

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

## SYNOPSIS

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 freezer. As a result, the freezer delivers better chamber temperature uniformity necessary for stability of stored product, better viability of frozen biological materials, and more accurate monitoring of operating anomalies that may warrant investigation by service personnel in advance of maintenance problems. This report examines new compressor technology developed by SANYO specifically for use in the ultra-low temperature freezer, 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<sup>2</sup>.

PERFORMANCE	SANYO	Brand N	Brand R	Brand F
Temp Uniformity Range (setpoint @ -80°C)	4.2°C	9.0°C	12.5°C	7.7°C
Chamber Temp. Top (setpoint @ -86°C)	-86.0°C	-77.5°C	-81.4°C	-81.4°C
Max Warming Point, 10 sec. Opening (10 second 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)

(RIGHT:) SANYO Model MDF-U73VC with optional sliding drawer racks holds up to 57,600 1.8ml vials in a compact 9.5 sq.ft. footprint.



### Introduction

Enhancing the viability of biochemical and biomedical products is essential in today's life science market. Depending on desired protocols, preservation of biological materials requires storage at temperatures ranges from -10°C to -40°C, -86°C and as low as -150°C or colder. Because material stored in these freezers is of such a high value, or irreplaceable altogether, the potential for freezer failure is no longer considered an acceptable risk in the life science community.

### Basic Ultra Low Temperature Refrigeration System

Due to the significant temperature differences between ambient (room temperature) and the freezer (-86°C), two systems are required for incorporating individual compressors and refrigerants with different boiling points for absorption and dissipation of heat. A single refrigerant does not have the physical properties to cover such a wide temperature range. Thus, ultra-low temperature freezers employ a cascade refrigeration technique whereby two independent refrigeration circuits operate in a "high stage" and "low stage" configuration.

### SANYO Compressor Development

Since mechanically refrigerated ultra-low temperature freezers were adopted into the mainstream scientific community in the late 1940s, research investigators have learned that storing biological materials at colder temperatures enhances cell viability by reducing metabolic activity. Biological products can be sustained for longer storage periods at lower temperatures provided protocols for sample preparation and pulldown to storage temperature match scientific methods. SANYO, a global leader in the design and manufacture of laboratory environmen-

tal control equipment, has developed a proprietary refrigeration compressor specifically for ultra-low freezer applications. Bypassing the commercial air conditioning sourcing model, SANYO has successfully tested and refined its own compressor to meet the physical challenges of ultra-low temperature operation using new, environmentally safe refrigerants. Collaborating with industry leaders in refrigeration chemistry, lubrication pathways, natural and synthetic oils, and cabinet insulation technologies, SANYO engineers have created a highly reliable ultra-low temperature freezer based on the performance of compressors doing the work they were specifically designed to do.

### Cabinet Design Prerequisites

Concurrent with refrigeration system research, SANYO pioneered the development of a composite cabinet wall based on a combination of conventional, high-density foamed-in-place insulation and new, state-of-the-art vacuum insulation panels (SANYO VIP®, U.S. Patent No. 6,260,377) permitting a thinner wall profile and increased interior volume. This design optimizes use of available laboratory space by permitting more storage in the same footprint.

### Key Compressor Components

Each component of the new SANYO compressor has been electronically designed and modeled in stereolithographic beta form to exceed actual operating conditions. Pistons, connecting arms, valve plates and wrist pins are designed to handle high load capacities. All testing is performed in a +35°C ambient.

Proper delivery and return of lubricants is a key factor in extending component life. Compressor motor sizing is predicated on

refrigerant flow as well as energy required for initial pull down, and then sustained ultra low temperature with reserve capacity. Motor windings are configured to accommodate fluctuating electrical supplies in many institutional settings. At the same time, SANYO's commitment to "green products" is expressed through more efficient motor operation with reduced energy consumption.

### 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 the SANYO research and development laboratory prototype compressors were tested under harsh environmental conditions to exceed actual freezer use in typical labs. Because SANYO controls its own compressor design, all amendments and re-engineering options were explored as needed, with new prototypes brought into test quickly. Life testing and tear downs delivered critical data to SANYO engineers, permitting beta test results to be synthesized into the complete design program in support of the global ultra-low freezer program.

### Design Mandate:

#### Reduce Discharge Temperature

SANYO's new ultra low temperature compressor employs a unique orientation of ional components to reduce (continued)

My life. My work. My choice.

discharge temperatures and compressor heat while using commercially available refrigerants and lubricants. Heat reduction results range from as low as 25°C below previous SANYO compressors and more than 40°C below leading brand compressors used by numerous competitors.

At the heart of the SANYO solution is a compressor 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 SANYO technique uses existing lubricating oil to cool the low stage compressor, passing the resulting heat load to the high stage compressor which, by design, is already doing less work.

By shifting a portion of the burden from the low stage to the high stage, SANYO balances the load 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.

#### Applying the Benefit

With lower compressor discharge temperatures and pressures, newer refrigerants can be more effective. Combined with SANYO's patented VIP® insulation (vacuum insulated panel), the migration of ambient heat from the laboratory to the interior is minimized. 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.

#### Smart Refrigeration Monitoring System

While compressor improvements have led to more efficient refrigeration performance, SANYO engineers have tapped the company's extensive resources in electronics and controls to develop the SANYO Status 3 control, alarm and security system. More than just a controller, the SANYO Status 3 collects internal data from waypoints deep within the cascade refrigeration system, and processes this information by comparing to normative values written to the on-board algorithm. This continuous, self-diagnostic protocol is automatic. If values range beyond those written to the factory-based performance permissions, the SANYO freezer will display an advisory signal on the main control panel.

#### Run Time Data

High ambient temperatures, numerous or prolonged door openings, and introduction of warm or room temperature product into the freezer storage compartment can cause prolonged refrigeration system run time. The SANYO Status 3 monitors compressor run time and performs diagnostics based on ambient temperatures, door openings, voltage and other usage factors. If the low-stage compressor run time is inordinately high, the Status 3 will notify the user that the system and installation should be reviewed. These calculations are based on the following:

- Length of time from previous door opening
- Operating time below set point
- Ambient temperature

In simple terms, the freezers senses when it is overloaded or operating under stress. The SANYO Status 3 warning system will alert the user of this condition in advance of any pending performance issues.

#### Compressor Run Time/ Power Consumption

The SANYO ultra-low system employs a high-stage and low-stage compressor controlled by the Status 3 microprocessor control system. By design, SANYO high-stage compressor runs 100% of the time, permitting the low-

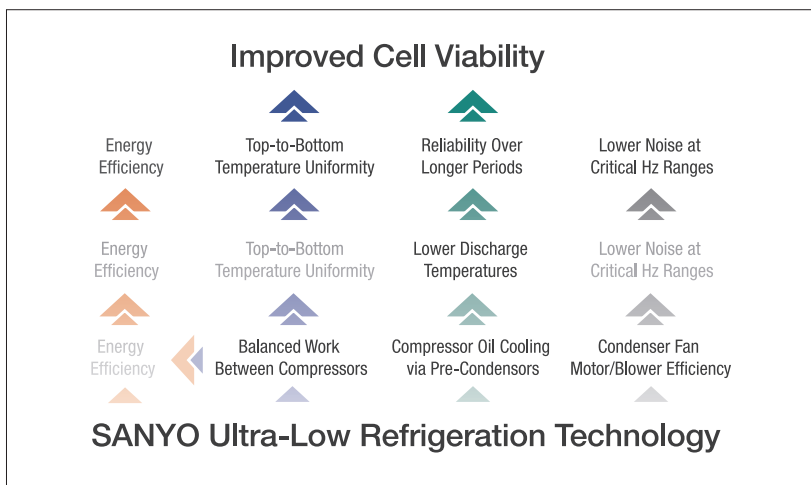
stage compressor to cycle on demand for cooling from the interior chamber, reducing high head pressures on the low-stage system, permitting easier start-up and reducing energy demand. Since conventional cascade refrigeration systems cycle both systems On and Off, the high and low stage compressors must "step start" nearly simultaneously or with a slight delay. This requires a high power demand for two systems to start, and can trip a circuit breaker during periods of high electrical demand.

The phenomena of high-temperature "in-rush currents" over time can weaken and degrade compressor windings resulting in compressor failure. New SANYO compressors feature oversized windings designed to anticipate and accommodate in-rush currents within the normal performance envelope to mitigate compressor degradation due to frequent start-ups.

#### Thinking Green, Thinking Safe®

SANYO is conscious of the need to protect our environment and conserve energy. As a corporate pioneer in life science laboratory equipment and appliances, and as a global source of solutions ranging from energy management to solar power and alternative energies, SANYO remains committed to providing the best possible laboratory equipment for research and clinical needs. This commitment was demonstrated when SANYO took the initiative to revamp and redesign newer refrigeration systems that would employ new, environmentally-friendly refrigerants throughout the laboratory without compromising performance.

5. Federal Register, Entela, Inc., Expansion of Recognition. - 64:11501-11502; Publication Date: 03/09/1999; Publication Type: Notice; Fed Register #: 64:11501-11502; Standard Number: 1910.7; 1919.7; Title: Entela, Inc., Expansion of Recognition. U.S. Department of Labor, Occupational Safety and Health Administration, Docket No. NRTL-2-93.



#### Conclusion

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



**SANYO Commercial Solutions**  
A Division of SANYO North America  
1062 Thorndale Avenue, Bensenville, IL 60106 USA  
Toll Free USA 800-858-8442 • Fax 630-238-0074  
www.sanyobiomedical.com

SANYO Canada, Inc.  
1-300 Applewood Crescent • Concord, Ontario L4K 5C  
Phone 905-760-4025 • Fax 905-760-9945