Improving Temperature Uniformity at -86 C in a Mechanically Refrigerated Ultra-low Freezer by Reducing Compressor Discharge Temperatures and Apportioning Energy Management between Low and High Stage Cooling Circuits

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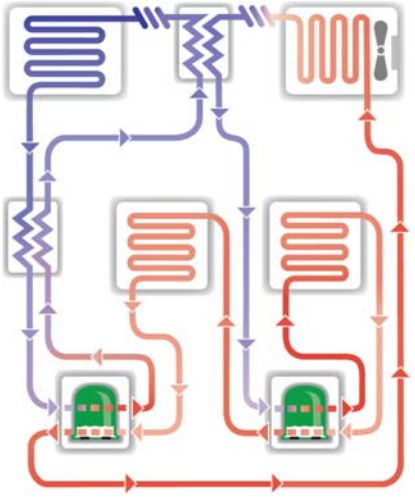


Figure 1. The SANYO cascade refrigeration system employs two independent refrigeration circuits indirectly connected by an inter-stage heat exchanger. SANYO's proprietary integrated lubricating oil cooling system automatically apportions the workload between compressors and permits both compressors to operate well within the expanded performance envelope.

Abstract

The development of an application-specific refrigeration compressor for use in a mechanically refrigerated cascade system results in lower compressor discharge temperatures, more balanced workload between high and low stage compressor systems, and more efficient location of evaporator systems around the interior chamber in the -86 C ultra-low temperature (ULT) freezer. As a result, the freezer provides the chamber temperature uniformity necessary for stability of stored product, viability of frozen biological materials, and accurate monitoring of operating anomalies. This report examines new compressor technology specifically for use in ultra-low temperature freezers (Sanyo Commercial Solutions, Bensenville, IL) and how this new technology will enable biorepositories and laboratories to comply with new recommended practices emerging from federal agencies such as those expressed in First Generation Guidelines for NCI Supported Biorepositories.[1]

Introduction

Depending on desired protocols, preservation of biological materials requires storage at temperatures ranges from -10 C to -40 C, -86 C, and even as low as -150 C or colder. Because material stored in these freezers is of such a high value, or even irreplaceable, the potential for freezer failure is not an acceptable risk. Ultra-low freezers require two compressors working together, so these units are critical to the operation.

Cause and effect

The challenges of maintaining reliability in an ultra-low refrigeration system relate to the system as a whole, and most specifically to the compressor, compressor motor and wrist pins integral to the design.

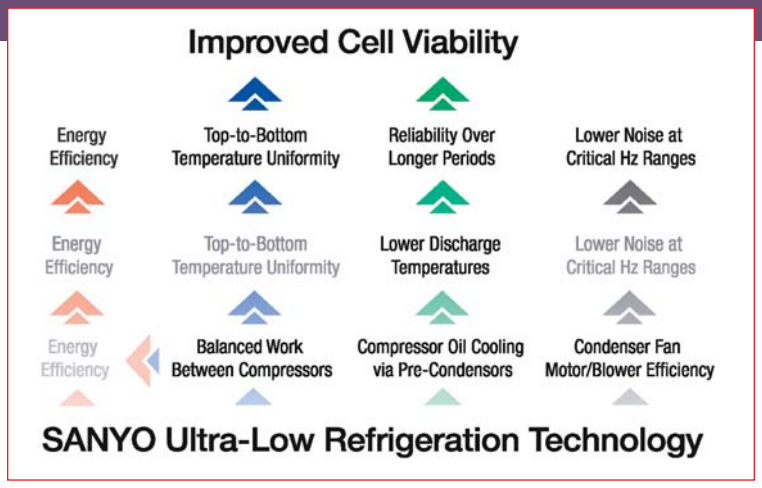
■ Commercial air conditioning compressors, which are sometimes used by ultra-low temperature freezer manufacturers, are not designed for ultra-low temperature applications. In ultra-low circuits, these compressors are subjected to higher than normal operating pressures in the effort to achieve and sustain evaporator temperatures. Operating pressures generate heat. These pressures demand more compressor motor torque to accommodate start-up as well, adding more stress.

■ Refrigeration oil required to lubricate internal compressor components can break down chemically over time, resulting in poor component lubrication, additional heat, and a reverse cascade effect of heat generating more heat.

■ Operating conditions in laboratories, hallways, mechanical rooms and repositories are less than ideal. Most freezer installations are compromised by a variety of factors: lack of air conditioning in labs or hallways; low voltage at the freezer connection; voltage fluctuations and power surges; lack of adequate ventilation; dust and particulate build-up on condenser fins surrounding condenser tubing; frequent freezer-door openings; and poor sample-handling techniques, such as the introduction of large amounts of warm or room temperature product without pre-freezing.

■ Despite advances in refriger-

Performance	SANYO	Brand A	Brand B	Brand C
Temperature Uniformity Range (setpoint @-80°C	5.8°C	9.0°C	12.5°C	7.7°C
Temperature, Top of Chamber (setpoint @-86°C	-86.0°C	-77.5°C	-81.4°C	-81.4°C
Max Warming Point,10 Sec.Opening (10 second highest inner door opening)	-75.0°C	-34.3°C	-57.7°C	-76.8°C
Noise Level (1 meter from unit)	43.8 dB(A)	51.7 dB(A)	52.0 dB(A)	72.0 dB(A)



ant chemistry, oils and lubricating additives, today's environmentally friendly non-CFC refrigerants are not as efficient as earlier CFC-based ozone depleting refrigerants of the past.

Compressor and cabinet development

SANYO developed a proprietary refrigeration compressor specifically for ultra-low freezer applications, designed to meet the requirements of ultra-low temperature operation using new, environmentally safe refrigerants. Concurrent with refrigeration system research, a composite cabinet wall was developed based on a combination of conventional, high-density foamed-in-place insulation and vacuum insulation panels (V.I.P.) permitting a thinner wall profile and increased interior volume. This design provides more storage volume in the same footprint.

Since the original V.I.P. design was introduced, company researchers improved the open cell panel technique, creating better matrices to support sustainable vacuum and permitting manufacturing engineers more latitude in composite orientation with conventional foam. As a result, evaporator coils within the thin-wall SANYO cabinet are arranged for interior uniformity and best heat removal (energy transfer), further reducing the burden on the cascade refrigeration system.

A better compressor yields better uniformity and improved reliability

Heat from multiple sources contributes to compressor wear. Heat is generated by compressors working to compress low density refrigerants required in the low-stage of the cascade loop. Additional heat is absorbed by room temperature product placed into the freezer, as well as migration from the ambient environment.

In research and development, prototype compressors were tested under harsh environmental conditions to exceed actual freezer use in typical labs. Life testing and tear downs delivered critical data, permitting beta test results to be synthesized into the complete design program.

Design mandate: reduce discharge temperature

SANYO's new ultra low temperature compressor employs a unique orientation of conventional components to reduce discharge temperatures and compressor heat while using commercially available refrigerants and lubricants. Heat reduction results are as low as 25 C below previous SANYO compressors.

At the heart of the new compressor is an oil cooling loop that reapportions the working heat byproduct between the low stage compressor and the high stage compressor. Due to low molecular weights in low stage refrigerant formulations, low stage compressors must work harder to achieve cooling targets. The new technique uses existing lubricating oil to cool the low stage compressor, passing the resulting heat load to the high stage compressor.

By shifting a portion of the burden from the low stage to the high stage, the load is balanced on both compressors while reducing operating pressures and keeping heat loads and discharge temperatures well within tolerances required to prevent chemical breakdown of oils and refrigerants. As a result, refrigeration capacity is expanded and structural engineers have more latitude in strategic application of evaporator coils around the interior chamber, a key to temperature uniformity and, ultimately, to cell viability.

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Applying the benefit

With lower compressor discharge temperatures and pressures, newer refrigerants can be more effective. This combines with the VIP insulation to minimize the migration of ambient heat from the lab to the interior. Evaporator wrapping concealed within the composite wall is wrapped around the interior chamber to achieve best energy transfer and leverage common physical properties of cold air density within the storage area.

Compressor run time/ power consumption

The ultra-low system's high-stage and low-stage compressors is controlled by the Status 3 microprocessor control system. By design, the high-stage compressor runs 100% of the time, permitting the low-stage compressor to cycle on demand for cooling from the interior chamber, reducing high head pressures on the low-stage system, permitting easier start-up and reducing energy demand. Since conventional cascade refrigeration systems cycle both systems On and Off, the high and low stage compressors must "step start" nearly simultaneously or with a slight delay. This imposes a high power demand. The phenomena of high-temperature "in-rush currents" over time can weaken and degrade compressor windings resulting in compressor failure.

Conclusion

By apportioning the oil cooling function between specially designed SANYO compressors, and by cooling the compressor oil to minimize compressor operating temperatures, the SANYO ultra-low tem-perature freezer refrigeration system is balanced to decrease component stress, increase system lon-gevity and reliability, and improve temperature uni-formity necessary for better cell viability regardless of where the specimen is stored within the chamber.

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