TECHNICAL DEVELOPMENT REPORT

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SANYO

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

Joe LaPorte and Mistry, Deepak M., SANYO Commercial Solutions, a Division of SANYO North America Corporation[1]

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[2].

(RIGHT): SANYO Model MDF-U73VC with optional storage 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 temperature 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.

Simple Refrigeration Principles

A mechanical refrigeration system is designed to remove heat (or move energy) from one location and transfer it to another. Key components in a refrigeration system include a compressor, a cabinet for the stored perishable product, evaporator, condenser and refrigerant. The evaporator is wrapped around the top, sides and back wall of the interior chamber within the cabinet insulation. The compressed refrigerant liquid passes through the evaporator where it flash expands into a vapor and absorbs heat. The compressor moves refrigerant through the system and compresses the vapor into a high pressure liquid in the condenser. The condenser releases the heat to the ambient environment and the process continues on demand from the controller so that the interior chamber remains at the desired setpoint.

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. *(See Illustration 1, SANYO Cascade Refrigeration System.)*

In the cascade process, the low stage system removes heat from the product located in the interior chamber. These products typically include vials, bags, canisters or other commonly used storage containers or labware selected for archival use. Heat from this stored product is absorbed by refrigerant gas in the evaporator tubing wrapped around the interior chamber and concealed in the insulation. This heat is transferred to an interstage heat exchanger where it is passed off to the high stage system and ultimately released to the ambient as room air is circulated through the condenser coils by a motor/blower/fan assembly. The interstage heat exchanger serves as the evaporator for the high stage system.

1. Joe LaPorte is National Service Manager and Deepak M. Mistry is Scientific Products Marketing Manager, SANYO Commercial Solutions, a Division of SANYO North America Corporation

2. Federal Register / Vol. 71, No. 82 / Friday, April 28, 2006 / Notices Re: Department of Health and Human Services, National Institutes of Health, First-Generation Guidelines for NCI Supported Biorepositories. Agency: National Institutes of Health (NIH), National Cancer Institute (NCI).

Compressor
The most important component of any mechanical refrigeration system is a reliable compressor. Because ultra-low freezers require two compressors working together, these compressors are particularly critical to the operation. Most ultra-low freezer manufacturers acquire their compressors on the open market from commercial suppliers who also market their products to air conditioning, refrigeration, supermarket, food and beverage, consumer goods and other commercial/industrial OEM customers. In terms of unit production, compressors sold for ultra-low temperature applications comprise a very small fraction of overall compressor production worldwide. As a result, ultra-low freezer manufacturers must make concessions to adapt open market compressors to highly refined ultra-low systems.

Because relative demand and economies of scale dictate how compressor manufacturers serve their markets, manufacturers of ultra-low freezers, classified as OEM customers, have little leverage in compressor design and/or adaptation to mass produced product required to overcome heat and lubrication challenges presented in the ultra-low environment. In some cases, compressor manufacturers will not warrant their products to the OEM customer if the compressors are used in high-stress ultra-low applications. This in turn affects the scope and nature of the freezer manufacturers' warranty to the customer.

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 are not designed for ultra-low temperature applications. In ultra-low circuits, these compressors are subjected to higher than normal operating pressures required to achieve and sustain evaporator temperatures. Operating pressures generate heat. These pressures demand more compressor motor torque to accommodate start-up and to maintain ultra-low temperatures, thus adding stress and potentially more heat into the system.
- Some ULT Freezer manufacturers increase the compressor motor horsepower in an attempt to overcome these issues. If the total refrigeration system is not properly balanced, however, excess motor capacity simply adds heat to the system.
- 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 lack of air conditioning in laboratories or hallways, low voltage at the freezer connection, voltage fluctuations and power surges, high ambient temperatures and lack of adequate ventilation, dust and particulate build-up on condenser fins surrounding condenser tubing, frequent freezer door openings and poor technique such as introduction of large amounts of warm or room temperature product without pre-freezing.
- Despite advances in refrigerant 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.

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 environmental 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.

Since the original VIP design was introduced, SANYO researchers developed proprietary improvements in the open cell panel technique, creating better matrices to support a 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 optimal interior uniformity and best heat removal (energy transfer), further reducing the burden on the cascade refrigeration system.

PERFORMANCE	SANYO	Brand N	Brand R	Brand F
Temp Uniformity Range (setpoint @ -80˚C)	**5.8**˚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 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)

SANYO Comparison Chart, Uniformity, Noise

A byproduct of the SANYO design permits a hot gas bypass to circulate around the peripheral edges of the cabinet door gasket, warming the gasket to mitigate the build-up of moisture to prevent ice formation or mold on external services.

Vertical Component Integration
The concept of Vertical Component Integration is central to SANYO's entire product line. SANYO manufactures its own oil separators, circuit boards and vacuum insulation panels, and designs its own compressors. This integrated supply chain assures component quality from source to application, and permits SANYO to evaluate and improve its own components without third party involvement.

Together with other refrigeration system components such as filter dryers, heat exchangers, condenser and evaporator tubing, metering devices, motor windings and sophisticated microprocessor-based electronic controls, SANYO has created a holistic solution to biological preservation.

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 conventional components to reduce 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.

If a condition self-corrects (as most do in highly fluctuating environments), the signal will switch off. If the condition persists, however, the signal will notify the user that a professional assessment of freezer performance is required. Oftentimes, this assessment can be initiated by a quick query of on-board data from the controller, conducted by in-house facilities maintenance personnel familiar with standard ultra-low freezer operations.

3. Testing and Evaluation: Consumer Advisory Performance testing and published data on SANYO ultra-low temperature freezers is based on extensive testing in a +35°C ambient to simulate worst-case conditions. When comparing performance of competitive ultra-low freezers it is important to establish and verify conditions under which tests are performed. Tests performed at temperatures below +35°C may exhibit lower compressor discharge temperatures; these discharge temperatures are not typical of real-world conditions, however, and should be used with caution when evaluating new or replacement freezer selection. For summary information on SANYO test conditions contact SANYO.

Status 3 Functions

High Ambient Conditions

- The SANYO Status 3 system tracks high ambient (room or hallway) conditions which can occur periodically, but are not recommended for long term operation. These usually constitute ambient temperatures at or above +35°C. Repeated excessive ambient readings will activate the warning and the user must investigate the reason for the high ambient condition. The SANYO freezer will continue to function, but subjecting the freezer to extreme ambient conditions results in longer refrigeration run time and higher energy costs.

Low Voltage

- Low voltage is common in many laboratories due to increased power demand in clinical and research environments, drug discovery, storage and processing. These conditions are most common in older institutions or those that have been retrofitted for laboratory use.
- Often, freezer users mistakenly assume that proper power (120 volts or 208/230 volts) is readily available and sustainable at the wall electrical outlet. Often, however, supply voltage is erratic and usually lower than desired for proper freezer operation. The SANYO Status 3 detects low voltage and warns the user through the freezer control panel monitoring system. When this notification occurs, building maintenance or facilities engineering personnel should be contacted to investigate the issue.
- To protect the valuable stored product, SANYO ultra-low freezers with voltage enhancement systems will automatically correct the voltage through an internal transformer and boost the voltage to the proper level.

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 freezer 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[4]

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.

CFC Free Refrigerants

- SANYO was the first ultra-low freezer manufacturer to employ non-HCFC R508 low-stage refrigerant, now recognized as today's industry standard and widely available. This non-proprietary refrigerant is available to refrigeration service professionals on the open market.
- The high stage refrigeration system is a mixture of R134a and R410a (Puron®), available to refrigeration professionals on the open market as well.

Continued on back page.

4. SANYO has established a corporate-wide initiative – Think GAIA – to emphasize the company's commitment to energy conservation and environmental integration. GAIA, which stands for "the living earth", suggests that the earth is a green organism where mankind and all livings things exist in harmony. By treating the Earth as a living organism, SANYO is creating products needed to promote harmony with this precious planet. In practice, GAIA is a threefold approach consisting of action on environmental, energy and lifestyle fronts. In each of these areas, SANYO is redefining conventional ideas and taking advantage of unique technological resources to propose global solutions for the Earth and all living things.

Low Stage Capillary Tube.
Liquid refrigerant under pressure is passed through the capillary tube where it flash evaporates in the low stage evaporator to absorb energy (heat) from the product stored in the freezer.

Freezer Cabinet with Evaporator.
The evaporator coil is strategically wrapped around the interior chamber and concealed within the composite wall of vacuum insulation panels and conventional foamed-in-place urethane insulation.

Low Stage Refrigerant.
Commonly available worldwide, R508.

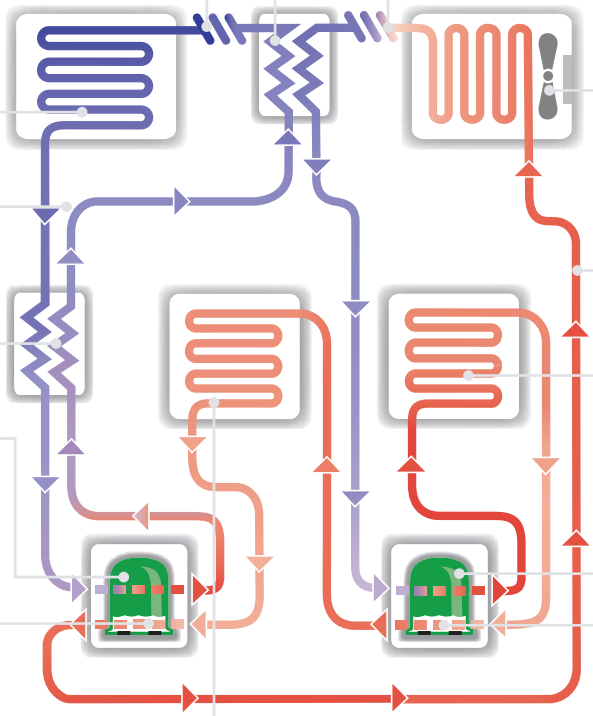
Low Stage Heat Exchanger.
Energy is absorbed by the refrigerant gas and transferred to the low-stage heat exchanger to cool discharge gas.

Low Stage Compressor.
The compressor pumps refrigerant through the low stage circuit.

Low Stage Oil Reservoir.
High stage refrigerant passes through the low-stage oil sump to cool lubricating oil resulting in high-stage compressor energy being used to minimize the workload on the low stage compressor.

Air Cooled Pre-Condenser.
Removes energy (heat) from the high stage refrigerant enroute to the low stage compressor.

Interstage Heat Exchanger.
Energy is transferred to the high stage circuit.



High Stage Capillary Tube.
Liquid refrigerant under pressure is passed through the capillary tube where it flash evaporates in the interstage heat exchanger to absorb energy (heat) from the low stage refrigerant circuit.

Main Condenser and Motor/Fan Assembly.
The motor/fan assembly blows ambient air across condenser coils to move energy (heat) from the high stage refrigerant to the ambient environment.

High Stage Refrigerant.
Commonly available worldwide. A combination of R134a and R410a (Puron®) selected for optimum cooling performance in compliance with international environmental protection laws.

Air Cooled Pre-Condenser.
Removes energy (heat) from the high stage refrigerant enroute to the high stage oil reservoir.

High Stage Compressor.
The compressor pumps refrigerant through the high stage circuit.

High Stage Oil Reservoir.
High stage refrigerant passes through the high stage sump to cool lubricating oil en route to the low stage compressor through the air-cooled pre-condenser.

Instrumentation *(Not Shown). Temperature and pressure sensors throughout the high and low stage circuits transmit information to the SANYO Status 3 central controller for operation, monitoring and interpretation.*

Figure 1, SANYO Cascade Refrigeration System:
The SANYO cascade refrigeration system employs two independent refrigeration circuits indirectly connected by an interstage heat exchanger. SANYO's proprietary integrated lubricating oil cooling system[6] automatically apportions the workload between compressors and permits both compressors to operate well within the expanded performance envelope.

SANYO ULTRA-LOW TEMPERATURE FREEZER TESTING PROTOCOL

Ambient Temperature During Test	+35°C. Important: Performance testing and published data on SANYO ultra-low temperature freezers is based on extensive testing in a +35°C ambient to simulate worst-case conditions. When comparing performance of competitive ultra-low freezers it is important to establish and verify conditions under which tests are performed. Tests performed at temperatures below +35°C may exhibit lower compressor discharge temperatures; these discharge temperatures are not typical of real-world conditions, however, and should be used with caution when evaluating new or replacement freezer selection. For summary information on SANYO test conditions contact SANYO.
Voltage Range During Test	Variable. For 220V, AC, 60Hz models testing is conducted over voltages ranges starting as low as 202V to simulate brown-out conditions typical of real-world installations.
Freezer Load During Test	Variable. Thermal mass of a fully loaded freezer at equilibrium under normal ultra-low temperatures yields the best performance data. SANYO freezers are tested under empty, half-load and full-load conditions.

6. SANYO, U.S. Patent Pending

CFC Free Refrigerants continued from page 5

RoHS Compliance

- In 2006, RoHS (Restriction of Hazardous Substances) legislation (EU Directive 2003/95/EU) became effective. RoHS relates to the restriction of hazardous substances and reductions in environmental pollution.
- Through RoHS legislation the EU and other participating countries are banning toxic substances in electrical equipment such as lead, cadmium, mercury, chromium 6+, PBB and PBDE.
- While compliance with this legislation has posed a significant challenge for SANYO, all SANYO ultra-low freezers and components are now 100% compliant to RoHS standards.

Electrical Standards

- All SANYO products including ultra-low temperature freezers are tested and certified by Entela[5] NRTL (National Recognized Testing Laboratory) to assure compliance with US and International standards for electrical safety prescribed in 29 CFR 1910.7(c). SANYO has selected Entela for independent testing to accelerate testing on new products while maintaining the highest standards for quality, safety and performance.

Noise Reduction

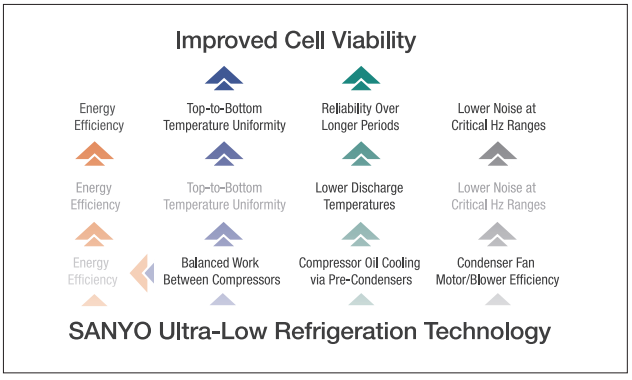
- Ultra-low freezers are often located within research and hospital laboratories or production facilities. Users prefer close proximity for easy access to valuable stored products.
- If operating noise from refrigeration compressors is excessive, and/or compounded by installation of multiple freezers in adjacent locations, the working environment is severely compromised.
- SANYO has included advanced noise abatement in all contemporary ultra-low freezers and noise reduction levels are well below those of competitive freezers. Data is available upon request.

Inventory Management

- Those familiar with the technical design of the SANYO ultra-low freezer can draw a quick connection between lower compressor discharge temperatures and better, more efficient inventory management.
- Because benefits of the SANYO compressor design extend to evaporator tubing surrounding the interior chamber, and the interior chamber is part of the thin-wall composite based on the patented VIP® vacuum insulation panel cabinet, SANYO can offer more useable storage volume within the same sq.ft. of floor space than competitive models.
- The concept of High Density Storage is enabled by advances in SANYO compressor design. The cost per cu.ft. (or liter) of interior storage space is significantly lower in a SANYO ultra-low freezer, generating immediate return on investment based on first costs, operating costs and maintenance costs over time.
- Additionally, the placement of evaporator surfaces within the cabinet walls achieve exceptional documented ultra-low temperature uniformity, thereby permitting investigators more freedom in placing valuable cell lines and biologicals within the interior cabinet, and assuring uniform cell viability when harvesting products from the ultra-low archive.

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 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.



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.

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