Smart Energy Compact Chiller for Helium Compressors

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ABSTRACT

Recent advances in smart energy compressors for helium cryocoolers have shown to significantly reduce power consumption during operational lifetime, especially when the system is cold or in "standby" mode. However, these compressors typically require at least a 3 ton industrial chiller or larger for adequate chilled water cooling.

This paper introduces an updated version of the Quantum Design (QD) smart energy chiller dedicated to operation with a variable speed, water cooled helium compressor (QD model HLC 4500). Running at fixed speeds (60 Hz capsule, 60 Hz head) with a Gifford-McMahon (G-M) cold head or pulse tube, cooling power is found to be similar to the cooling power of a standard compressor and industrial chiller with power savings of up to 2 kW at 60 Hz. Additionally, the variable speed compressor can be adjusted to reduce power consumption when cooling power needs are less which results in potential power savings of up to 5 kW.

The chiller features dedicated cooling of the helium and oil circuits that leads to increased efficiency and a smaller footprint than other commercially available chillers. A weatherized housing allows for flexible installation options including operation outdoors in a variety of climates.

INTRODUCTION

In 2012, Quantum Design introduced a "Modular Architecture" option for the HLC 4500[1] water cooled helium compressor that allowed a simple modification of the standard compressor to provide a compact solution for customers without access to a chilled water source[2]. While the new design retains the core feature of separate brazed-plate heat exchangers (BPHX), to optimize cooling, new improvements have been implemented such as a simplified cooling scheme, a two stage digital controller to control fan and refrigerator power and optimization for outdoor installation.

Previous studies have shown that reducing the speed of the compressor scroll capsule can significantly reduce overall power consumption on Gifford-McMahon (G-M) cold heads[3,4] and pulse tubes[5,6]. By varying the head and capsule speed of the compressor, cooling power can be optimized while taking advantage of the reduced power draw at lower speeds. Further power savings come from utilizing the chiller refrigerator to only cool the helium circuit rather than unnecessarily overcooling of the oil circuit as standard in a traditional industrial chiller solution.

Cryocoolers 19, edited by S.D. Miller and R.G. Ross, Jr.

RADIATOR DESIGN UPDATE

Figure 1 shows the updated configuration of the compressor and chiller interface. Previously, the helium circuit featured dedicated copper lines running between the condenser unit and helium BHPX, which had the advantage of directly cooling the helium gas with R134a but complicated the installation as the distance between indoor and outdoor units can extend up to 30 meters. this will add significant cost in materials and requires a certified refrigeration technician for installation. By diverting some of the water/glycol mixture cooled by the radiator to the refrigerator (controlled by a manually controlled globe valve) for further cooling, the interface between the indoor and outdoor unit is now simplified to three rubber hoses. The smaller diameter (1/4" ID) helium supply hose carries refrigerator chilled water to the helium BHPX while the larger diameter (3/4" ID) oil supply hose carries radiator cooled water to the oil BHPX. A single ¾" ID rubber hose returns heater water back to the chiller for cooling. A 1/3 HP centrifugal pump keeps the water continuously pumping with discharge pressure of approximately 20 psig and flow of 4 gallons a minute when 30 meter lines are used.

Another objective of the redesign was to ensure that the chiller can operate a distance up to 30 meters from the indoor unit at an outside ambient temperature up to 45°C while keeping the helium temperature optimally between 15 to 28°C with a maximum of 35°C as specified by G-M and Pulse Tube manufacturers[7,8] Operating at higher helium temperatures can potentially reduce the effective cooling power of the system. Also, previous studies have also shown that oil carryover from the compressor coalescing filter to the adsorber is substantially higher at helium temperatures above 30°C requiring more frequent service[4]. To accomplish this design objective, the following hardware updates were implemented: a U-shaped radiator to increase heat exchanged area, a larger fan with increased air flow, a larger refrigerator unit to increase cooling capacity and a larger pump to accommodate the pressure drops of 30 meter hoses (Figure 2). Additionally, a protective environmental coating is added to the finished refrigerator assembly and all electronics are contained within a NEMA 4X enclosure with liquid tight cord grips for each cable (no external connectors). The overall footprint of the chiller is 22 x 22 inches while a standard 3 ton industrial chiller takes up over double the floor space[9].

THERMAL PERFORMANCE EXPERIMENTAL RESULTS

The updated HLC 4500 chiller is designed to operate under a wide range of ambient temperatures from -30°C to 45°C which makes it suitable for outdoor installation in most climates. Figure 3 shows the effect on the compressor temperatures while running the chiller at the upper range of allowable ambient temperatures. From the data, we see that while running the chiller at the most thermally stressful condition (45°C ambient temperature and full compressor scroll speed of 60 Hz) the helium temperature stays below the 35°C recommended for cold heads and below the 90°C maximum helium discharge (capsule) recommended by the helium scroll compressor manufacturer.

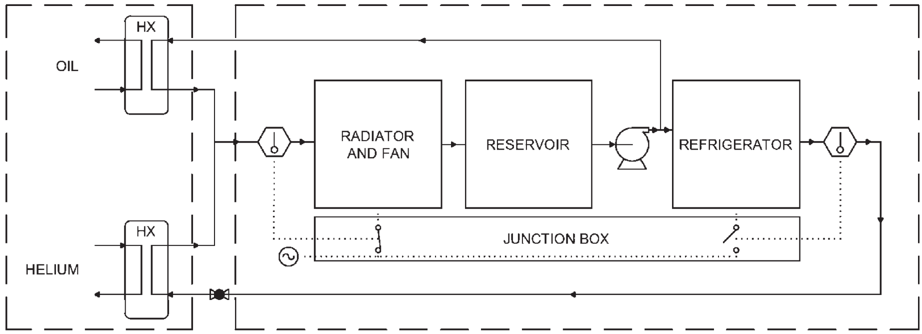

Figure 1. Updated configuration of water cooled compressor and chiller

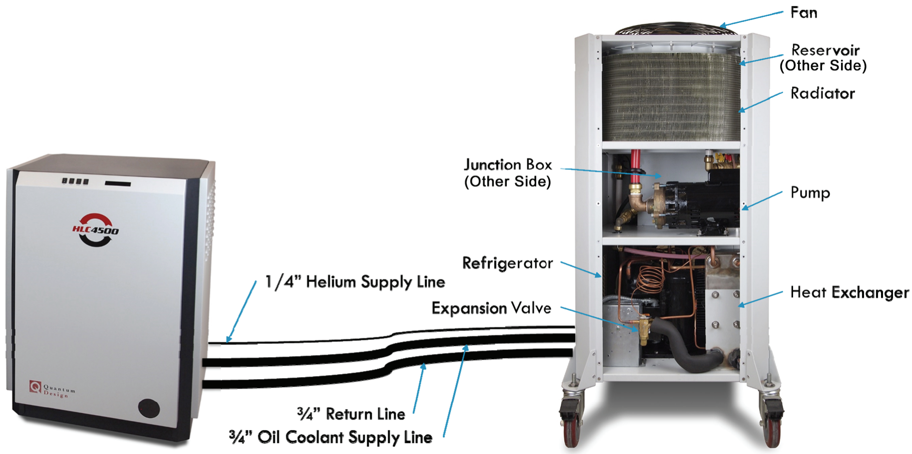

Figure 2. Updated configuration of water cooled compressor and chiller

Should the chiller ambient temperature raise above 45°C, the chiller refrigerator unit features a built in thermostat that will shutoff power to the refrigerator to prevent damage to the refrigeration compressor. Additionally, the HLC 4500 compressor features adaptive speed control that will reduce the compressor speed to keep the compressor running if the capsule temperature reaches 90°C. These adaptive features can also keep the compressor running at reduced cooling power if there is reduced chilled water flow (such as a pinched rubber hose) or air flow (such as significant debris build up on air filters).

When the full cooling power of the compressor is not needed and an energy savings is desired, the compressor can be run at reduced scroll capsule and head speeds. Running the compressor at reduced speeds also reduces capsule, oil and helium temperatures, which along with the shorter duty cycle of the wear components of the compressor and head, can reduce wear and lengthen the lifetime of major system components. Figure 4 shows the reduced capsule temperature range of 50°C to 60°C and reduced helium temperature of 17°C to 25°C. The automated temperature controller of the updated chiller design also eliminates the need to throttle the flow of chilled water when compressor speeds are changed or ambient temperatures shift, allowing for a more hassle free experience for the end user.

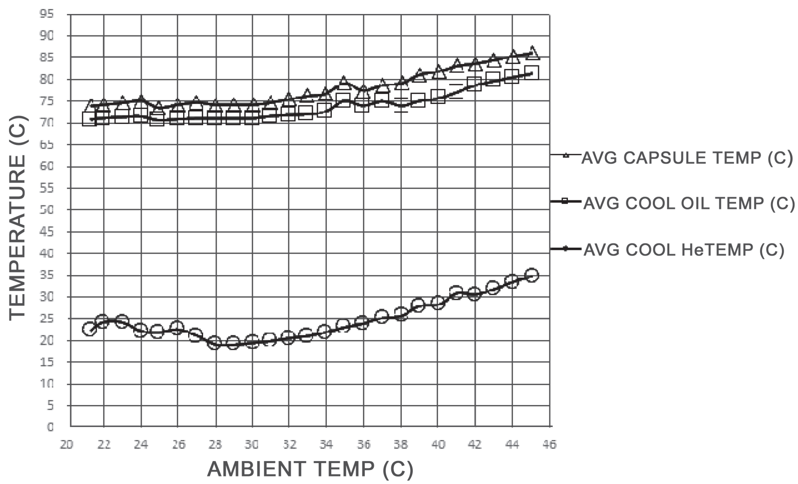

Figure 3. Thermal testing results at 60 Hz capsule speed

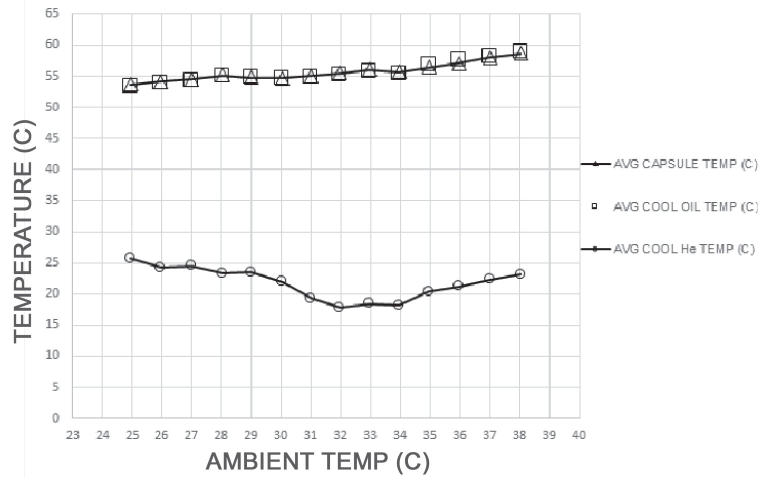

Figure 4. Thermal testing results at 30 Hz capsule speed

POWER DRAW EXPERIMENTAL RESULTS

The HLC 4500 and chiller combo was run with several RDK-415D[9] G-M 1.5W cold heads and flow impedance fixtures, with a static helium charge pressure of 1.5 MPa, at various speeds while cooling down and while cold. Head speed was kept at 60 Hz. The actual power draw of the compressor and chiller was measured with a 3 phase Fluke 437 power meter. Figure 5 shows that the actual power draw of the HLC 4500 compressor varied greatly depending on compressor

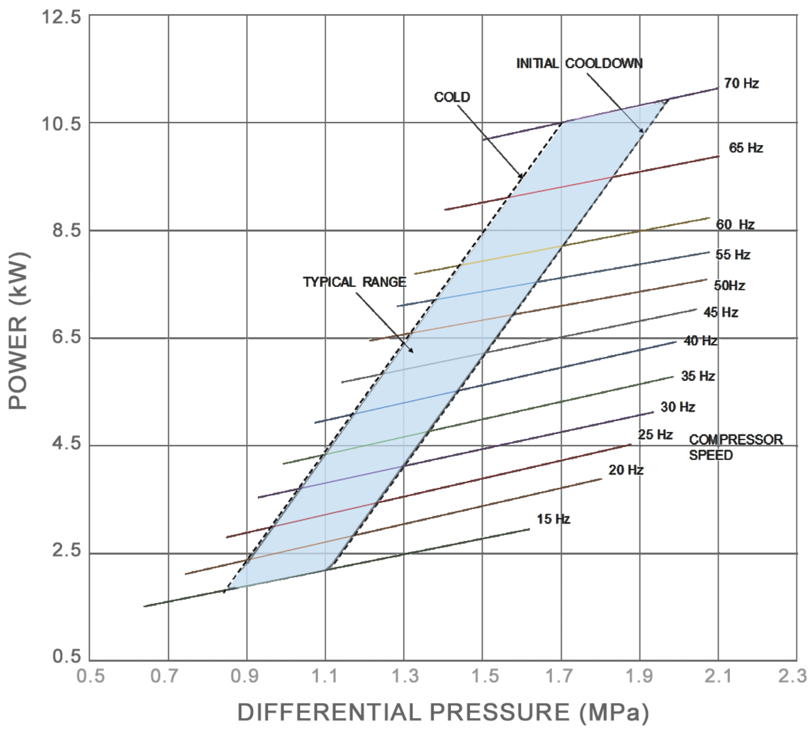

Figure 5. HLC 4500 compressor actual power draw at various speeds

scroll speed and differential pressure (Supply Pressure - Return Pressure) of the compressor. During cool down at a given speed, the differential pressure typically was about 0.3 MPa larger than the differential pressure once the system was cold at 4.2K leading to a power reduction of about 0.5 kW once cold.

The chiller power draw varies depending on which chiller components are energized as shown in Figure 6. At lower ambient temperatures, the fan and refrigerator power will cycle to maintain the helium temperature in the desired 20 – 28°C range giving the chiller an actual power draw of 0.4 to 1.3 kW depending on cooling needs. The HLC 4500 and chiller paired with an average 1.5 W cold head has a maximum power draw of 11.8 kW during cool down at 70 Hz in higher ambient temperatures (above 30°C) and a minimum power draw of 2.1 kW while cold at 15 Hz and running in a lower ambient temperature (below 30°C). By comparison, a Sumitomo F70 compressor has a maximum measured power draw of 9.0 kW when charged to 1.5 MPa, running at 60 Hz and cooling down a 1.5 W cold head. However, the F-70 requires an external chilled water source, typically a minimum of a 3 ton industrial chiller with a maximum power draw of 3.5 kW[10] bringing the total max power draw up to 12.5 kW. Once cold the minimum power draw of the F70 and 3 ton industrial chiller combo is reduced to approximately 11.0 kW. From these results we see that the potential power savings of the HLC 4500 and chiller can be significant, especially if the application does not require the full cooling power capacity of the cold head. At 60 Hz and in cold state, the combined power draw of the HLC 4500 and chiller is approximately 9.0 kW.

COOLING POWER EXPERIMENTAL RESULTS

The HLC 4500 and chiller combo was run with a SRP-082B2S[11] 0.9W 4.2K class pulse tube at various compressor and remote valve speeds. Figure 7 shows the HLC 4500 achieved 0.88 W 2nd stage cooling power at a capsule speed of 71 Hz and remote valve speed of 62 Hz. The F70 compressor was able to achieve 0.88 W 2nd stage cooling at 60/60 Hz due to the larger Copeland scroll capsule[12] used by the F70 compared to the Hitachi scroll capsule[13] utilized by the HLC 4500.

The HLC 4500 allows the capsule and head speeds to be independently set so that cooling power can be optimized and we found that generally for a given capsule speed ideally the head speed should be several Hz lower to maximize cooling power on the pulse tube as shown in Figure 8. At a 40 Hz capsule speed, cooling power is reduced to 0.4 W but overall power draw is reduced to 6.3 kW – an approximate 5 kW power savings compared with the F70 and industrial chiller combination. Also from the data we see that cooling power falls off substantially at capsule speeds less than 40 Hz limiting the practical use of the pulse tube below 40 Hz and limiting further significant power savings.

Next the HLC 4500 and chiller combo was run with a RDK-415D cold head at various capsule and head speeds. The results of these tests are seen in Figure 8. Figure 9 shows a 2nd stage cooling

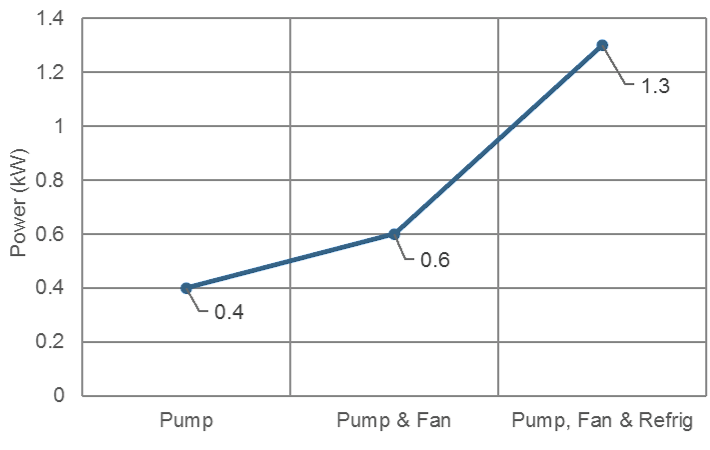

Figure 6. HLC 4500 chiller actual power draw by operational state

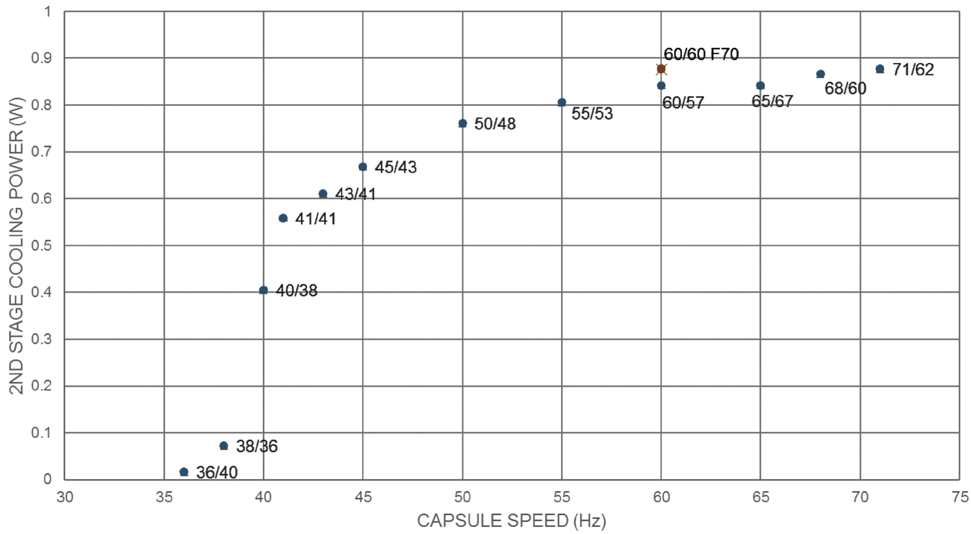

Figure 7. Cooling power with 4.2 K pulse tube at tuned (capsule/remote valve) speeds

power of 1.95 W at 66 Hz. Unlike the pulse tube, the G-M cooling power follows capsule speed more linearly – allowing for practical application at speeds down to 15 Hz. At 15 Hz capsule speed the available 2nd stage cooling power is still a significant 0.3 W – an approximate 8 kW savings over an F70 compressor and industrial chiller combo. Running the compressor at a capsule speed less than 15 Hz is not recommend (nor allowed) on the HLC 4500 as there is not sufficient differential

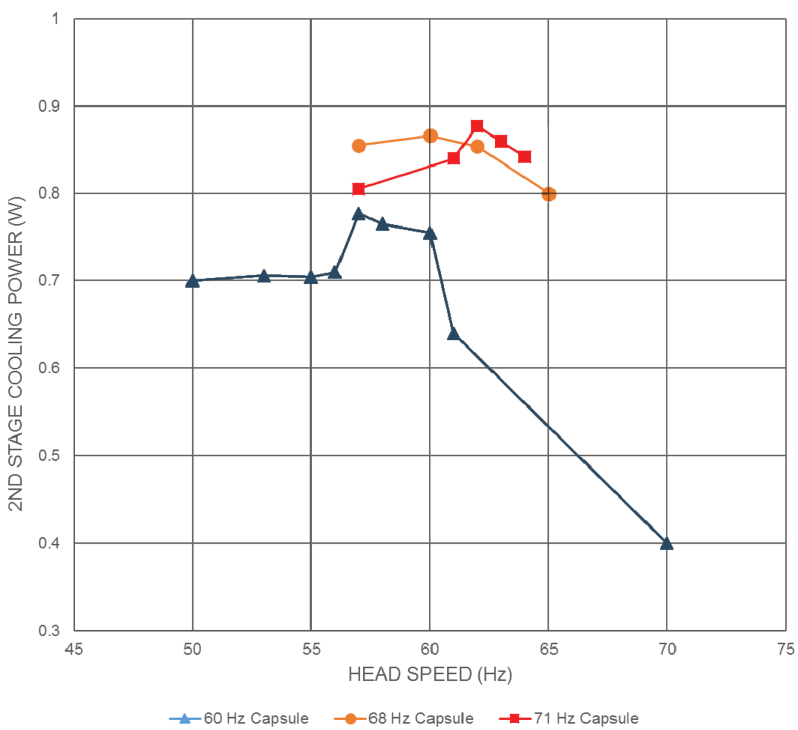

Figure 8. Head speed “tuning” to optimize cooling power at a given capsule speed

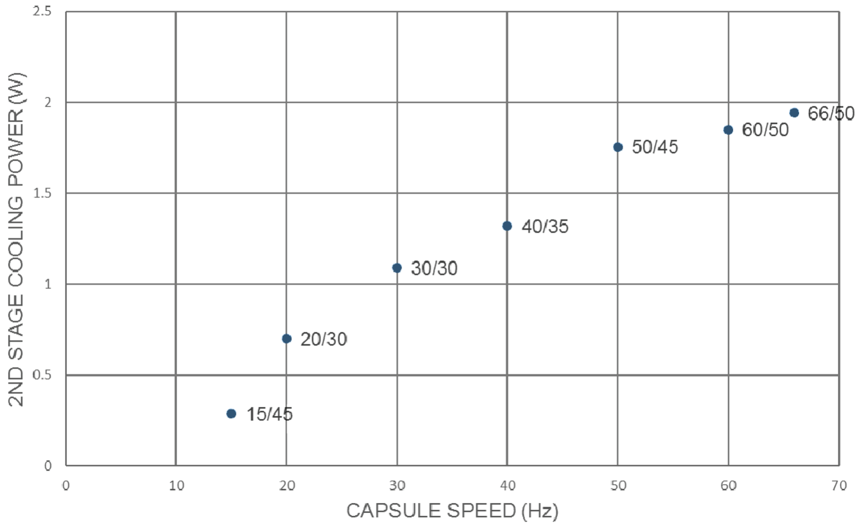

Figure 9. Cooling power with 4.2 K G-M at tuned (capsule/head) speeds

pressures at lower speeds to adequately return oil to the capsule from the coalescing filter. Like the pulse tube, keeping the G-M head speed several Hz lower than a given capsule speed yields maximum 2nd stage cooling power. Depending on the compressor configuration, the upper limit for capsule speed ranges from 66 to 71 Hz and is a result of the maximum capsule inverter rating of 18 amps. Unless ultimate cooling power is the top application priority, the additional power draw and wear on moving parts should also be considered when determining the maximum allowed capsule speed.

CONCLUSIONS

The updated modular architecture of the HLC 4500 helium compressor and chiller provides a novel smart energy helium compressor solution by enabling the end user to "dynamically tune" capsule and head speeds, allowing for optimization of cooling power needs and total power draw. Reducing compressor speeds also helps lengthen the service life of major system components such as scrolls, bearings and moving seals. Further testing planned includes: expanded thermal testing in cold environments, cold head tuning refinement, testing at capsule speeds above 70 Hz (larger inverter) and optimization of 1st stage cooling power. Compressor speeds and parameters can easily be remotely adjusted via CAN bus offering further automation and refinement of compressor diagnostics and control. Further software development is planned to streamline the graphical user interface and offer real time display of power draw and cooling power.

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9. Model RDK-415D: a 1.5W 4K class helium cryogenic refrigerator manufactured by SHI Cryogenics Inc.
10. Model ACI-3: a 3 ton air-cooled chiller manufactured by Pacific Rim International.
11. Model RP-082B2S: a 0.9W 4K class helium cryogenic refrigerator manufactured by Cryomech Inc.
12. Model ZCH72: a horizontal helium cryogenic compressor manufactured by Emerson Climate Technologies.
13. Model S603DH: a vertical helium cryogenic compressor manufactured by Hitachi Appliances, Inc.