CRYOGENIC INDUSTRIES

# FrostByte

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## A New Paradigm in $CO_2$ Recovery

With the recent installation of its newest $CO_2$ recovery system, Wittemann has set a new precedent in recovering $CO_2$ from an ammonia ($NH_3$) production process. The system was designed, fabricated and commissioned for PAK ARAB in Multan City, Pakistan.

Prior to recovering carbon dioxide, an ammonia-producing plant must first convert natural gas into gaseous hydrogen by means of "steam reforming." Steam ($H_2O$) is mixed with natural gas, then heated and passed over a catalyst to form hydrogen (H), carbon monoxide (CO) and carbon dioxide ($CO_2$). Further processing yields a stream of a relatively "pure" $CO_2$, available as feed stock to the Wittemann $CO_2$ recovery system.

While the recovery system's mechanical equipment was designed to produce 192 metric tons per day (MTPD) of beverage quality $CO_2$, the static equipment was supplied for a future capacity expansion to 384 MTPD. The Wittemann equipment scope of supply included a purification, compression, dehydration, liquefaction, and stripping system, 2x250 metric tons (MT) of bulk $CO_2$ storage, and five mobile $CO_2$ transport trucks. In addition to the $CO_2$ processing equipment, the system included a motor control center, PLC control system with SCADA (Supervisory Control and Data Acquisition), an ammonia refrigeration system, field piping, wiring, and insulation.

Though typically supplied as "stand-alone" equipment, Wittemann combined ammonia-cooled gas coolers, a $CO_2$ liquifier, liquid $CO_2$ pumps, and knock-out drums onto several prepackaged skids to minimize the equipment footprint and outdoor installation. Special consideration was also given to reducing power consumption. Unlike many gas compression systems, which use wasteful gas recycle-and-recompression (at 100% energy use) to achieve turn-down in reduced gas through-put, Wittemann's $CO_2$ recovery system utilized oil-lubricated screw compressors. This offers turn-down to approximately 30% and lowers power consumption during reduced gas availability.

Not only does the liquid carbon dioxide produced by the Wittemann recovery system meet or exceed ISBT guidelines for beverage quality $CO_2$, but the superb design achieves efficiency while providing operational flexibility for the customer.

# Turbo Expanders: Dwelling on Efficiency

*By P. Westermann P.E.*

Since the early 1960s, turbo expanders have been increasingly used in hydrocarbon gas processing plants. The other primary market application of turbo expanders is for the production of industrial gases, such as oxygen. The production of industrial gases might not typically be recognized as essential to hydrocarbon engineering. However, reducing the production costs of industrial gases is fundamental to the viability of efficient and environmentally responsible global energy solutions, such as oxygen-based synthesis gas production and the liquefaction of natural gas using nitrogen as a refrigerant. The turbo expander efficiency gains achieved in industrial gas turbo expanders can also benefit hydrocarbon gas process plants. As aerodynamic efficiency improvements drive expanders to thinner, longer blades, strength and natural frequency considerations become critical in the design of turboexpander rotors. Reliable use of a higher efficiency turbine design is feasible by restricting specific ranges of constant machine speed during the startup.

## Separating Efficiently

Today's cryogenic air separation plant uses a turboexpander to produce the low-temperature (cryogenic) refrigeration for the fractional distillation and liquefaction of air (-196 °C). A 100% efficient (isentropic) expansion extracts the maximum possible energy from the gas as the pressure is dropped, typically through a radial in-flow turbine. Power extracted from the turbine gas stream usually drives an integral-shaft booster compressor to "pre-boost" the turbine. The booster compressor is specifically sized to load the turbine at the optimum speed at the design process conditions.

Electricity is the chief cost of production in the industry gas industry. The amount of electricity used per Nm3 of gas produced is basically a function of the thermodynamic efficiencies of the compression and expansion of gas. Therefore, improving the compressor and turbine efficiencies has been paramount to directly reducing the cost of the product; i.e., the oxygen, nitrogen, and argon gas. Studies commonly reveal that, due to the energy invested to produce cryogenic temperatures, a point increase in turbine efficiency is economically equivalent to four or five points in the booster compressor efficiency.

Booster compressors have process conditions similar to many commercial radial out-flow centrifugal compressors. Therefore, numerous tools and resources are available for improving the compressor aerodynamic and mechanical design. On the other hand, the expander turbine's high pressure ratio and cryogenic process conditions pose rather unique challenges in the optimization of both efficiency and mechanical reliability.

## The Art Of Design

For over forty years, ACD LLC has strived to continuously improve the efficiency and mechanical reliability of cryogenic turbo expanders. The design is a synergy of streamline analysis programs, Computational Fluid Dynamics (CFD), Finite Element Analysis (FEA), 5-axis machining capability, a framework of field-proven designs, and an invaluable database of cryogenic performance tests. Using these tools, ACD is able to provide the highest efficiency possible while maintaining reliability and unit life.

In addition to evaluating the aerodynamic performance effects of geometrical modifications, CFD is an indispensible tool for analyzing the interaction between the inlet guide vanes and the turbine wheel blades. The resulting fluctuating pressure field for a high pressure ratio turbine is shown in Figure 1. Although the amplitude of the excitation force is relatively small at operating speeds, the particular number of nozzles and blades can generate an excitation that matches the natural frequencies of the turbine wheel.

Figures 2 and 3 show natural frequency mode shapes for a blade and disk mode, respectively, which were determined by Finite Element Analysis (FEA). These natural frequency mode shapes are relatively simple and easily analyzed. There are numerous other natural frequency modes that must be reconciled while optimizing the aerodynamic design within the required operating speed range. A shrouded turbine wheel may be used to optimize, eliminate, and move natural frequencies out of the operating speed range. The shrouded turbine wheel is typically

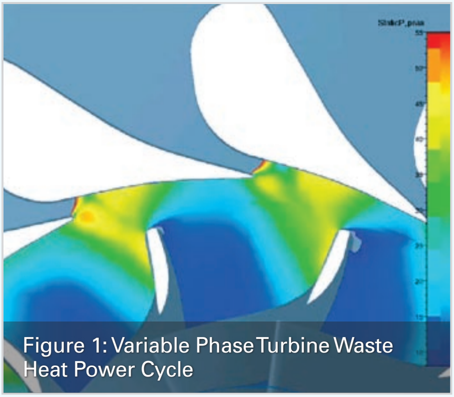

Figure 1: Variable Phase Turbine Waste Heat Power Cycle

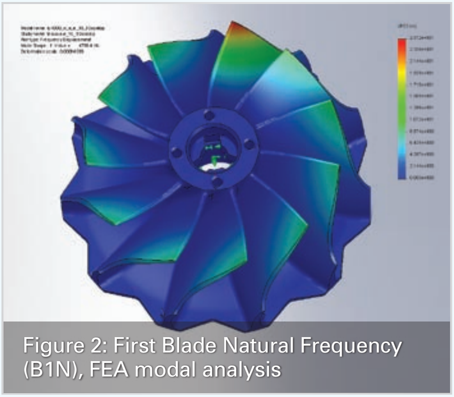

Figure 2: First Blade Natural Frequency (B1N), FEA modal analysis

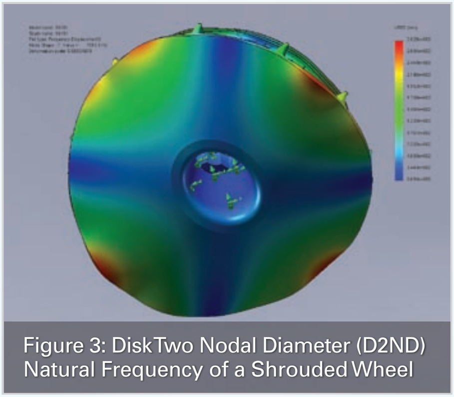

Figure 3: Disk Two Nodal Diameter (D2ND) Natural Frequency of a Shrouded Wheel

Figure 4: Single Piece 5-Axis Machining of Shrouded Expander Wheel

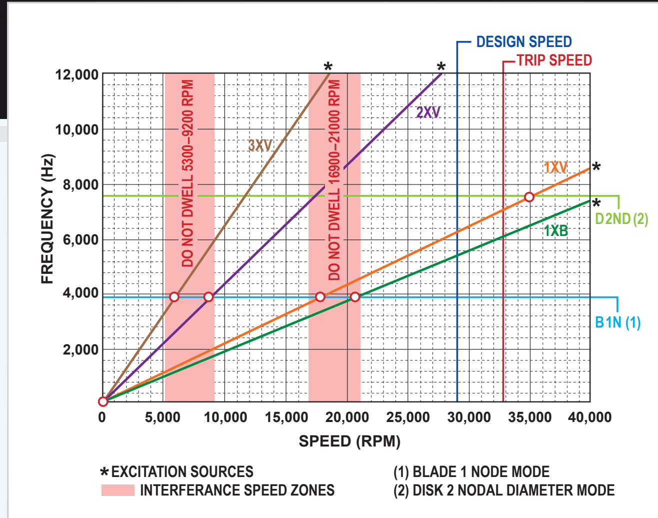


Figure 5: Campbell Diagram

5-axis machined from a single-piece forged aluminum biscuit as shown in Figure 4. Shrouded wheels, however, are a significant cost increase and not always required for acceptable operating ranges.

The excitation of potentially damaging wheel natural frequencies and their source of excitation are determined using a Campbell[1] diagram. The vertical axis of the Campbell diagram is for the wheel natural frequency and the horizontal axis is for the rotor speed. The problematic turbine wheel natural frequencies are plotted as horizontal lines. Excitation sources are a function of rotational speed, such as multiples of the number of vanes and blades. These diagonal lines intersect the wheel natural frequencies at the operating speeds that must be avoided. These intersections are referred to as "interference speeds." A typical Campbell diagram is shown in Figure 5. The excitation sources are multiples of the number of inlet guide vanes (1xV, 2xV, 3xV) and the number of wheel blades (1xB). Dwelling at a constant speed within the two speed ranges, identified as "Do-Not-Dwell" zones, will cause resonance and rapid accumulation of damaging fatigue cycles. For example, at a 6,000 Hz natural frequency, a million fatigue cycles accumulate in less than three minutes.

Constant speed operation at interference speeds causes an essentially unbounded amplification of the excitation stresses in the turbine wheel. The crystalline structures of metals possess virtually no internal damping to dissipate the excitation energy. When the frequency and shape of the excitation match that of the natural frequency, the condition is referred to as resonance[2] . The more closely the frequency and shape of the excitation directly match that of the natural frequency, the higher the amplification factor. For this reason, the lower order natural frequency mode shapes are easily excited by low number multiples of the number of vanes and blades.

Numerous test methods allow verification of the natural frequencies and mode shape of a turbine wheel. The simplest and least comprehensive method consists of mounting the wheel on a shaker-table with pickups to measure the response of the blades and wheel. Typically, the response spectrum exhibits the characteristic high amplification factor and the narrow frequency band of the undamped natural frequency resonance[3] .

## Ramping Up To Efficiency

After a considerable amount of engineering and design iterations, an aerodynamically efficient turbine design will likely still have some interference speeds between zero and the trip speed. Fortunately, resonance can be minimized by accelerating or decelerating through these speed zones. For a turbine designed with a conservative speed margin from the design speed, the low inertia rotor allows the turboexpander to quickly pass through the interference speeds to prevent damaging resonance.

If the process requires unrestricted operating speeds from zero to the trip speed, i.e., operation at speeds far from the specified design and off-design cases), there are engineering solutions to protect the turbine's mechanical integrity. The wheel's natural frequencies can be increased by thickening the blades and modifying the wheel's disk and hub profile. This compromise, however, results in a less efficient aerodynamic design.

As the demands on industrial gas turbo expanders rise, cryogenic equipment manufacturers must meet the design challenge. Aerodynamic efficiency improvements can be mechanically reliable if careful study of excitation and natural frequency is performed. Observance of "Do-Not-Dwell" zones offers additional room for turboexpander advances.

References:

Campbell, W. "The Protection of Steam-Turbine Disk Wheels from Axial Vibration." *Trans. ASME 46* (1924): 31-160.

Thomson, William T., *Theory of Vibrations with Applications*. New Jersey: Prentice-Hall, Inc., 1972.

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**Cosmodyne Celebrates**

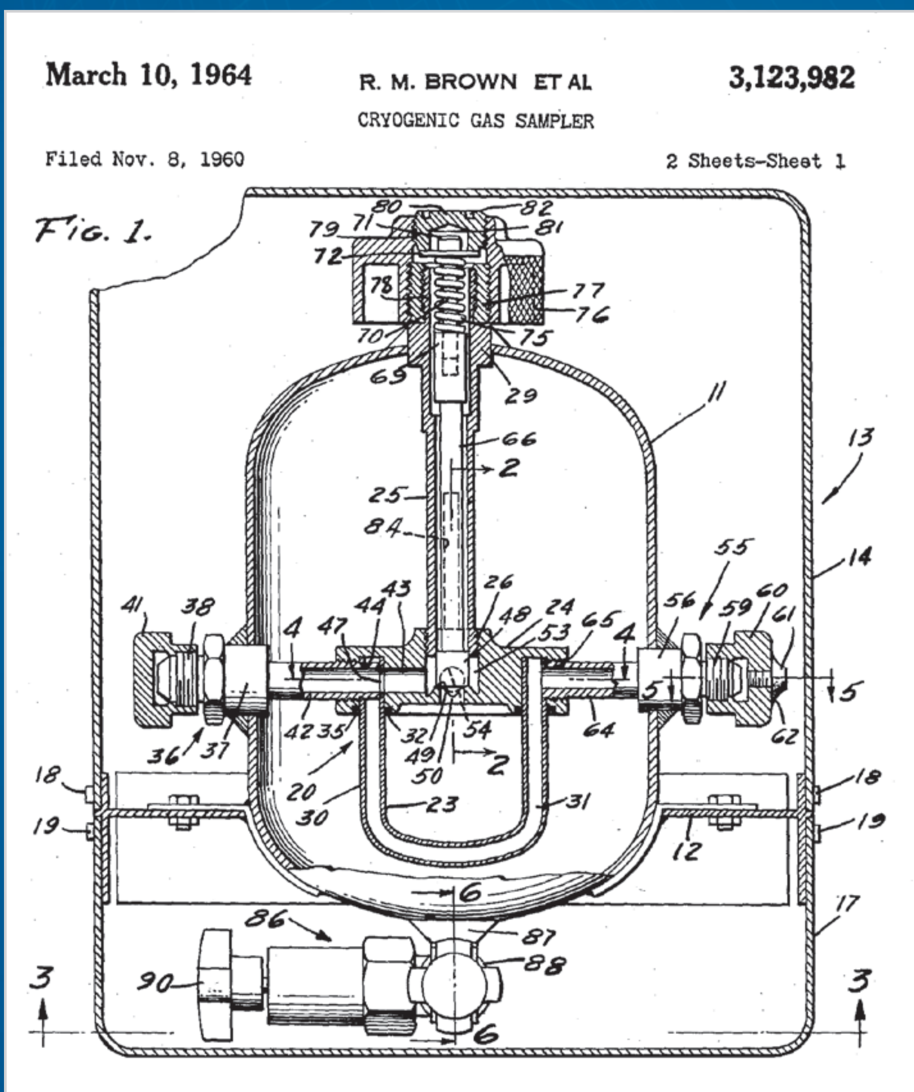
# Golden Anniversary of Sampler Production

This year, Cosmodyne is marking the fiftieth anniversary of their Cryogenic Liquid Sampler which has been in continuous production since 1960. The Sampler has gained such wide acceptance in the cryogenic gases industry that it is frequently referred to as “the Cosmodyne” by its users, much as Kleenex© is used as the generic term for facial tissue.

The Sampler, which is the first and most successful design of its kind to obtain, store, and transport a sample of a cryogenic gas for laboratory analysis, received patent number 3,123,982 on March 10, 1964. Its design ensures that the sample obtained is truly representative of the fluid being sampled.

Born out of concerns about propellant purity for Intercontinental Ballistic Missiles (ICBMs), the design was developed to accurately sample cryogenic fluids with minimal distortion from flashing fluids.

The Sampler was tested at Edwards Air Force Base in the early 1960s. The Edwards test group purposely contaminated a tank containing liquid oxygen with a known trace quantity of propane and then withdrew samples using the Cosmodyne Sampler to determine if it provided an accurate sample—which it did. The United States Air Force published military specification MIL-S-27626, written around the




Cosmodyne sampler in 1968 and gave it the designation TTU-131/E. Thousands of Samplers have been manufactured in various sizes and configurations since its initial introduction to the Industrial Gas Producers and Military users.

Versions of the Sampler have been produced for use in liquid hydrogen and hypergolic fuels as well as liquid oxygen, nitrogen, argon, methane, and ethylene (among others). The most exotic of these were the versions used for the hypergolic rocket fuels, Unsymmetrical Dimethylhydrazine (UDMH) and Nitrogen Tetroxide (N2O4), neither of which is actually cryogenic but still in need of accurate sampling.

The Sampler is approved by the U.S. Department of Transportation (DOT) for shipment in its fitted case and meets European Pressure Equipment Directive (PED) requirements.

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# Cosmodyne's Aspen 1000
# Racks Up Frequent Flier Miles


In 1998, a Cosmodyne Aspen 1000 embarked on a South American odyssey that would span a length of five years. The high efficiency, modular air separation plant was purchased in 1996 by Indura, Chile's leading industrial gas company. Designed to cost-effectively produce liquid oxygen, liquid nitrogen, liquid argon, and gaseous nitrogen, the Aspen plant met the growing air separation needs of South America.

Emerging developments in the Peruvian industrial gas market prompted Indura to change the intended plant location from Chile to Peru. In 1998, the modular plant was transported from Southern California to its first site of installation in Lima, Peru.

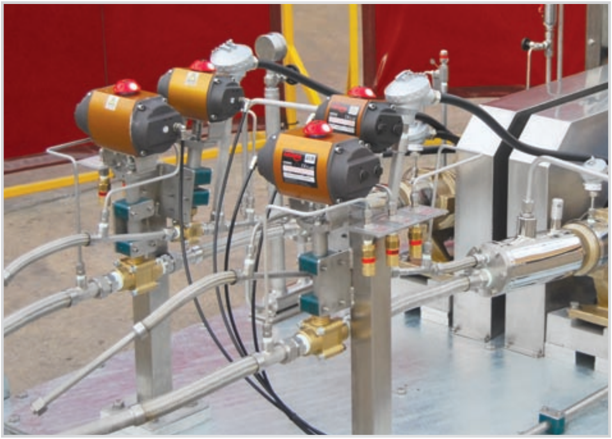
The Aspen 1000 enjoyed a year of successful operation in Peru, before further economic opportunities initiated its relocation to Chile in 1999. Its new destination was an industrial facility, where the equipment would provide gaseous nitrogen and oxygen to the customer and the resulting LOX, LIN, and LAR to Indura for sale on the merchant market.

Indura proceeded to disassemble the plant and pack it for relocation. The modular construction of the Aspen's Air Treatment Module (ATM) minimized the efforts, and the plant was successfully transported to Chile in 2001. Over the course of the next year, Indura was able to obtain the necessary permits for commercial operation. Following approval in early 2002, the company upgraded the air separation plant and made the necessary modifications to change the operating electric power frequency from 60 to 50 Hz.

After years of travel, disassembly, and reassembly, the Aspen 1000 was determined to make Chile its final home. The Aspen 1000 has been in continuous operation for eight years continuously with normal conditions and performance. The standard structural design of the cold box withstood the 8.8 earthquake in February of 2010. Though local electrical power was out for two days, the unit was restarted with no complications after the temporary interruption. The plant has since continued to operate successfully at its Santiago location.

# Allows Remote Monitoring

With the recent shipment of its second dual reciprocating pump skid, Cryoquip-Australia enjoys the continued success of their advanced remote text messaging systems. Designed for Praxair Mexico, the system uses ACD's reciprocating WDPD model to pump liquid nitrogen from a vessel at 150 psig (10.5 barg) to a buffer cylinder at 3,000 psig (210 barg). Using pressure regulators, the stored nitrogen can then be used to supply gas to laser cutting machines at 300 to 500 psig.

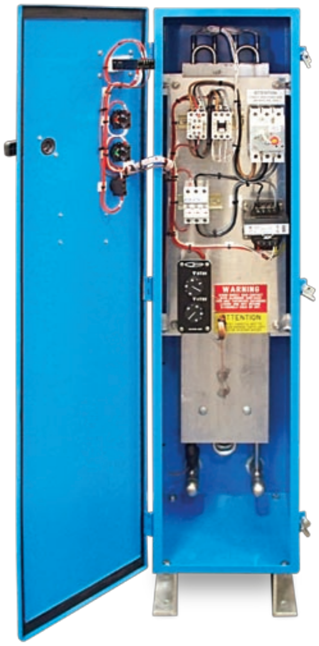


With the integration of a Programmable Logic Controller (PLC), the unique pumping system is able to automatically start, stop, and switch pumps. The Short Message Service (SMS) text-enabled skid allows the client to monitor the system remotely—a significant advantage for un-manned pumping installations required at remote customer sites.

Modern PLC's are now fitted with various types of communication protocols, one of which is a GSM Modem. Depending on the type of SIM card used in the modem, the customer can either "dial into" the PLC to review the pump's operation or use SMS text messaging to review and alter the operation. If a pump trips or operates out of its desired operating range, a descriptive message is sent to a technician who can often SMS a reply to correct the problem. Vessel level, pressure, and other pump operating information sent via SMS enables the technician to make accurate diagnostics before traveling to the site. Technicians can also wire additional instrumentation through to the PLC for monitoring and receive notifications prior to scheduled maintenance.

The dual WDPD skid is one of over 50 systems supplied by Cryoquip-Australia to companies throughout Southeast Asia, Australia, Taiwan, and the Middle East. Requiring only a bulk vessel to function as cylinder filling stations, these complete systems are ideal for small gas companies. Gases supplied using traditional cylinder packs are costly and inefficient, utilizing only about 75% of the gas. High pressure gas applications, such as laser cutting, spray metal applications, remote purge and pipe line testing, and large torpedo cylinder acoustic emission testing, can now benefit from Cryoquip's economic, efficient, and low maintenance pumping systems.

# Cryoquip Develops A New Series of Modular Electric Vaporizers



Developed as an economical alternative, Cryoquip's new VECX/VEBX Series of modular, cabinet-style electric vaporizers and gas heaters offers the reliability of the successful VEC and VEB Series without the heavier, larger footp vt within a small electrical control cabinet.

The VECX/VEBX Series utilizes high quality, easily replaceable electric heating elements and stainless steel heat exchanger tubes suitable for all atmospheric hydrocarbon and exotic gases. Heating elements and tubes are specially located in highly conductive aluminium modules to meet the specific demands of the process. The vaporizer's heat transfer is enhanced by using special internal spiral vanes which promote boiling and turbulence within the gas internally in the stainless tube. This also reduces fluid slugging and surging and controls pressure drop.

Designed for high or low pressure applications, the vaporizer units can be connected directly into the gas supply line using external threaded or welded connections. When the gas discharge temperature falls below a pre-selected set point during operation, the temperature control system sends power to the heater rods which, in turn, evenly heat up the thermal block. The heat is then absorbed through the stainless steel tubes into the gas flow.

With a simple, reliable, and flexible control system, the VECX/VEBX Series can be left in "stand by" mode regardless of gas flow. This control system feature maintains the module at a pre-selected constant temperature which ensures that the vaporizer is ready to react immediately when the liquid cryogen or gas flow resumes.

The new electric vaporizers are pressure rated up to 690 bar and individual electrical components are CSA, U.L., and IEC approved. Improved insulated panel enclosures provide dust and moisture protection, and the modular cabinet can be easily installed indoors or outdoors as a wall-mounted or free standing unit. Available in multiple voltages and flows, Cryoquip's VECX/VEBX Series ultimately allows customers to select the economical, modular vaporizing unit that best meets their needs.

# Cryoquip Celebrates Its 10th Year of Manufacturing in Europe

In July of 2000, Cryoquip Inc. ventured into the European cryogenic and industrial gas markets in the hopes of providing local customers with the benefits of lower prices, quicker deliveries, and the unique knowledge of local market needs.

The Cryoquip-Europe facility began as a small sales and manufacturing site in Southeast England. As the company flourished, it soon outgrew its 800 square meter (8,611 ft2) facility and transferred to its current location in Kent, England in 2004. The new facility offered triple the amount of storage space, allowing Cryoquip-Europe to expand its manufacturing, repair, and testing capabilities.

What first started as a product line of ambient vaporizer and related products soon developed into an extensive product line, which now includes high pressure stainless lined vaporizers, piping modules, skids, forced draft vaporizers, and most recently, the patented Uniflo vaporizers. Since the expansion, Cryoquip-Europe has continued to secure major supply contracts and has increased its sales five-fold.

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25720 Jefferson Avenue
Murrieta, CA 92562-9524 USA

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**ACD** acd@acdcom.com
**ACD – Brasil** sales@cibrasil.com
**ACD CRYO** info@acdcryo.com
**ACD – India** sales-india@acdllc.com
**CI – Brasil** sales@cibrasil.com
**Cosmodyne** info@cosmodyne.com
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**CryoCal** sales@cryocal.com
**CryoCanada – Toronto** info@cryocanada.com
**CryoCanada – Red Deer** sales@cryocanada.com
**Cryogenic Industries – China** kennyyu@acd-china.com
**Cryogenic Industries – Houston** sales@cihouston.com
**Cryogenic Industries – Korea** info@ci-korea.co.kr
**Cryogenic Industries – Malaysia** sales@cimalaysia.com
**Cryoquip** sales.us@cryoquip.com
**Cryoquip – Australia** sales.au@cryoquip.com
**Cryoquip – China** sales.cn@cryoquip.com
**Cryoquip – India** sales.in@cryoquip.com
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**Cryoquip – UK** sales.uk@cryoquip.com
**Energent** lhays@energent.net
**Pittsburgh Cryogenic Services** pittcryo@pittcryogenic.com
**Rhine Engineering** contact@rhineengg.com
**Wittemann** co2@wittemann.com
**Wittemann – India** rlonial@wittemann.com

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