DIY Refrigeration

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Prefix

This article revolves primary around the refrigeration system used on boats which involve an engine driven compressor. Now, in 2018, more and more boats are utilizing the advances that have been made in the efficiency, and cost effectiveness, of solar panels, and refrigeration systems are slowly being moved to electrically driven plug and play systems. This notwithstanding, the Theory of Refrigeration remains the same no matter what the motive power is, and there are still many older boats around that still use engine driven systems and so perhaps what follows might help.

Introduction

One should state for the opening sentence of this article that unless the reader has a ‘Refrigeration Technician Certificate’ it is illegal and therefore very unwise to take a spanner to your boat’s refrigeration system (There would seem to be some exceptions to the installation of the Plug and Play systems!) Furthermore, under New Zealand law, the Climate Change Response Act 2002 makes it an offence to knowingly release refrigerant gas into the atmosphere. This means that for all practical purposes only a trained and certified refrigeration professional can carry out any major work on a boat’s system. But consider the following. My small launch has a simple deep freeze refrigeration system powered by a compressor which is driven from the engine. It’s as basic as it can be, yet it has certainly been the most troublesome system on the boat. Over some 25 years it has required three new compressors, one new condenser, and a complete rebuild of the ice box and the cold plates. For the first of the above problems the boat was trying to tell me that something was amiss. The actual problem was liquid slugging. But it happened extremely rarely, like only about every two years or so, and at the time I did not have the knowledge to interpret the signals. After the liquid slugging problem was solved I became interested in how refrigeration worked, and this knowledge proved invaluable later on when subsequent problems arose.

Any refrigeration unit, particularly a deep freeze system, can take many hours from start up, to finally reach its normal and stabilized operating state.

Unlike the home domestic Fisher and Paykel freezer, pretty much every boat has a one off unique installation. The final set up on a vessel will have resulted in a package that reflects ideas and requirements from: the boats builder, the commissioning owner, and the installing Technician.

When you have a Refrigeration Technician service the boat it is not realistic to expect them to be fully conversant with the idiosyncrasy of your particular installation, nor would you expect them to remain on the vessel for hours waiting while the deep freeze reduces down to its stabilized temperature.

So. You are their ears and eyes. If you have an understanding of what is going on, and are observant about the operation of the refrigeration system on your vessel, you can preempt many problems and that can help your Technician.

You are looking for is ‘What is normal for your vessel’ And when you detect something that appears changed then perhaps its time to make the phone call.

The Theory

The main reason that any refrigeration systems works, is because of changes to temperature and pressure in a closed and sealed system.

Condensation Temperature. This is the temperature at which a medium, say for example R134a, will change its physical state from liquid to vapour. Additional to this, is that the exact temperature that this physical change will take place is also totally dependant on the pressure that is currently being applied to the medium. So in a closed system if you know the pressure you can look up the temperature in the R134a tables.

Latent Heat. Latent Heat is the heat energy that is absorbed or liberated when a substance reaches the condensation temperature for its present pressure and so undergoes a change of state at that given temperature and pressure.

Imagine a pot of water with a thermometer in it, sitting on a gas ring at sea level. Turn up the gas and the heat applied to the water will cause the temperature of the water in the pot to rise at a steady rate. However, when the thermometer in the pot reaches 100C (Centigrade) the water will have reached its condensation temperature and then it will begin to boil. Now it commences a change of its physical state from a liquid to a gas And even though the same amount of heat is still being applied to the pot from the gas ring underneath, the thermometer reading the heat of the water will not rise above 100C. The gas ring is still putting out the heat as before but the energy from the burning gas is being used or absorbed in the process of converting the molecular structure of the water from liquid to steam. This apparent loss of energy is latent heat.

If you were to now take the pot of water up a reasonable sized mountain and do the experiment again, because the air pressure on the surface of the water in the pot at this new altitude is less than at sea level the water will boil at a lesser temperature than 100C. Mountaineers know that unless they have a pressure water boiler, they can only ever have a tepid cup of tea.

A simple kitchen pressure cooker changes the situation again. Because the pressure cooker is sealed, as the water inside first begins to boil at 100C the initial steam given off raises the pressure inside the cooker and because the pressure has increased, the temperature continues to rise as it responds to the increase in pressure. And as well the condensation temperature of the water also increases and so consequently the water will get much hotter than 100C before it fully converts into steam. Eventually the safely valve releases and the pressure cooker stabilises but now everything inside is much hotter than our original open pot and because it is hotter, the food inside cooks a lot faster than normal.

Latent Heat and *Condensation Temperature* combined with the manipulation of the actual *pressure* inside the sealed system is what makes the refrigeration system on a boat work.

Refrigeration Gas

In the example above we talked about water changing from liquid to gas, but in marine refrigeration the medium used is very different. Up until the mid 1990's it was predominantly a gas called R12, sometimes called Freon-12. R12 is a Chlorofluorocarbon (CFC) and unfortunately this class of chemical has been proved to have a disastrous effect on the world's Ozone layer. It destroys it. Essentially, R12 is no longer manufactured, and is now banned from use by most Governments, New Zealand included. While it may just be possible to find a boat that it is still using R12 the probability is unlikely, and so most systems running today will be using the replacement product, R134a.

R134a is a Hydrofluorocarbon (HFC) It is not thought to damage the Ozone layer but may contribute to the 'Green House Effect'. For most of its refrigeration properties, it operates much like its predecessor R12. There are some differences that should be noted. It requires a different compressor oil namely a Polyolester (POE), whereas R12 used a mineral oil, and because R134a has a smaller molecular size than its predecessor, it can be more prone to leaking from seals and hoses.

R134a is used in refrigeration because it has condensation temperatures that are very suited to the application For example at sea level pressure, (approx 14.7 psi *actua*l, zero psi *gauge*), it 'boils' i.e. changes state, at minus 26C

DIY Tips

R134a is not particularly dangerous, but inhaling any gas leaked into the boat should be avoided.

Never place any part of your person near a serious leak. As the gas escapes to the air it will instantly freeze and cause serious damage if it comes in contact with human flesh.

It is heavier than air so a major leak could result in it settling to the lower part of the vessel.

If you decide to purchase a gas detector ensure that it will detect R134a. Not all do.

The Compressor

The compressor is the 'engine' of the system. It is responsible for moving the refrigerant about and for creating and maintaining the high and low pressure areas to allow the R134a to change from gas to liquid and back again so releasing or absorbing latent heat in the process

Compressors tend to be of two main types *hermetic* and *belt driven.* A hermetic compressor is where the compressor and the electric motor which powers it, are both sealed inside a canister like chamber. Only the delivery pipes and the power lead exit through sealed openings. The advantage of this type is that gas leaks are minimised as everything is sealed away. A disadvantage is that any mechanical problems inside the chamber are not assessable for repair so even a minor failure means the entire unit must be scrapped and replaced. A belt driven compressor has the drive shaft sticking out the front so that the unit can be driven either by an electric motor or more commonly, from a V belt running on the front pulley of the boat's main engine. Belt driven compressors are versatile in that they can be mounted and powered such as what suits the vessel, but they do have one common disadvantage. The gas is contained inside the compressor by means of a shaft seal. While different manufacturers do differ in their technique, this seal is usually two machined and mated surfaces held together by a spring action and lubricated by the oil which circulates around the system along with the gas. In actuality it is this thin layer of oil which provides the gas seal hence the best thing that can be done for boat systems is to run them regularly. This helps to maintain the oil seal. Over time some minor leakage of gas must be expected from a belt driven compressor

DIY Tips

After running for a while the compressor makes a 'buzzing' noise. This could mean that it is low on lubricating oil. It could also mean that the system has too much R134a in it. Seek help. A normal compressor when running just makes a satisfying mechanical hum.

Loud Banging and/or serious tapping noises emit from the unit, or the compressor appears to bog down or partially stall. This could be 'liquid slugging' Liquid slugging is when the R134a arrives at the compressor in its liquid form, not in its gaseous form. As liquid is not compressible, the unit momentary seizes. A serious 'slug' can instantly destroy the compressor. If you suspect slugging shut the compressor down immediately.

Serious frosting and ice build up all over the compressor. This should be avoided, as it can be a precursor to the above liquid slugging problem. It might be more usual perhaps to see some condensation on the unit or even that the unit runs hot to touch, say around 40C. Observe. What is normal for your installation? Has it recently changed?

The Condenser

The compressor pressurises the R134a vapour in this part of the system. The hot compressed gas then passes out of the compressor discharge port and is carried by pipe to the condenser. On most boats the condenser is a specific refrigeration type of heat exchanger which is cooled by the same sea water flow that is being used to cool the main engine. When the hot compressed R134a is cooled inside the condenser it falls below its condensation temperature and reverts back to a liquid. This is a change of state and when the R134a does this it liberates heat, latent heat, which is removed from the system by the cooling sea water on the other side of the condenser heat exchanger coils. One way to look at it, is to imagine that the R134a is being prepared in advance for its future role of cooling the ice box.

DIY Tips

When the condenser is working well, it might be usual to note that the temperature of the liquid R134a exiting the unit is in the region of 6C to10C greater than the temperature of the

sea water passing through the unit. This can be measured at the appropriate inlet and outlet pipes with a hand held infrared thermometer.
One of the most disastrous problems that can befall a boat refrigeration system is to have the internals of the condenser heat exchanger fail and for this to result in sea water getting into the R134a pipes. Recovery from sea water contamination can be done but it will be an extremely protracted process and unbelievably expensive. So look after the heat exchanger. If it has zincs- some do, a lot don't- keep the zincs changed. If you have any doubts about the integrity of the condenser…. Get help immediately!
If, in the unlikely event that the cooling sea water flow through the condenser is terminated, but the vessel is still mobile, turn the compressor OFF!! Without cooling, dangerous over pressures may occur in the system.

The Receiver
After exiting the condenser the liquid R134a now passes into the receiver. The receiver is just a container which holds a sizable amount of liquid R134a. Its purpose is primarily to hold a reserve of liquid so that there can be a steady and consistent flow to the expansion valve. Sometimes the receiver is a stand alone unit but often it is built into the condenser and the two units form only one physical presence. It will always have a service valve at its outlet port, and sometimes, very rarely, it will also have a second service valve at the inlet port. These valves are only for use by the Refrigeration Technician and should never be touched by the boat owner.

The Dryer
Liquid R134a is moved from the receiver to the expansion valve and in doing so it first passes through the dryer. The dryer is a small tank filled with a desiccant to remove moisture and as well it usually also contains a filter screen to remove and hold any debris which might be trying to circulate with the refrigerant. Moisture in a fridge system is a big problem as we will see a little later when we discuss the expansion valve. The dryer is a 'serviceable' item and will from time to time, be replaced by the Refrigeration Technician.

The Sight Glass.
The sight glass is a round clear glass unit in the line and is usually placed just after the dryer. This one piece of equipment is perhaps the most important 'tool' in diagnosing the health and welfare of the whole system. Sometimes it has a protective cover over the glass. It serves two extremely important functions. Most sight glasses will provide an indication as to whether there is moisture in the system. This is done by observation of a small colour dot in the centre of the glass. It will change colour if it detects moisture. The colour codes are usually written on the face of the sight glass.
One of the most difficult servicing acts for any boat system is to determine just how much R134a refrigerant is actually inside the system. Too little and the whole unit will operate far below its best efficiency. Too much and there is a risk of compressor damage from liquid slugging.
DIY Tips
Keep an eye on the moisture indicator and if it changes colour towards indicating moisture, have it checked.
Is the R134a charge in the system correct? When the compressor is first turned on, and the engine is running a bit above idle, then after a few seconds, liquid should begin to flow through the sight glass. The stream of liquid should increase over a minute or two until the entire sight glass is full and now appears clear. Sometimes a gas bubble will remain stuck in the centre, but it should eventually disappear. As the refrigeration system cools down over the next few hours, the sight glass should continue to remain full. Often when a system is a bit low on gas, the sight glass will be full on start up but will show a reduced liquid stream, ie bubbles, when the system has been cooled right down. On some deep freeze systems, with the deep freeze really frozen down to say an air temperature of minus 15C or more, it is OK for some minor bubbles to just start to appear in the sight glass. Most important is to know what

is normal for your system. On my boat, the system seems to operate best when, with the freezer box at minus 15C, just occasionally, the odd bubble can be seen passing through the sight glass. However at any ice box temperature above this, the sight glass is full of liquid.

R134a Heat Exchanger

The idea here is that a heat exchanger is installed in the gas lines just before the expansion valve. It works by having the left over 'cold' that is residing in the low pressure gas that is exiting the ice box and on its way back to the compressor, cool down the high pressure liquid R134a which is approaching the expansion valve. It's called S*ubcooling.* These heat exchangers are not cheap and to fit one would require serious modifications to the refrigeration system. There is a cheat's solution however. On my boat the two copper pipes in question travel along a bulkhead right beside each other. It was a simple operation to remove the mounting brackets, ease the two pipes together and affix them in close contact with a dozen cheap hose clips. Enclose the connection with a cover and some instant foam insulation and there you have one cheap heat exchanger.

Does it work?? Well all I can say is that ten minutes after initial start up, the infrared thermometer indicates that the temperature of the liquid gas exiting the crude heat exchanger and heading for the expansion valve is some 4 to 5C lower than when it entered. Guess that's got to be something for nothing!!!! BUT.. Don't do this without expert assistance. Get it wrong and you could wreck the compressor.

The Expansion Valve and the Ice Box/Freezer

The ice box on most boats is an insulated container which has a cold plate installed on one or more sides of the box. The cold plate itself is a small tank which contains within it a series of woven evaporator pipes surrounded by an antifreeze solution. The ratio for the antifreeze solution used on my boat is Ethylene Glycol mixed 3.5 litres to 9 litres of water giving a Specific Gravity of 1.038 with a freeze point of approx. -14C, and this seems to work just fine. Ethylene Glycol can be obtained as Engine Antifreeze. Just make sure that it is concentrated (approx. 95%) and it is indeed Ethylene Glycol based. The 'coldness' produced by the refrigeration process chills down and semi freezes the antifreeze solution in the cold plate(s) to perhaps, in a freezer application, a temperature of below minus 20C. When the compressor is not running the semi frozen cold plates then keep the contents of the ice box frozen. Most installations seem to need a running time for the engine of about an hour every 24 hours to keep the deep freeze well below zero C.

And as we have discussed so far the R134a, presently in its liquid form and under high pressure from the compressor, now arrives at the expansion valve which will be mounted just before the ice box. The expansion valve is where the real work of a refrigeration system takes place. It is a controllable mechanical restriction in the line which has the following effects. Because of the restriction is allows the compressor to maintain high pressures on the units and line leading to it, and also allows the compressor to pull a low pressure on the units and the line leading away from it. The expansion valve is smart in that it usually has a sensing bulb clamped to the outlet pipe of the ice box and this allows it to react to the evaporation process in the icebox tubing by opening and closing. This controls the flow of R134a.

The expansion valve allows the liquid R134a to burst through into the evaporator piping of the icebox/refrigerator. Because this piping is connected directly to the suction side of the compressor and is therefore maintained at a low pressure the R134a moves to the other side of its condensation temperature and immediately 'boils off' to revert back to its vapour state. And, as it did at the condenser earlier on, this physical change from liquid to vapour invokes the phenomenon of latent heat resulting this time in considerable absorption of heat from the surrounding area. This removal of heat cools down and freezes the icebox and depending on the boats individual set up may also keep the galley fridge cool for the milk and the wine.

The outlet from the deep freeze box is now piped back to the suction side of the compressor, The R134a, now as a vapour with its cooling work done is drawn back to the compressor, to again be compressed and to continue to circulate once more around the system. On a lot of installations there is, mounted in the suction line just before the compressor, a small tank called an accumulator. This is there to help protect the compressor from liquid slugging as the accumulator's function is to catch and help prevent any R134a that for some reason is still as a liquid, from getting sucked into the compressor and causing damage.

DIY Tips

The expansion valve is adjustable, but only by a Technician.

Keep an eye on the frosting that forms on the walls of the ice box. It should be reasonably even from top to bottom on the walls that have evaporator tubing in them. If the frosting is not even it may indicate that the expansion valve setting, called *Super Heat*, may need adjusting. (Partial frosting could also indicate that the R134a level is low and the system may need a top up).

Observe the amount of ice frosting that travels back along the suction pipe which returns to the compressor. Serious frosting can be a result of an incorrect super heat setting. However it is normal for some frosting to occur. The compressor itself should not freeze up. Somewhere in the middle is the normal for your system.

If any moisture has managed to get into the system, even a tiny amount, the water will instantly freeze at the expansion valve orifice and completely plug it closed. No R134a will pass to evaporate and consequently no cooling will take place. This can be usually seen by observing the expansion valve and noting that no frosting is taking place on the pipe leading from it and into the freezer box. Also the colour indicator in the sight glass should be showing the presence of moisture. It might just be possible to clear this problem by shutting down the system, allowing the plug of ice to thaw, and then restarting. The hope is that the drop of water will circulate around and be removed by the desiccant in the dryer. Several attempts may be needed, and it may come right, but this problem indicates that servicing of the entire system is urgently called for.

If radiator antifreeze solution has been used in the cold plates, and in the unlikely event that some of the cold plate solution leaks out and contaminates the food contents of the deep freeze, <u>do not consume the food</u>! Antifreeze solution is highly poisonous!!

Tools That Assist

Some DIY refrigeration tools.

The first and by far the most useful is a simple temperature gauge in the deep freeze box. This is just an elementary battery powered indoor/outdoor dwelling temperature gauge available from many stores or online and is sold to households to show the indoor temperature and via a small sensor on a long wire, Bluetooth, WiFi, the outdoor temperature. I have this mounted inside on the rear cabin wall and the 'outdoor' sensor is routed through to literally just dangle in the bottom of the ice box. The little sensor needs to be kept away from the surface of any objects in the ice box. After all it is the air temperature that I am trying to read. This was easily achieved by placing the sensor inside a plastic practice golf ball. Now the sensor unit cannot touch anything and it will indeed be just indicating the air temperature inside. It's a most useful gadget. It controls how long I run the system each day, and once you get to know your boat it provides a reference against which to judge the entire system performance.

The second tool I have is an infrared thermometer. Again these are readily available. It operates by being held close to, but not touching, an object and it can read the temperature of the target and display if on a small screen. I find this unit useful for keeping an eye on the temperatures around the refrigeration system, an example. What is going on around the liquid flows through the condenser? It's also a handy gadget to keep a check of other temperatures in the boat for example, around the engine, the gearbox, the other three heat exchangers, the shaft seal, and the thrust bearing.

And the final tool is an R134a detector or sniffer. This little unit was purchased on line and was very reasonably priced. It operates by detecting the Hydrofluorocarbon molecules and when it does so, it emits a loud clicking noise. Its main problem is that it can be super sensitive, and to help compensate for this it has a manual adjustment knob and also an inbuilt sensitivity compensator. In practice, getting the sensitivity adjusted correctly can be a problem. It pays to read the manual very carefully, and even so, it still takes a bit of getting used too. But with perseverance, it is worth the effort. When using it, one needs to be patient and careful and just slowly follow around the refrigeration pipes and refrigeration components holding the tip of the detector close. Pay special attention to joints and hoses. Expect some reaction around the compressor near to the drive shaft and check this area only after the compressor has been standing unused for a while. After standing for a while, some of the compressor lubricating oil can drain from a worn shaft seal and then a leak will occur. Once the unit has been started, the lost oil is returned to the seal and the leak may decrease. Also when checking for leaks in the refrigeration system look for any damp oil spots. If R134a is escaping, it will often bring some lubricating oil out with it and this oil stain is usually visible as a small stain. Any suspicious stains should be checked with the sniffer.