Basic Comparison of Low Temperature Cooling Methods

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There are various cooling methods available today that can impact both equipment and product performance. This paper aims to give an overview of the pros and cons of some of the most commonly used methods, and offer the most effective use of each.

Methods and Descriptions:

Dry Ice is a solid form of carbon dioxide with a temperature of -78.5°C (-109.3°F) at atmospheric pressure. 1 pound of dry ice = 246 BTUs. It's colourless, odourless, non-flammable and slightly acidic. If the environment in which dry ice is used or stored is above -78.5°C the dry ice will sublime, meaning it will change from a solid to a gaseous state without going through the intermediary liquid state. Because of this phase change, the rate of which is heat dependant, dry ice is considered to be an 'expendable' refrigerant.

Dry ice is widely used in medical, industrial and scientific applications. Most applications involve breaking blocks of dry ice into pieces and placing them in a solvent in an insulated container and producing a slurry. The cold bath can then be used to remove heat from an intended application or used as a cold bath for maintaining the temperature of a product or process placed in the bath. In order to maintain the bath or process at a specific temperature, temperature control must be added.

Because dry ice is an expendable refrigerant, it must be constantly replenished, the rate of which is determined by the heat load imposed on the dry ice. For applications other than one-time use, dry ice must be regularly reordered so as to prevent running out and shutting down the process it's cooling. Additionally, dry ice must be stored in well insulated containers using valuable space. It must be transported from its storage site to the process site and must be broken into useable pieces to fit the process. The storage, transportation and breaking of the dry ice is costly (in addition to the cost of the dry ice itself), in that an individual must be assigned to perform these tasks.

Because of the low temperature of dry ice, inherent hazards exist. Prolonged exposure to dry ice can cause severe skin damage through frostbite. Because dry ice is solid carbon dioxide, as it sublimes it becomes carbon dioxide gas which displaces oxygen containing air which can result in asphyxiation if the area in which it is used is not properly ventilated.

Liquid Nitrogen (LN2) is liquefied nitrogen with temperature of -196°C (-321°F) at atmospheric pressure. 1 litre of LN2 = 152 BTU's. It's a colourless and odourless cryogenic liquid. When stored in well insulated containers it can be transported and stored for relatively long periods of time. Because no insulated container can eliminate all ambient heat input, the liquid nitrogen will begin to boil — the rate of which is dependent on the amount of heat input and form nitrogen gas. Because of the volatility of LN2 it is considered to be an 'expendable' refrigerant.

Liquid Nitrogen is widely used in medical, industrial and scientific applications. Because it's a liquid it can be used in baths for maintaining a process at a particular temperature or by piping the LN2 to a process to be cooled at a location away from the storage site of the LN2. The temperature of either of these applications can be controlled with the use of an LN2 controller, which regulates the amount of LN2 used, thereby maintaining a constant temperature in the bath or at the remote location. The cost for using LN2 can be significant because of plumbing, insulation, ventilation and other safety devices required for the use of LN2 in addition to the cost of the LN2.

Despite its reputation as an excellent cooling medium, its efficiency is limited by the fact that LN2 boils as soon as it comes into contact with a surface the temperature of which is greater than -196°C, enveloping the contacted material with insulating nitrogen gas. This phenomenon is known as the Leidenfrost effect applies to any liquid that comes in contact with a surface the temperature of which is significantly higher than that of the liquid contacting it. Cooling rates and efficiency can be enhanced by immersing an object into a slurry of LN2 and an appropriate solvent rather than LN2 alone.

Because of its extremely low temperature, inherent handling risks exist. Proper venting of nitrogen gas is necessary to prevent extreme pressure build up (liquid to gas expansion ratio is 1:694). Additionally, since nitrogen is colourless, odourless and tasteless, care must be taken to prevent asphyxiation from vented vapours.

Mechanical Refrigeration is accomplished by the use of a hermetically sealed system to provide a cold surface to satisfy heat removal applications. Mechanically refrigerated systems are most commonly electrically powered. The system in its most basic form consists of a refrigerant, compressor, condenser, refrigerant control device and evaporator. The refrigerant leaves the compressor as a gas and enters a condenser where, as the name implies, it condenses into a liquid. The liquid refrigerant then flows through the refrigerant control device and enters the low-pressure evaporator where it expands and through the process of evaporation, produces a cooling effect. The gaseous refrigerant then returns to the compressor and the cycle is continuously repeated. Heat dissipation in mechanically refrigerated systems must be addressed. Heat is generated from two main sources in the system — from the condenser and the compressor. This heat is either dissipated by ambient air movement through the system or by water cooling.

Mechanically refrigerated systems can be single stage, cascade, triple cascade or autocascade in design. The difference being the ultimate low temperature achieved at the evaporator that is dictated by the application or process to be cooled. Typically, a single stage system has an ultimate low temperature of -55°C, a cascade system of -100°C and a triple cascade of -130°C depending on the refrigerant or combination of refrigerants used. These systems are widely used in medical, industrial and scientific applications and are often used as a replacement for expendable refrigerants.

Because mechanically refrigerated systems are hermetically sealed they cool without the use of expendable refrigerants and for that reason, must be sized according to the application. In other words, a mechanically refrigerated system has a finite heat removal capacity at a given temperature. Mechanically refrigerated systems cooling capacity can be increased by increasing the volumetric displacement of the compressor, choice of refrigerant (and other considerations) at the time of design. Expendable refrigerants can increase cooling capacity simply by increasing the quantity of the expendable refrigerant being used.

Mechanically refrigerated systems are available in several basic configurations including: chamber coolers, immersion coolers or recirculating coolers. Each of these configurations can be modified to suit specific cooling applications depending on heat removal and temperature requirements.

	Dry Ice	Liquid Nitrogen	Mechanical Refrigeration
Advantages			
Readily increase heat removal	•	•	
Low temperature	•	•	•
Cryogenic temperature		•	
Readily available		•	
No expendable refrigerant cost			•
No handling			•
System sized for operating efficiency			•
No health risks			•
No safety issues related to ventilation			•
Disadvantages			
Ongoing cost of refrigerant	•	•	
Inventory to assure supply	•	•	
Space to store	•	•	
Specially insulated storage area	•	•	
Labor to handle/replenish	•		
Safety issues	•	•	
Expensive plumbing and insulation		•	
Initial purchase cost			•
Heat dissipation			•
Power consumption			•

Figure 1: Comparative Summary of advantages & disadvantages of different cooling techniques