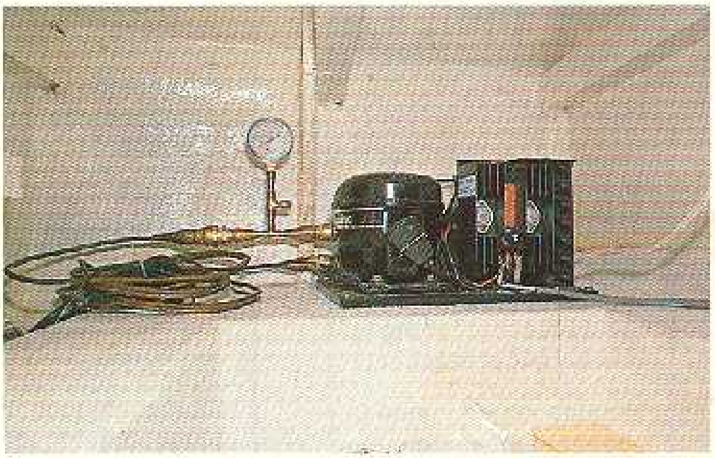


The lower alternator is driven at very high speed, using oversized crankshaft pulley, to produce 110v AC. This is rectified to drive the 110v DC motor.



A 12v DC system that uses hold-over plates. These 'plates' are essentially sealed containers holding a solution of salt in water chilled by cold Freon.

Looking down on a 12v system which cycles instead of using hold-over plates. On left is air-cooled heat exchanger; on right is hermetically sealed compressor.



The 12 volt system on our boat, Papilio Ruga, *mounted on top of the box. This is the Cold Machine from Adler Barbour and we mostly power it from solar panels.*

may be AC powered. If AC powered, the current may be produced either by a generator attached to the engine or by a separate generator, or shore power may be used. Let's look at each in turn, and see what the merits of each system are.

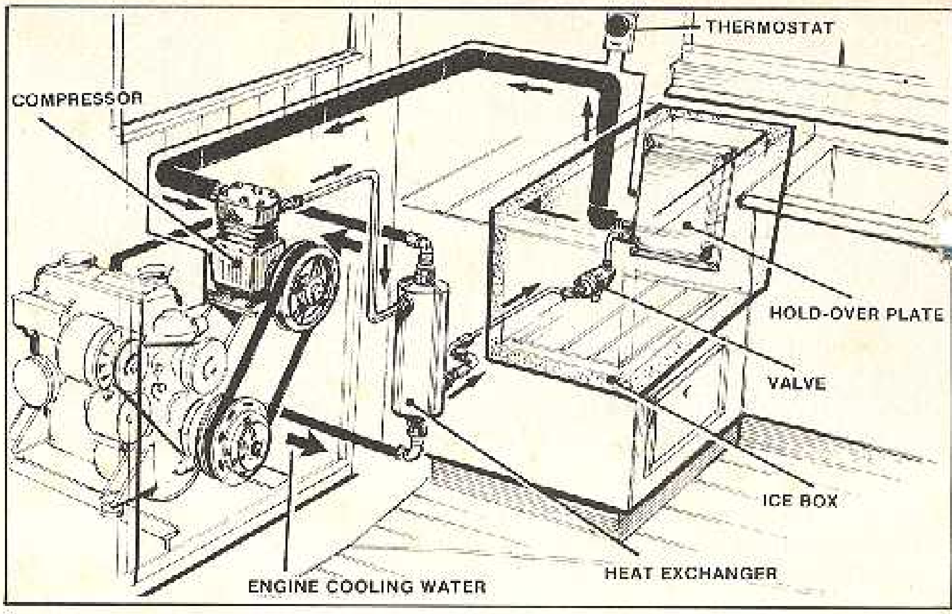
Running a compressor directly off the engine must be the most efficient, since there are no loses in converting the engine's mechanical energy to another form. Each time an energy conversion takes place, there is a loss. When mechanical energy is converted to electrical energy, then subsequently converted back to mechanical energy by a motor, the losses are compounded.

The most common way to drive a compressor off the engine is to use a magnetic clutch. The clutch is activated electrically to engage the compressor. Obviously the engine must be running for the compressor to run. Since presumably the engine is not going to be running continously, this type of compressor must be used with some kind of holdover system. That is the first disadvantage, the holdover plates add to the cost of, and the space used by the system. The second snag is that since the engine must run to drive the compressor, it cannot be run off shore power. A way round this is to install a second AC electrically powered compressor, to run off shore power. This again adds substantially to the cost and space used.

The big advantage of an engine-driven compressor is that a very powerful compressor can be used. Basically, the bigger the compressor, the quicker the holdover plates will freeze, and the shorter the running time will be per day. On larger boats, with a separate generator providing AC power, a better system would be to use an AC-driven compressor. At 110 volts or 220 volts, a large compressor can be driven without drawing a phenomenal current. Such a compressor has the additional advantage that it can also run off shore power. Again, unless the generator is expected to run continously, hold-over plates must be used.

There are some systems that use a special alternator driven off the main engine to provide 110 volt AC. This current is rectified and used to drive a 110 volt DC motor. The system can run on shore power, but it is hard, and costly, to build such a system for a large compressor to be run off the alternator. Unless a separate generator is available, it is best *not* to consider a 110 volt or 220 volt system, except as an auxiliary system to run off shore power.

What about a 12 volt system? The problem is that a large enough compressor to freeze down hold-over plates in a reasonable time



Schematic of a typical engine-drive compressor system. Probably the most efficienty refrigeration type since there are no power conversion losses. Usually features an electro-magnetic clutch.

draws too much current; it is difficult to re-charge the batteries fast enough. If the compressor runs while the batteries are being charged, much of the current is diverted to the compressor motor, leaving the batteries only partially charged. In practice, it is often necessary to run the engine just for the compressor, then for the batteries. This results in longer engine running times than if an engine-driven compressor were used, where all the electricity generated could go straight to the batteries. Remember too that diesels in particular do not like long periods of light running.

Fairly recently, Danfoss, a Scandinavian company developed a compressor similar to those in domestic refrigerators, but powered by 12 volts. This was made possible with the advent of brushless DC motors. The motor and compressor are hermetically sealed, eliminating the favourite place for Freon to leak out, which is around the compressor drive shaft.

Using a small, efficient compressor that utilises a continuously available power source (the 12-volt battery), it is possible to eliminate the hold-over plates, and let the unit cycle on a thermostat. By utilising a battery charger, the system can run on shore power. If power consumption is to be kept low, such a system is probably best limited to a small, extremely well-insulated box.

For a small boat, the modest power available, and a fairly small box to cool, this is perhaps the best type of system to choose, particularly if the boat spends any time alongside, when shore power is available.

We chose a unit of this last type of system. We built a very well-insulated box of about three cubic feet capacity, and have managed to keep the power requirements down to a minimum.

There are many units available using the same Danfoss compressor; indeed, Danfoss themselves put out a unit, although it is not really designed for marine use. Most of the units use an air-cooled heat exchanger. Some, including Danfoss' own, rely upon convection current to carry the hot air away. In the often close confines of a boat, a forced flow of air across the heat exchanger element is to be preferred. We chose the Cold Machine, by Adler Barbour*, as being perhaps the best engineered and best thought out unit. Beware; some units have cooling fan motors that draw almost as much current as the compressor. Our unit draws around 5 to 6 amps when it is running, and in our box, it runs around six to eight hours a day. This gives an average consumption of about 25 to 45 ampère hours per day.

What particularly appealed to us was that we can get this amount of power from our solar panels on good sunny days. Provided we are not trying to freeze large amounts of ice or cool many cans of beer at a time, we can enjoy the luxury of cold drinks, without having the pleasure marred by the noise of the engine thumping away for hours at a time. ●

*(*The Cold Machine is available in the UK from Telesonic Marine Ltd., 60 Brunswick Centre, Marchmont Street, London WC1N 8AE. Tel: 01-837 4106)*

NEXT MONTH: How to build an efficient ice-box — the materials and methods.