UNIQUE METHOD FOR LIQUID NITROGEN PRECOOLING OF A PLATE FIN HEAT EXCHANGER IN A HELIUM REFRIGERATION CYCLE.

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Precooling of helium by means of liquid nitrogen is one the oldest and most common process features used in helium refrigerators. The principal tasks are to permit a rapid cool down to 80 K of the plant, to increase the cooling power of the plant in low temperature operation and to increase the rate of pure liquid production. The advent of aluminum plate fin heat exchangers in the design of helium refrigerators has made this task more complicated because of the potential damage to these heat exchangers.

INTRODUCTION

SLAC was just one of the places where damage to the main Helium/Helium/Nitrogen heat exchanger has occurred. The most common reason has been the failure to maintain the barrier between the helium and the nitrogen gas flows. After suffering such a failure at SLAC, a new method was sought when the heat exchanger was replaced. The solution is unique as it uses helium in all parts of the heat exchanger, thus avoiding the problems associated with nitrogen. Helium is circulated in a semi-closed loop through a liquid nitrogen bath and is then sent via a short transfer line to the liquid nitrogen inlet on the main plant. The inlet to the system is tied to the helium return line from the main plant, providing a constant source of low-pressure helium gas to the precooler system. This also prevents the intrusion of air into the system because the low-pressure side is always maintained above atmospheric pressure by the main system. The advantages are that only helium is used in the main plant and no high-pressure helium is used in the precooler, making the full output of the main compressor available to the plant for liquefaction.

THE NATURE OF THE PROBLEM

When the time came to replace the Aluminum plate fin heat exchanger in the Research Yard Refrigerator [1], a study was undertaken to try and understand the failure mode and come up with a solution. In private conversations with Jim Kilmer of Fermi National Accelerator Laboratory and engineers from Altec, the replacement manufacturer of our new heat exchanger, two theories were put forward for the failure modes in the heat exchangers.

1. A plant upset where the nitrogen is frozen by the lower temperature return Helium
2. The failure was the result of 2-phase flow in the nitrogen path with the resulting failure coming from the rapid localized cooling when the liquid vaporized. This excess cooling would then exceed the thermal parameters of the heat exchanger.

Either way, it appears that the solution was to find a way to not use nitrogen in the heat exchanger. An earlier work-around was used on the SLC final focus when some part of the high-pressure stream was diverted, cooled and sent through the leaking He/N2 path. This fix required a reduction in flow to the turbines with the resulting reduction in cooling power.

THE SOLUTION

A calculation was done to see how much flow would be needed to use Helium in the Nitrogen path in the heat exchanger. The entropy values were compared for each gas at 77.4 K and 300 K (Table 1)[2].

Table 1

Entropy for Helium and Nitrogen

Temperature K	Nitrogen h(J/g)	Helium h(J/g)
77.4	14.1	430.00
260	420.5	1365.00
300	462.1	1572.70
Delta h @ 288 K	449.62	1510.39

The T-S Diagram [3] from the manufacturer of the plant requires a Nitrogen precool at 20 g/s for a flow of 140 g/s in the main flow path. However, our capacity is only 100 g/sec so a scaling was done giving 14.25 g/sec of Nitrogen. This scaling reduced the required cooling capacity of the nitrogen from 8414 watts to 6407 watts at 288 K. Helium flow rates (Table2)[2] relates the Nitrogen flow to a thermally equivalent Helium flow.

Table 2

Helium flow rates for a given Nitrogen requirement

	Nitrogen	Helium
g/s	14.25	4.24
J/s	6407	6407
Density g/l		6.15
Flow m^3/h		93.97

These numbers indicated that it would be possible to replace the nitrogen precooler with a helium loop with no loss of performance. A search was started around the lab to identify possible parts for the system. A nitrogen precooler heat exchanger was located from an older experiment (Figure 1). Also located was an unused Corken DA 690 dry compressor (Figure 2).

The Corken was rated at 102.28 m^3/h at a maximum rpm of 825. With all the required items needed, the system was designed to take suction gas from the CTI-4000 return line at 0.11 MPa and send the helium to the precooler at 0.239 MPa. Flow from the precooler was then sent via a vacuum jacketed transfer line to the liquid nitrogen inlet on the CTI-4000 (Figure 3). To prevent over cooling the top plate and compressor, a control loop was added to the LabView control system to stop the compressor should there be an upset in the CTI-4000 operations.

Figure 1

LN_2 Precooler

Figure 2

Corken Compressor Installation

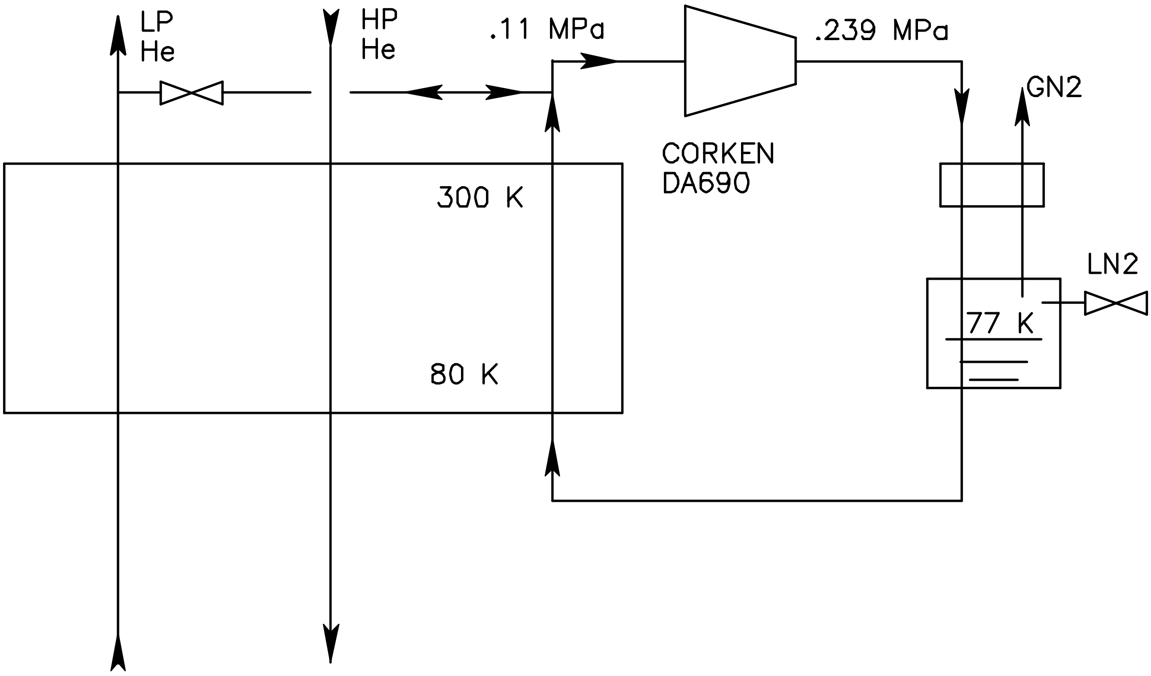

Figure 3

Flow Path of Helium Precooler

OPERATION

The precooler was operated for the last two high power runs of SLAC Experiment E-158. The experiment placed a heat load of 1 kW on the cooling system at 17.5 K. This required the plant be operated at or near maximum conditions (Table 3.)

Table 3

Operational parameters

Flow High Pressure Grams/second	Return pressure MPa	Precooler flow m^3/h	Temperature Kelvin
102	0.110	101.94	89

FUTURE IMPROVEMENTS

The present precooler does not have enough capacity to permit pumping the LN_2 to a lower temperature. If the need occurs, the old heat exchanger has three flow paths of which two are now connected. This will permit the operation in two flow paths. We can then use this heat exchanger in the new precooler with larger flow paths in a pumped regime and operate the precooler with a 67 K outlet temperature.

CONCLUSIONS

A unique method for nitrogen precooling a plate fin heat exchange was developed. It provided the needed cooling power for SLAC E-158 and has the ability to be expanded to give more cooling power should the need arise in the future.

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