Comparing refrigeration technologies

Standard refrigeration systems consist of several key components: a compressor, a condenser, and pressure drop device, and an evaporator. This system hasn't really changed in the last few decades, but the individual components have seen optimizations and key technological advances which have significantly impacted the performance and efficiencies of cold storage equipment. Unlike standard refrigerators, an ultra-low temperature freezer uses two refrigeration systems working in tandem to achieve the extremely cold temperatures of -80°C. There is only one different system on the market, the Stirling engine, but in general, the principles of refrigeration remain the same.

Key Takeaways/Benefits/Separating Features

- A refrigeration cycle requires the acting coolant to be "colder" than the chamber in which the heat is expected to be removed. Refrigeration is simply the transfer of heat from one location to another.
- Understanding refrigeration components and refrigeration cycle:
  - Compressors change the pressure of the working fluid (low pressure, low temperature gas to a high pressure, high temperature gas.
  - Condensers take a high pressure gas and change it into a high pressure liquid.
  - Pressure drop devices (metering devices like a capillary tube or throttling valve) drop the pressure and temperature of the liquid.
  - Evaporators absorb heat from the cabinet, changing the fluid from a low temperature, low pressure liquid to a low temperature low pressure gas.
- A ULT freezer uses two of these systems in parallel. The "high" stage system gets the working refrigerant (fluid) down to about -45°C and the "low" stage system gets the working refrigerant (fluid) down to about -90°C. When the low stage absorbs heat from the refrigerated space or cabinet, it transfers this heat to the first stage. The first stage then expels this heat into the ambient environment.
- Newer systems utilize high efficiency components like variable speed compressors and microchannel condensers. Variable speed compressors are capable of running a different speeds which allow them to change the rate at which the refrigerant moves throughout the system – this in turn varies the cooling capacity of the system. What does this mean to a user? Well, now a single system can operate at multiple temperature setpoints without sacrificing sample temperature. This means tighter overall cabinet temperatures without wasting energy or money.
- There is one more key component we haven't mentioned – the refrigerants. Because of new global regulations, the use of refrigerants that have shown to have negative impacts on the environment (mainly hydrofluorocarbons or HFCs) is being phased out. Cleaner hydrocarbon refrigerants like propane and ethane are now being used. In addition to being better for the environment, the hydrocarbon refrigerants promote lower pressures and temperatures in the refrigeration system. This drastically improves the mechanical wear and tear on the refrigeration components – extending the life of the system. Additionally, hydrocarbon refrigerants improve overall performance: better peak variation, lower energy, and lower noise.

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Comparing systems of top ULTs:

Thermo Scientific™ TSX Ultra-Low Temperature Freezers: 2-stage cascade hydrocarbon refrigeration system

- **Benefits:** Improved performance (lower energy, lower peak variation, lower noise).
- **Focus areas:** Compressors systems are mechanical in nature and mechanical devices can wear. TSX compressor failure rates are less than 0.13%.

PHCBi™ VIP ECO MDF-DU702VH: 2-stage cascade hydrocarbon refrigeration system (Embraco™ compressors same as TSX)

- **Benefits:** Improved performance (lower energy, lower peak variation, lower noise)
- **Focus areas:** Compressors systems are mechanical in nature and mechanical devices can wear. Location of the control sensor that dictates the turning on/off of the refrigeration system does not correspond with the actual cabinet temperature. Data shows there is a 4-5°C temperature difference between the control sensor and the cabinet temperature.

Stirling Ultracold™ SU780XLE: Stirling engine with thermosiphon and evaporator

- **System:**
  - Uses ethane as the working evaporator fluid.
  - Stirling engine is the "compressor" which changes the pressure of the working fluid (helium) in the engine.
- **Benefits:** Lowest steady-state energy on the market.
- **Focus areas:** Low energy comes at a cost of sample temperature security. Peak variation is higher in the Stirling. Door opening recovery is significantly longer than the TSX or ECO. Stirling engine uses mechanical components (like a compressor) including springs which expand and compress constantly. This 100% runtime of these components will inevitably lead more quickly to mechanical failure.

In review

All cold storage equipment does one thing – they take heat from one location and move it to another. This seems easy enough, but when we are talking about temperatures moving from ambient (20°C/68°F) to extremely cold temperatures like -80°C (-112°F), it requires a more sophisticated refrigeration system. Cascade refrigeration uses to systems working in tandem to move heat from the cabinet into the refrigerant which is passed from the low (cold) stage system to the high ("warm") stage system before it is rejected from the unit as heat to the surrounding environment. For decades these systems have been built on the same basic design principles, and these are the same today. One manufacturer utilizes a different system, Stirling. But in practice the principles of compression – condensing – expansion-evaporation are still the same.

If the systems are effectively operating in the same manner, how do we distinguish between them? This is where the system efficiencies and reliability come into question. Not all components themselves are equal, and a properly designed system is optimized with selected components to drive the most efficient and effective overall unit performance. Additionally, each component needs to be reliable in order for the system itself to last. Some may say compressors are unreliable, but "compressors" have been and are used in almost every refrigerator and freezer, HVAC unit, and vehicle air conditioning systems. The reliability comes in the construction of the component and the operating environment that component is subjected to. From a component perspective, the concerns are moving parts and mechanical wear. No matter what device is used, either a Stirling engine or a conventional compressor – there are moving parts. Not all moving parts stand up to mechanical wear and operation. Stirling engines uses springs to actuate the "compression" cycle. These will inevitably wear out. We can't say the compressors used on Thermo Scientific's hydrocarbon refrigeration systems will last longer than others, but we can say that our units operate at lower pressures, lower temperatures, and lower stress than older generations products. The compressor failure rate of our TSX ULTs is less than 0.13%; you be the judge.

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