CRYOGENIC INDUSTRIES

FrostByte

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High purity, high flow rate vaporization presents a system challenge for Cryoquip engineers

A large capacity, high purity nitrogen gas vaporization requirement recently put to the test the Cryoquip thermal engineering team. A system capacity of nearly 53,000Nm^3/hr (1,871,677 scfh) for a variety of high purity electronic applications was specified. The geographical location of the system dictated the consideration of, and compliance with, stringent engineering design parameters such as low vapor (fog) and noise emissions, limitations on local utilities, physical space constraints, stringent seismic code compliance, and very high wind loads. The customer also required the system be easy to install, require minimal skilled labor to commission, operate and maintain, and be able to operate unattended.

The challenge was to strike a balance between the physical size of the unit and the high performance rating necessary to meet the gas flow requirement considering the limitations placed upon the design by the location and the customer specification. Paramount was a system possesing a high degree of reliability.

Reviewing the thermal performance and taking account of the high temperature difference on the air side created by such a large thermal load, the calculated surface area necessary to capture sufficient thermal energy from the environment lead towards a unique design forced-convection heat transfer unit. Conventional fin designs and arrangements would lead to the design being too large to be considered safe considering the extreme climatic conditions specified by the customer's specification. High capacity units also present the designer with flow distribution and surge prevention problems. It is relatively straightforward to calculate the necessary surface area required to achieve the required vaporization, and even fit that area into a restricted space. The challenge is to achieve even distribution of the liquid throughout the unit, prevent surging, minimize pressure drop, and fully utilize the vaporizer efficiently.

Mal-distribution is a common design problem in applications involving cryogenic fluids. The phenomena are further complicated in units of higher capacity. It is very important the designer carefully compares and calculates the impact of multiple heat exchanger passes as it relates to header size and the impedance of the heat exchanger. Improperly designed vaporizers can mal-distribute the fluid entering into the heat exchanger circuits. The results of mal-distribution are more of a problem in exchangers in which a phase change occurs. Typically in these types of exchangers once mal-distribution develops it can actually become even greater as time goes on. The fluid imbalance will increase especially in vaporizers because the circuit taking more flow will continue to take more flow as the

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Inside This Issue

Acceleration of liquids in two-phase nozzles generates mechanical energy

Recent advancements in the theory and design of two-phase nozzles and turbines have led to successful two-phase expanders for several diverse applications. The most successful of these has been replacement of the Joule-Thomson valve in commercial refrigerant systems. Over 125 units are now operating, some with over five years of reliable duty.

The most fundamental aspect of a two-phase expander is conversion of the enthalpy of the gas-liquid mixture to mechanical energy. This conversion is most easily accomplished in a nozzle designed to produce small droplets, which have a large surface area for momentum transfer from the expanding gas phase.

Figure 1 is a photograph of a two-phase nozzle being operated with a mixture of nitrogen and water. The fluids are mixed at high pressure at the inlet to the nozzle. This mixing process is designed to produce a spatially uniform mixture (but not necessarily small droplets). The gas phase, accelerated by the pressure difference to the exit, shears the liquid to produce small droplets, typically 25-100 microns, in the region of the nozzle throat. The pressure gradient is lessened after the throat region to minimize the slip between the accelerating gas phase and the liquid. As can be seen in Figure 1 the exiting two-phase mixture is well collimated, indicating a proper expansion. For the particular set of conditions chosen the flow reaches sonic velocity, 167 ft/s (51 m/s), at the throat and exits the nozzle at 303 ft/s (92 m/s), a Mach Number of 1.8.

An analysis of the flow in two-phase nozzles was made which considers the gas-liquid slip, droplet breakup, gas-liquid heat transfer, momentum exchange, and wall friction. The droplet breakup was determined by applying Weber Number stability criteria. Drag coefficient correlations for solid spheres were applied to compute the momentum transfer between the gas and liquid phases. Heat transfer relations for solid spheres were also used.

Because of the small, uniform droplets formed these assumptions provide close agreement between theory and experiment. The comparison of predicted and measured exit velocities is shown in Figure 2.

The analysis has now been extended to determine two-phase cryogenic expander performance. Because of the low surface tension and high gas density of fluids at cryogenic temperatures, very small droplets are produced which enhance the two-phase nozzle efficiency. A recent study of a two-phase turbine for liquefied natural gas yielded a two-phase nozzle efficiency of 95%.

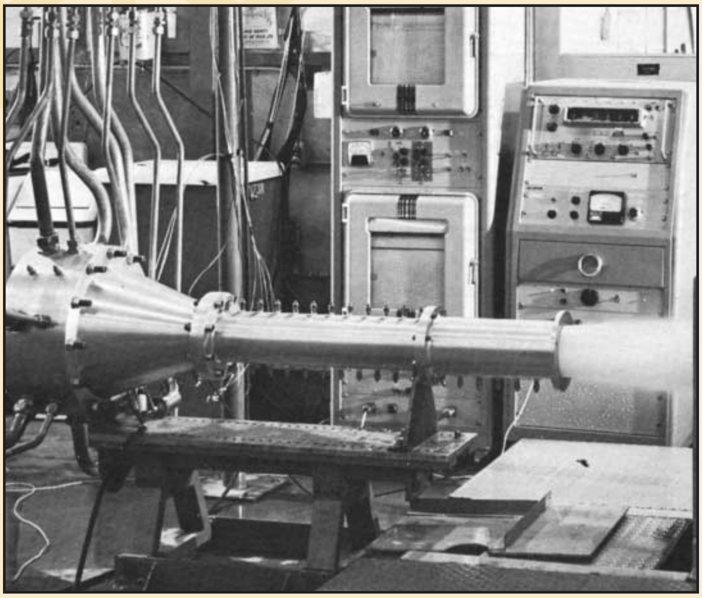
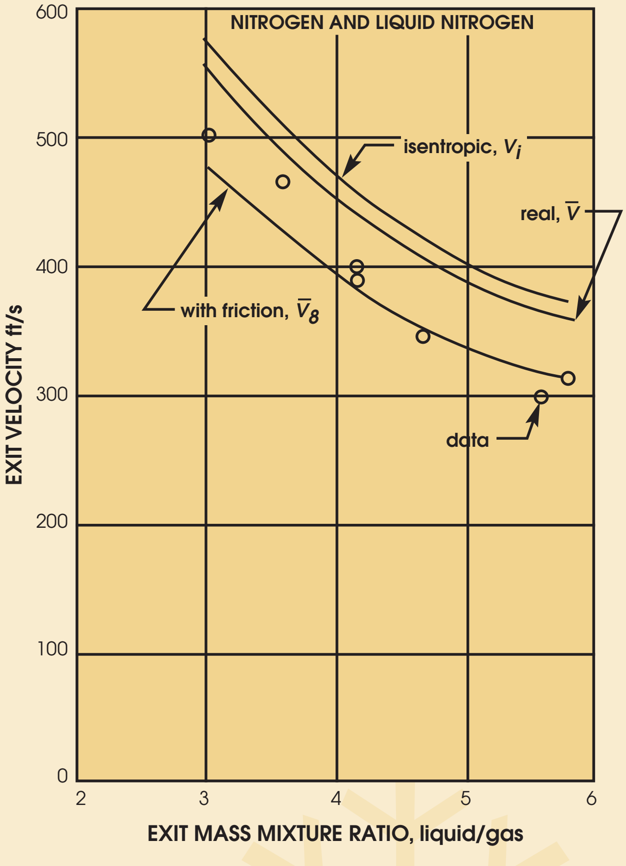


Figure 1: *Experimental nozzle in operation.*

Figure 2: *Comparison of theoretical and experimental exit velocities for liquid nitrogen nozzle.*



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What causes flange joints, which were initially tight, to loosen up & leak on cool down? Often cryogenic lines are run in copper or aluminum and the flange connections use stainless steel bolts. Both aluminum and copper shrink faster than stainless steel when cooled to cryogenic temperatures. This relieves the tension in the bolts and may result in flange leaks. Careful specification of the initial bolt torque can minimize this by ensuring that there is still adequate force to seat the gasket and offset the pressure forces. Re-tightening when cold also works but care must be taken not to overstretch the bolts when the pipe warms up. In some cases extra long bolts with Invar standoff avoids the problem.

What causes vaporizers to surge? Surging is evidenced by fluctuating flow rates and rapid pressure swings. There are two causes of this surging. First, when cold liquid runs through a hot pipe it vaporizes very quickly on the warm surface. The rapid production of gas cannot move down the pipe fast enough so it begins to push the liquid back upstream re-exposing the dry surface. As the surge of gas moves down the pipeline the pressure collapses allowing liquid to flow again onto the dry warm surface restarting the process. When the natural frequency of these events matches a resonance frequency of the system a pronounced surge will occur. The second cause of surging is unique to vertical surfaces as found in many ambient air vaporizers. In these units the flow path is up and down through a series of extrusions forming a multiplicity of liquid traps in the colder areas. As this trapped liquid evaporates it pushes the liquid over the top to the next trap. This oscillating internal flow is the cause of the surge. Careful selection and design of the vaporizer can eliminate many potential surging situations. Generally, avoiding low-pressure drop designs will reduce the risk of surging.

Why do many ground-mount centrifugal pumps have seal cavity purge connections while truck-mounted units don't? First, some ground-mounted pumps use labyrinth seals instead of mechanical face seals which depend on a steady flow of seal gas (such as nitrogen) to prevent leakage of the fluid being pumped. However, even with mechanical face seals, it is a good idea to purge the seal cavity. Ice is a deadly enemy of the mechanical face seal. These seals are conventionally provided with a bellows to obtain proper alignment between the rotating and stationary elements of the seal. When the pump is shut down, the cold surfaces cryopump moisture into the seal cavity and the water settles in the lower portion of the bellows. The next cool down freezes the water and causes the seal to cock resulting in either leakage or high wear, or both. On mobile units there is no readily available source of purge gas and ice formation in the bellows is a major cause of short seal life.

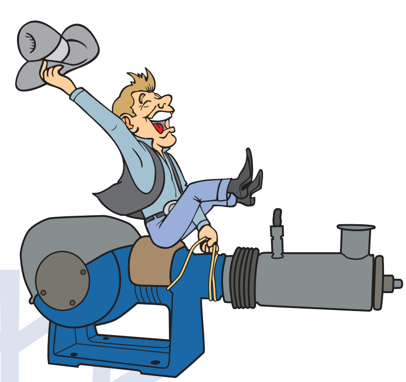
Why are point-of-use tanks equipped with both bottom & top fill lines? Most storage tanks have their pressure building regulators set at near the desired gas pressure (typically 8 to 10 bar [116-145 psi]). After time, the liquid in the tank becomes saturated at this pressure and then higher due to the heat leak up to the relief valve pressure. Except at times of heavy draw, heat leak is enough to maintain and increase tank pressure. This pressure increase is desirable compared to venting valuable product. The liquid in the transport is maintained at much lower pressure (typically about 1 bar [15 psi]) and hence is much colder than the liquid in the stationary tank. As the liquid is pumped into the tank care must be taken to maintain the demand pressure. This is conventionally done by balancing the flow between top and bottom fill ports on the tank. Liquid in the bottom temporarily raises the pressure in the tank by compressing the vapor above the liquid, while liquid directed to the top fill depresses the pressure by condensing the vapor with the cold liquid. Carefully balancing these two flows enables maintenance of the tank pressure within an acceptable band.

New facility

Cryogenic Industries Service Companies opened a new facility in Houston, Texas, USA. Cryogenic Industries - Houston offers a wide range of services to its west south central US customers including cryogenic reciprocating and centrifugal pump repair for the industrial gas industry and oil field service market. Flow meter, vacuum pump, and CO_2 pump repairs are also performed.

The facility is located 5 minutes from Bush Intercontinental Airport in a 10,000 ft^2 (3,048 m^2) building with 28,000 ft^2 (8,534 m^2) for storage. The strong suit of the company is its exchange program. CI-Houston has over USD 300K in spare parts and another USD 300K in exchange pumps, to guarantee that the pump its customers need is on the shelf, repaired, and ready for immediate shipment. This efficiency nearly eliminates costly downtime.

CI-Houston repairs these pump brands: ACD, Cosmodyne, JC Carter, Blackmer, Cardox, Cryo-Mec, Cryo-Mach, CCI, CVI, Drum, Kinney, Leybold.



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Cryoquip qualifies to manufacture to the PED

For several years Cryoquip has been supplying European gas companies with large vaporization systems for both customer station applications and air separation back-up. Cryoquip is qualified to manufacture pressure vessels in compliance with a majority of the main European countries' individual codes, and recently, China's ISQL for pressure vessels. Qualification to manufacture to these individual codes applies to all manufacturers wherever they are located around the world. This has added significantly to the cost of these products and has created a protectionist market. In the spirit of the European union concept of a free market throughout Europe, a uniform pressure vessel directive was created in 1997, known as the Pressure Equipment Directive (PED) 97/23/EC.

This directive harmonizes national provisions of hazard due to pressure. It applies to the design, manufacture, and conformity assessment of pressure equipment and assemblies with a maximum allowable pressure greater than 0.5 bar. Covered under the general term "Pressure Equipment" are pressure vessels, boilers, heat exchangers, tubing and pipe, vaporizers (as pressure vessels) as well as parts attached to the equipment, flanges, nozzles, valves, and lifting parts. Almost all Cryoquip's product range encompasses these products.

With Cryoquip's recent expansion into Europe it became imperative that Cryoquip fully embrace this directive and qualify both the USA and UK-based facilities in order to be able to offer its range of ambient air vaporizers and heat exchange equipment, CE approved, for use anywhere in Europe.

The European Pressure Equipment Directive 97/23/EC will be mandatory as of May 29, 2002 and will require a "notified body" appointed by a member state of the EU to carry out procedures referred to in the PED including review of final assessment of the product.

Cryoquip will use the services of TÜV Suddeutschland, who have been contracted since 1994 for certification of ambient vaporizers built to the German Pressure Vessel code AD-Merkblatter, as our approved notified body for our facilities in the US and UK. TÜV Suddeutschland is a qualified notified body on the list in the Official Journal of the European Communities, identification number 0036. The list of the tasks for which they have been notified in are European Approval of Materials, Approval of Operating Procedures of permanent joints and Approval of Personnel who make permanent joints.

Welders and weld procedures are qualified and certified to EN Standards. Cryoquip's quality control program for both facilities is qualified and approved by TÜV and meets or exceeds the requirements of the PED as well as other existing European National Standards such as I.S.P.E.S.L. (Italy) and CODAP (France).

This is an important technical milestone for Cryoquip. Without this qualification, Cryoquip would not be able to supply equipment to the European gas companies, jeopardizes Cryoquip's thriving European operation. With it, Cryoquip is a true global supplier to the gas industry.

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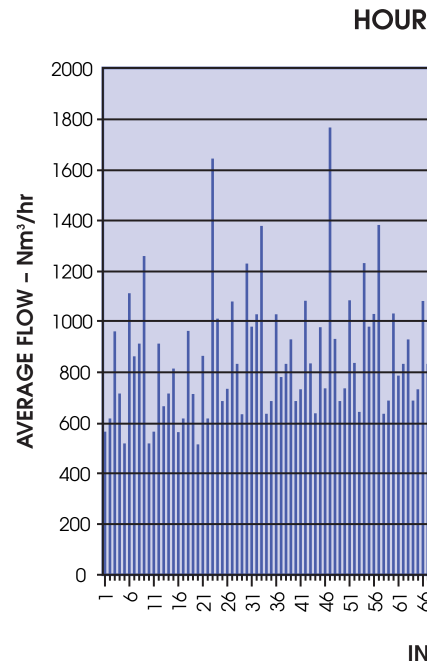
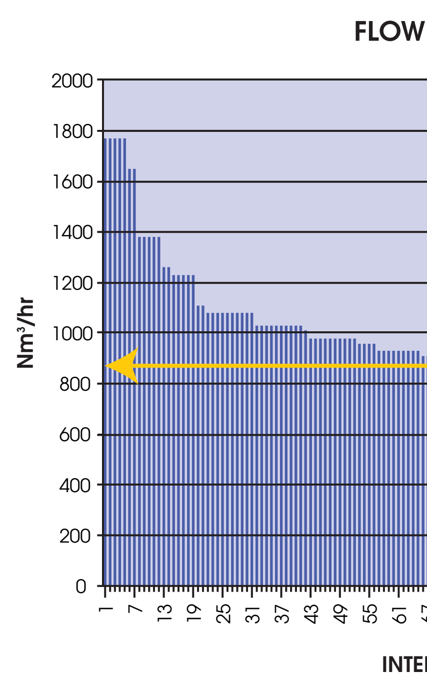
TÜV SÜDDEUTSCHLAND

A shortcut to





For more information contact George Pa

sizing liquid add N_2 generators

Figure 1

LY DEMAND FLOWS

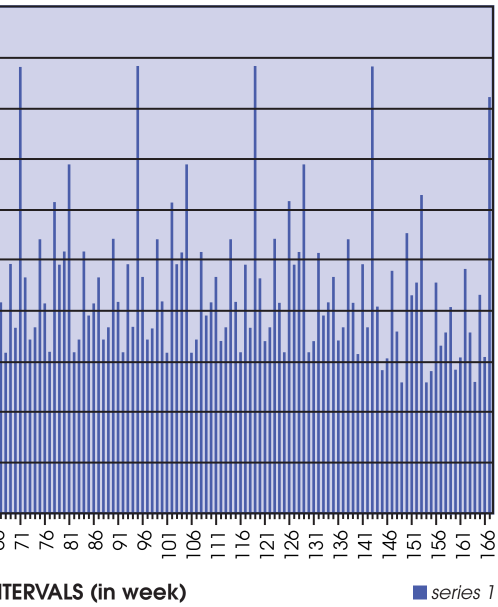
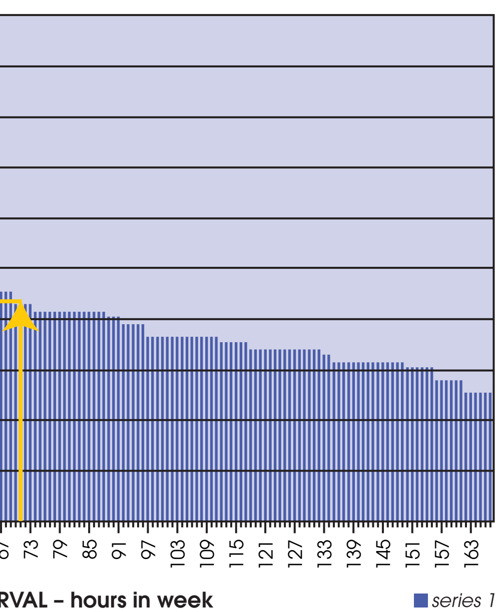


Figure 2

RATE PER INTERVAL



Nitrogen gas requirements frequently experience significant changes in demand over time. Selecting the proper size of an on-site generator is important in achieving an optimal cost structure. Generally the base load is assigned to a generator and the peak loads to imported liquid nitrogen. The cost of the on-site generated gas is a fraction of the imported liquid so proper size selection is critical. The following is a "quick" method for proper selection.

Most small liquid-add nitrogen generators do not turn down efficiently so the power at partial load is nearly the same as full load. Therefore oversized units waste power when the demand is less than the design flow. On the other hand the imported liquid is substantially more expensive than generated gas and running the generator at part load may still be cheaper than using liquid if the period is short enough.

Step 1

- Determine a characteristic period for load profiles. (This may be weekly, monthly, or other.)
- Select a measuring "interval" (minutes, hours, shifts, etc.).
- Obtain data on average flows over each interval over the period.

Example: See Figure 1 – Here the period is weekly, the interval is hourly, and the flow is in Nm^3/hr.

Step 2

- Rearrange the intervals in descending order of flow. (Hint: using a spread sheet program makes this task easy.)

Figure 2 shows the rearranged data from the example in Step 1.

Step 3

Determine the Incremental Cost of Gas Generated (IOGC). This is normally derived from the cost of power for an incremental volume of gas produced in the generator plus the incremental cost of capital related to a larger generator. (The extra liquid added is small and can be neglected).

Divide the IOGC by the cost of imported liquid delivered to the site to get the Cost Ratio (CR).In our example assume power at $0.05/Kwh, the Specific Power at 0.28Kw/Nm^3/hr and the incremental capital is $0.015/$Nm^3$/hr. The CR calculates to 0.42.

Step 4

Multiply the number of Intervals by the CR (0.42 * 168 = 71) and plot on the chart developed in Step 2. Read the gas generator size (in the example 860 Nm^3/hr). This is the optimum point. A larger generator than this would be more costly because the number of intervals actually able to use the gas is too few to justify the added capacity.

The above example demonstrates a quick method for size selection and is useful in roughing in the choice. A number of other factors such as model (frame) breaks in hardware, relative availability of imported liquid in the area, or long term changes in demand should be considered when making the final size selection.

This exercise is also useful as a quick method to determine sensitivity of the selection. For instance, try changing the power cost to see if the plant select alters significantly.

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Truck-mounted VDFC vaporizers designed for the oil field industry

Cryoquip Engineering Solutions

In response to oil industry applications, Cryoquip developed the VDFC series vaporizer, a truck mounted, direct-fired, diesel liquid nitrogen converter. The requirement specified intermittent flow rates in excess of 600,000 scfh (17,000 nm^3/hr) of high pressure nitrogen gas for use in oil well extraction enhancement, refinery cleaning, and other remotely located chemical purging applications. The vaporizer/converter had to be portable, independently powered, and compact enough to fit into a very restricted space on the back of a liquid nitrogen tanker truck. Cryoquip's solution is the VDFC vaporizer.

The entire vaporizer/converter system is truck mounted and self-contained. It is extremely compact in design and fits a minimal volumetric space relative to its capacity. Liquid nitrogen is supplied from the storage tank to an onboard boost pump, supplied by ACD. The boost pump raises the pressure of the liquid nitrogen and delivers it to the suction side of an onboard, high-pressure liquid nitrogen pump. The vaporizer is capable of operating at pressures up to 10,000 psig (690 bar). The high pressure liquid is injected into a specially designed vaporization coil where it is vaporized and superheated by exchanging heat with hot combustion gases from a diesel-fired burner system. The vaporizer has a complex arrangement of reverse flow combustion chambers with fuel nozzles with the capability of three stage firing to enhance the overall range of temperature control of the unit. Diesel fuel is supplied from the truck's fuel tank to the vaporizer through fuel filters, a boost pump, and fuel preheaters, into the high-pressure fuel pump. Diesel fuel is atomized at high pressures in order to provide complete combustion.

A hydraulically driven, multi-bladed fan provides air to the vaporizer combustion chamber for vaporization and for system cooling. The heart of the vaporizer comprises a unique arrangement of heat exchanger tubes and gas flow baffles which directs the hot air throughout the exchanger arrangement ensuring complete and efficient vaporization of the liquid cryogen. The vaporization of high volumes of nitrogen gas necessitates the input into the liquid cryogen of huge quantities of heat to ensure the complete vaporization of the liquid. The vaporizer design accomplishes the difficult task of introducing the necessary amount of heat into the heat exchanger and dissipating that heat into the surface area of the heat exchanger successfully, in a very short distance and minimal space, without compromising the overall reliability and longevity of the vaporizer. This direct-fired nitrogen vaporizer system has been specifically design to be used in tandem with the ACD 3-SLS cryogenic pump, to provide maximum system output efficiency. (See FrostByte, Vol. 11, No. 3.)

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High purity...*continued from cover*

pressure drop in that circuit decreases. The average fluid temperature in that circuit decreases, increasing the average fluid density and decreasing the circuit pressure drop. Likewise, the circuit flowing less fluid increases in average temperature and therefore decreases in average fluid density, increasing in pressure drop. The overall effect of the mal-distribution decreases the vaporizer efficiency. The much colder fluid mal-distributing through some passes combines with the fluid of other circuits, reducing the average discharge temperature of the vaporizer. The effect on the vaporizer is the reduction in the run time ability of the unit as the mal-distributing cicuits become colder and colder.

Large capacity, high flow vaporizers are especially susceptible to film boiling that can lead to surging. Cryogenic liquid entering a circuit boils rapidly along the inside perimeter of the exchanger surface. The center liquid column continues down the length of the circuit as the outer edges vaporize. Eventually the center liquid column vaporizes at a distance further down the length of the circuit creating a gas pulse increasing back pressure upstream. The pulse limits liquid from entering the circuit until the gas is relieved downstream. Once this occurs the cycle is repeated. If the natural frequency of these events matches the resonance frequency of the system which includes the system of piping and controls upsream and downstream of the vaporizer, pronounced surging will occur. This surging can be quite extreme and have adverse effects.

The designer also had to seriously consider the form of the inside of the extrusion element in order to maximize the overall effectiveness of the thermal design. Maintaining a high inside coefficient, especially in the boiling zone of

For more information contact Raul Boza at the unit, was paramount. This often overlooked parameter not only helps to reduce the adverse operating effects these high capacity units are prone to, but also helps to reduce the overall physical size of the unit, which was highly desirable in this particular application.

The final design of the forced draft convection unit featured the use of four high density, whisper quiet, axial fans powered by high efficiency, three phase electric motors. An advanced design air-side extrusion element arrangement maintained the most efficient use of the minimized surface area while guaranteeing maximum outlet temperatures and performance throughout the ambient temperature operational window. The design achieved its goal of the highest capacity ambient air design in the most limited space possible, together with the lowest pressure-drop-to-capacity ratio.

All the vaporizers required to meet the total flow rate demand were assembled and connected with low loss interconnecting piping modules at Cryoquip's headquarters in Murrieta, California, USA. All necessary welding was performed prior to the completion and testing of the units, and final assemblies were designed as bolt-together modules, which simplified final on-location assembly.

The Cryoquip vaporizers met or exceeded all of the original customer specifications. With the thermal energy required derived from the air and a negligible amount of power used for the main air blowers, they provided a highly efficient, zero maintenance, 26,000,000 btu/hr (6,552,000 kcal/hr), low operating cost, very reliable vaporization system.

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Calendar of Events

APR 23-26 THE SEVENTH CRYOGENICS 2002 – The Technology of Low Temperatures
Praha, Czech Republic – tel +420-2-684 7056, 683 6100
icaris@icaris.cz, www.isibmo.cz/cryogenics2002/

MAY 6-9 19TH ANNUAL OFFSHORE TECHNLOGY CONFERENCE
Houston, Texas, USA – tel +1.972.952.9494
service@otcnet.org, www.otcnet.org

JUN 11-13 GLOBAL PETROLEUM SHOW
Calgary, Alberta, Canada – tel +1.403. 209.3555
wesscott@ca.dmgworldmedia.com, www.petroleumshow.com

JUL 22-26 ICEC19 – 19th International Cryogenic Engineering Conference
Grenoble, France – tel +33.476.88.1291
sec@icec19.org, www.icec19.org

AUG 4-9 APPLIED SUPERCONDUCTIVITY CONFERENCE
Houston, TX, USA – tel +1.303.499.2299
asc@centennialconferences.com, www.ascinc.org

SEP 4-5 OIL SANDS TRADE SHOW AND CONFERENCE
Fort McMurray, Alberta, Canada – tel +403.209.3561
simonrose@ca.dmgworldmedia.com, www.petroleumshow.com

SEP 21-25 NWSA ANNUAL CONVENTION
Orlando, Florida, USA – tel +1.215.564.3484
nwsa@nwsa.com, www.nwsa.com

OCT 13-16 GASTECH 2002 – The 20th International Conference & Exhibition of the LNG, LPG and Natural Gas Industries
Daha, Qatar – tel +44(0) 1895.454533
j.tyler@turret-rai.co.uk, www.gastech.co.uk

OCT 29–NOV 1 OSEA 2002 – 14th Offshore South East Asia Exhibition and Conference
Suntec, Singapore – tel +44 (0)20 7862 2072
oil@montnet.com, www.montnet.com

An overburdened, overstretched executive is the best executive, because he or she doesn't have the time to meddle, to deal in trivia, to bother people.
–Jack Welch

Quote

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