Environmental Testing

Expendable Refrigerants

or

Mechanical Refrigeration

By

Gino DiBartolomeo – CEO, Environmental Stress Systems, Inc.

Introduction

Many functional & reliability tests performed on electronic or passive devices require thermal cycling. Thermal cycling usually involves the rapid and repeated heating and cooling of the device under test (DUT). Heating is a simple and straightforward process that involves passing an electrical current through a resistive device. The heat that is produced is then applied to the DUT by convection or conduction. Cooling the DUT though more difficult than heating can be accomplished by several different methods. In order to cool a device, some form of heat removal is necessary and there are many different ways of accomplishing this. This article will explore some of these various methods.

Topics

Expendable refrigerants

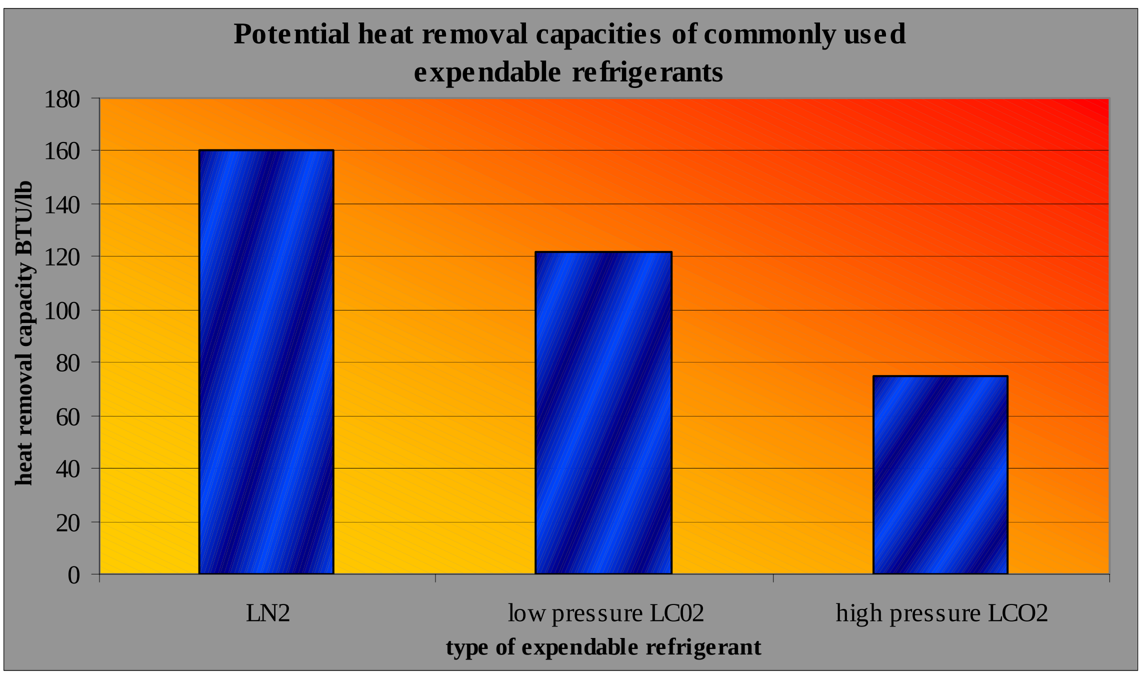
The simplest way to cool the DUT is to use expendable refrigerants such as liquid nitrogen or liquid carbon dioxide. Expendable refrigerants remove heat from the device by absorbing it and then they are exhausted into the atmosphere. These refrigerants have three main advantages:

- The equipment designed to use them usually has a lower initial cost due to a simpler design and fewer component parts.
- The cooling rates can be very fast. However, faster cooling rates are not guaranteed because there are a several factors that determine just how quickly expendable refrigerants can cool a device. Some of these factors will be covered in another section.
- Expendable refrigerants have the ability to remove large amounts of heat quickly. This is advantageous if the DUT dissipates a large amount of heat, the heat is concentrated or if shock (very rapid thermal change) testing is required.

The disadvantages of expendable refrigerants

- Overtime expendable refrigerants are very expensive to use due to several factors. Since they are only used once and not recovered it is necessary to continually replenish the supply. Some companies claim that their expendable refrigerant budget can be several hundred thousand dollars per year. It is not unusual for a single test site to consume over 100 dollars worth of expendable refrigerant per day.
- Safety is also an issue. Expendable refrigerants are usually exhausted directly into the work area and this can result in elevated levels of carbon dioxide or nitrogen in the air. Proper ventilation and air quality monitoring may be necessary to insure worker safety. There are also the inherent dangers in the handling of cryogenic fluids and the associated heavy, bulky cylinders. The use of expendable refrigerants can create ice and water condensation that can result in pools of water on the floor. The presence of individual storage cylinders and water puddles in the lab present a safety hazard and also make it very difficult to keep the test area looking clean, neat and professional.
- Delivery of an adequate supply of expendable refrigerant to the test area can also be very expensive. Delivery is usually achieved by one of two methods. Bulk delivery systems utilize a large storage tank outside of the building to hold a vast quantity of expendable refrigerant. The refrigerant is then distributed to the various test areas via an expensive insulated delivery system. Another method is to use separate storage cylinders of refrigerant to supply each test site individually. The bulk method has a very high initial cost and is inflexible in its application. The main advantage is that it eliminates the trouble of filling and handling the individual cylinders. Some companies claim that it can cost as much as 500 dollars per foot to install the distribution lines in a bulk system. Since the distribution lines in a bulk system are hard plumbed, re-locating a test site is not easy to do. The use of individual cylinders at each test site also has its disadvantages. The need to regularly refill and replace the cylinders is labor intensive and can create health and safety problems. However, it is more flexible and has a lower initial cost than a bulk system.

- An additional disadvantage in the case of liquid nitrogen and low-pressure liquid carbon dioxide is that the refrigerant is continuously being used up in the process of keeping itself at storage temperature. An average of three percent per day can be lost in this process. This means that a completely full cylinder will be completely empty after a month of storage even if none of the refrigerant is used for thermal testing.
- By using high-pressure liquid carbon dioxide, losses can be reduced because it can be stored at room temperature with no losses. However, high-pressure liquid carbon dioxide has roughly half the potential heat removal capacity of low-pressure liquid carbon dioxide. So, depending on the test and delivery system, a lot more of the high-pressure liquid carbon dioxide will probably be used to achieve the same results. Graph 1 shows the theoretical heat removal capacities of expendable refrigerants. In practice however yields are more complex to estimate. In the case of liquid nitrogen and low-pressure liquid carbon dioxide, a lot of heat can be absorbed in the process of delivering the refrigerant to the test site. This effectively reduces the net heat removal capacity of the refrigerant. The amount of heat removal capacity reduction is directly related to how well the refrigerant lines are insulated and how consistently the refrigerant is being used.



Graph1

Comparison between LN2 and LCO2

Liquid nitrogen has a much lower boiling point and under proper conditions can remove a lot more heat and produce much lower device temperatures than liquid carbon dioxide.

Due to its very low storage temperature it can absorbs an enormous amount of heat in the process of being delivered to the test sight and therefore its higher BTU/pound capacity can be very installation dependent. Liquid carbon dioxide does not suffer as much as liquid nitrogen does to delivery conditions because is has a much higher storage temperature. High-pressure liquid carbon dioxide is stored at room temperature and low-pressure liquid carbon dioxide is stored at 0° Fahrenheit.

When liquid carbon dioxide is used as a refrigerant it changes state from a liquid to a solid to a vapor. This phenomenon is known as sublimation. As the pressure drops the liquid carbon dioxide can passes through a solid phase. Solid carbon dioxide is called "dry ice". The "dry ice" phase of carbon dioxide is very difficult to manage and requires special expertise when using it as a refrigerant to prevent clogging of the evaporator. High-pressure liquid carbon dioxide has an additional undesirable trait. It is supplied in high-pressure cylinders. Each cylinder is typically filled with 50 pounds of liquid carbon dioxide. However, only about 35 of the 50 pounds can be drawn off as liquid and therefore be usable as a refrigerant. The remaining 15 pounds exists only as a vapor and therefore has no value as a refrigerant. In fact, if the storage temperature of the high-pressure carbon dioxide cylinder is above 87° Fahrenheit, its critical point, it cannot exist as a liquid at all and therefore is useless as a refrigerant. Considering that high-pressure liquid carbon dioxide has only about half the heat removal capacity of low-pressure liquid carbon dioxide, and that on average only about 70 percent of the high-pressure liquid carbon dioxide is usable, it is clear how inefficient this approach can be.

When you compare the strengths and weaknesses of the different expendable refrigerants it may at first appear that there is no best choice. However, there is one approach that in my opinion makes the most efficient and cost effective use of expendable refrigerant. It is a hybrid system that takes advantage of the best characteristics of the high and low-pressure liquid carbon dioxide. This method combines the high heat removal capacity of the low-pressure liquid carbon dioxide with the economical storage and delivery characteristics of the high-pressure liquid carbon dioxide. The device that makes this possible is called a satellite condenser.

Satellite condensers

A satellite condenser is a simple mechanical refrigeration and storage system that converts carbon dioxide vapor into liquid. It is usually located in close proximity to the test site. The bulk liquid carbon dioxide is stored remotely and delivered as a room temperature vapor. The carbon dioxide vapor is distributed to the test site by way of simple, inexpensive non-insulated tubing. The carbon dioxide vapor is re-condensed into liquid by the satellite condenser at the test site. Depending on its size, a satellite condenser can serve a single or several test sites. A properly installed satellite condenser can guarantee plenty of liquid carbon dioxide at the test site anytime it is needed.

Benefits of Satellite Condensers

This type of installation yields four primary benefits.

1. Almost no refrigerant is lost maintaining storage temperature and distributing the refrigerant.
2. Inexpensive and flexible distribution lines can be used. This is because the refrigerant is in a relatively low-pressure vapor state and can be distributed at room temperature.
3. More of the refrigerant that is purchased is used. This is because the satellite condenser re-condenses the vapor into a liquid. As long as there is sufficient condensing vapor pressure delivered to the satellite condenser then liquid refrigerant will be produced.
4. A ready supply of liquid carbon dioxide is always available right at the test site making for faster test cycle times. If the satellite condenser is properly installed then any vapor bubbles in the liquid carbon dioxide will rise up to the satellite condenser and be re-condensed into liquid. There is no waiting for the vapor to be purged from the supply line.

If your company has already invested heavily in a conventional liquid nitrogen or low-pressure liquid carbon dioxide bulk delivery system then the satellite condenser system may be difficult to justify. However, it is probably still the most cost-effective use of expendable refrigerant. But there is still a better way.

Mechanical refrigeration

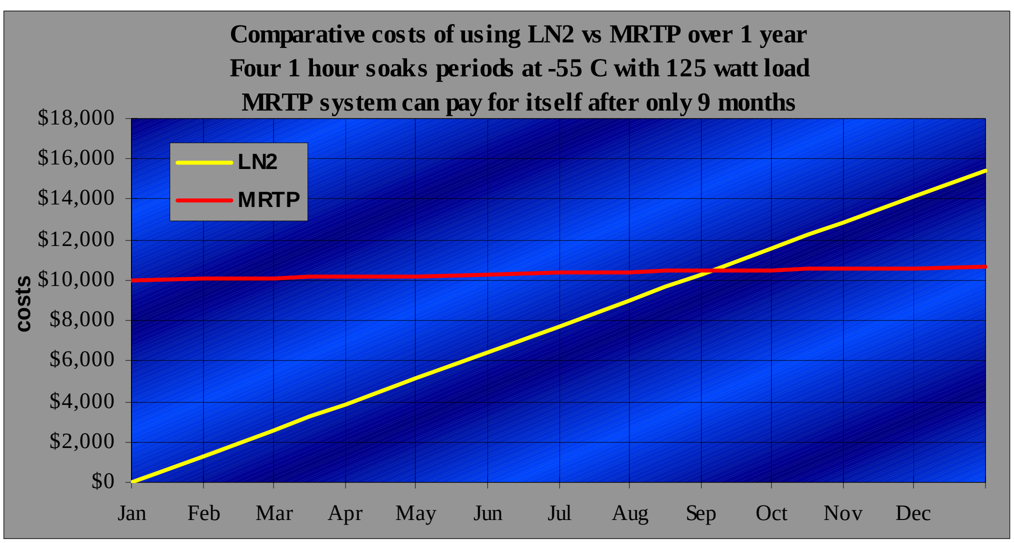
Mechanical refrigeration uses a vapor compressor and special refrigerant(s) in a closed-loop system to cool the DUT. The refrigerant is re-used over and over. Expendable refrigerants such as liquid nitrogen or liquid carbon dioxide require a great deal of energy to produce in the first place. By adding to that the cost of storage, distribution, and handling, it is easy to see why expendable refrigerants can be so costly to use.

Expendable refrigerants are commonly used because the initial system cost is usually lower. Often only the initial acquisition cost is considered rather than the total cost of operation. But probably more important is the fact that a lot of environmental stress screening equipment has been available for use only with expendable refrigerant. This is no longer the case. A growing awareness of the high costs involved when using expendable refrigerant has driven many companies to re-examine its use as the cooling medium for thermal cycling of devices. When all of the expenses involved in manufacturing a product are closely scrutinized, including items such as electrical power consumption and expendable refrigerant usage, it becomes obvious that there is tremendous potential for savings in this area. If expenses such as electrical power consumption and expendable refrigerant usage are merely considered as unavoidable operating costs or simply part of general overhead then there is little incentive to initiate change.

The importance of efficient product testing

It has been said that the expertise required to build electronic components in general and high frequency analog devices in particular is uniformly distributed among the companies that are involved in this endeavor. However, there is tremendous disparity in the approach and the efficiency of the functional test process. How efficiently the devices that you build are tested may to a great degree determine how competitive and profitable the final product is. It was this realization by several product managers and the subsequent communication with the manufacturers of environmental stress screening equipment that has resulted in the development and manufacture of thermal cycling equipment that uses closed-loop mechanical refrigeration.

Mechanical refrigeration has several advantages over expendable refrigerant as a means to cool electronic devices in thermal cycling. Probably the greatest single advantage of mechanical refrigeration is that it relies upon a fixed quantity of refrigerant that is installed at the factory and never needs replenishment. In many cases this single feature allows a mechanical refrigeration system to completely pay for itself within the very first year of operation. See the example in Graph 2 below. The complete storage and distribution system of expendable refrigerants is now eliminated. No more tanks, no more insulated distribution lines, no more bulky storage cylinders in the test area. There is no more need to connect, disconnect, transport, or fill portable storage cylinders. There will be no more ice balls on the piping, dripping water, and puddles on the floor. Because the mechanical refrigeration system only requires electrical power to operate, the system can be rolled to anywhere in the facility that it is needed and simply plugged-in to an AC outlet. That kind of flexibility is very attractive.



Graph 2

MRTP - Mechanically Refrigerated Thermal Platform

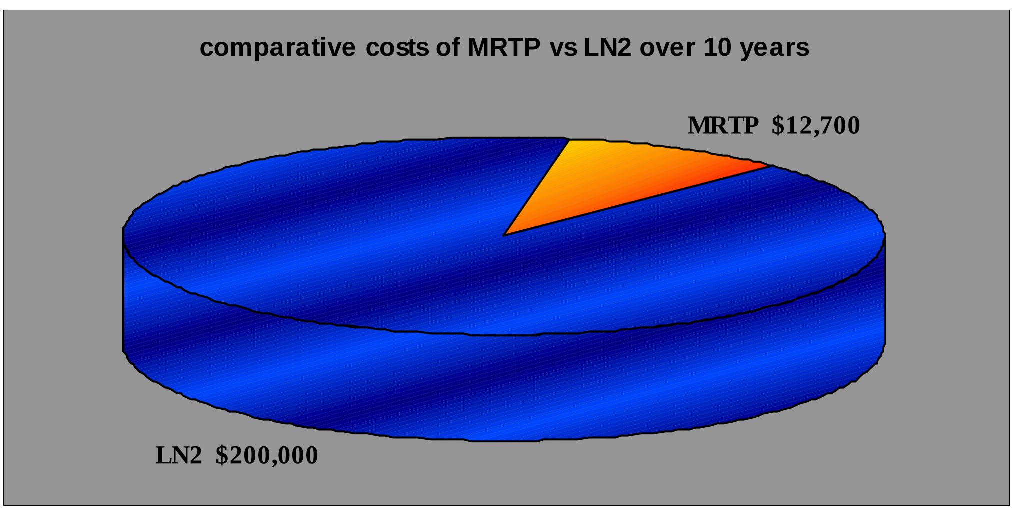
A re-think is necessary

Mechanically refrigerated systems require some re-thinking though. The systems must be properly sized to the job that they are expected to perform. With expendable refrigerants there is a virtually inexhaustible supply of available heat removal capacity. With mechanical refrigeration you essentially make what you need as you go along. Therefore it is very important that the system is capable of supplying the necessary heat removal capacity, which can be determined by considering four factors.

1. The total amount of heat that is dissipated by the device that is being tested.
2. The lowest temperature that the device under test must be cooled to.
3. The rate of temperature change in degrees C per minute that will be required.
4. The total weight of your device and the primary material that it is constructed of. With this information the mechanically refrigerated thermal cycling system can be properly sized to the application.

Conclusion

By far the most compelling reason to consider mechanical refrigeration as the source of DUT cooling in a thermal cycling system is cost. Consider Graph 3 showing the comparative costs between using mechanical refrigeration and expendable refrigerant over a ten-year period. The graph shows a thermal cycling scenario and the potential cost savings. In some cases, the cost savings returned by switching to mechanical refrigeration from expendable refrigerant can pay for the entire system in less than a year. The savings over ten years can be massive and the chart only represents the savings from a single test site.



Graph 3

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