TM-857
1800.000

Fermilab

CCI Report No. 370-107

OPERATING PROCEDURES FOR SWITCH YARD REFRIGERATOR

Prepared Under Fermilab Subcontract No. 92690
By Cryogenic Consultants, Inc.
Allentown, Pa.

For

Fermi National Accelerator Laboratory, Batavia, Illinois

April 27, 1978

CONTENTS

A. EVACUATION AND PURGE

Purpose

To remove air and condensables (mostly water) from the piping and vessels and replace these with pure helium gas.

Reason

The most troublesome of condensables is water. If water is left in the system, it will be carried into the cold box during the operation of the box. If enough water is present, freezing of the water in exchangers 1 and 2 will occur and generate a high pressure drop in these tubes. The most likely places for the existence of water are the charcoal and molecular sieve adsorbers. In fact, charcoal and sieve as added to the vessels are probably loaded with water.

1. Evacuation:

   1.1 A mechanical vacuum pump (3.0 bhp Kinney or equivalent) needs to be connected to at least one spot of the low and high pressure lines between compressor and cold box. MV-205-H & MV-105-H are likely spots.

   1.2 All valves in the cold box should be opened to the suction and discharge lines.

   1.3 Start the pump and open MV-105 and -205. Pump the system down to a pressure of 5 mm Hg and close valves MV-105 and -205.

   1.4 Observe the vacuum for some time on PI- . The change in pressure versus time will indicate the amount of leakage into the system. When the system contains water, the vacuum will rise to a level of 10-20 mm Hg, depending on the temperature of the system.

   1.5 Find and fix the gross leaks in the system.

   1.6 Re-evacuate to 10 mm Hg and fill the piping and vessels with dry nitrogen gas through valve MV- to a pressure of 2 psig.

   1.7 Close off the source of N_2 gas and determine the dewpoint of the N_2 gas in various components of the system. It is most likely that water will be present in charcoal vessel and molecular sieve. If the water content is high in these vessels, isolate them from the system by closing MV-053-H., MV-051-H and MV-031-H.

2. Drying of the System:

2.1 Cold Box Components:

2.1.1 Connect a source of dry N_2 gas to valve MV-105 and blow gas through the high pressure circuit of the cold box and out through bayonet P, F, G or R. Determine the dewpoint of the gas at the exit. If it is below 30°F, the box high pressure circuit is dry enough for operation.

2.1.2 Connect a source of dry N_2 gas to valve MV-205-H and blow dry N_2 gas through the cold box exchangers out at MV-231, MV-222, MV-252 and bayonets E, M and S. Measure the dewpoint at these locations. If below 30°F, the shell side of the exchangers is dry enough for operation. If not, continue flow at a low rate until the dewpoint is reduced to 30°F or below. If the dewpoint is very high (saturation at gas temperature) heating of the gas added to the cold box would be beneficial. The physical arrangement of the equipment will dictate the amount of insulation to be used.

2.2 Compressor and Warm Piping Components:

2.2.1 Measure the dewpoint of the compressor piping system.

2.2.2 To dry, the molecular sieve bed will be used. Reactivate this bed by heating and pumping.

2.2.3 With the molecular sieve bed dry, circulate N_2 gas through the compressors, charcoal bed, molecular sieve and bypass valve PV-103. The compressors will be driving the gas through. Measure dewpoint at the discharge of the third stage discharge of charcoal bed and discharge of molecular sieve bed. If the latter dewpoint increases, interrupt the operation and reactivate the molecular sieve bed before resuming the operation. When the dewpoint at the discharge of third stage and charcoal bed becomes -20°F or lower, the compressor system is ready for operation on helium. In that case, the molecular sieve bed will be isolated from the system by closing valves MV-052 and MV-053. MV-051 will be opened. The molecular sieve bed may now be reactivated.

3. Purge of the System:

3.1 With a dry system, replace N_2 with helium by three times evacuating to 10 mm Hg and backfilling with Grade A helium gas from high pressure helium storage to a pressure of 2 psig. This will dilute the air concentration by a factor of 400,000.

3.2 With the system filled with helium, bleed long dead-ended pipe sections for a few seconds each. This will remove the air located at the very tip of the dead-ended section.

B. COOLDOWN OF THE COLD BOX

It is assumed that the cold box is connected through two bayonets to a dewar or similar vessel. It is assumed that this dewar and the expansion engines have been evacuated, purged and filled with helium gas. The primary source of refrigeration for cooldown will be liquid nitrogen.

1. Open PV-107 and add liquid N_2 to the reservoir of exchanger 1. Establish a liquid level on PLIC-111. After the level is established, PLIC may be established as the controller for valve PV-107. During filling of the exchanger, observe the insulating vacuum of the cold box, either by vacuum gauge or by touch of the cold box shell. Loss of vacuum indicates a vacuum leak. The vacuum should improve because of cryopumping of the cold box.

2. Start the compressors.

3. Set compressor bypass controller PPIC-103 to maintain a head pressure of 250 psig.

4. Keep valve PV-154 closed, open MV-153 and start flow of helium by opening EV-107. Do this gradually, while observing insulation vacuum and pressures on PI-131 and PI-153.

5. Establish 240-250 psig pressure on PI-153 by opening EV-107 wide and controlling MV-153. Control flow through MV-153 not to exceed a compressor suction temperature below 40°F. Initially, gas flowing through MV-153 will be at ambient temperature, until all of exchanger III and most of exchanger IV is cold.

6. Progress may be checked by occasionally opening valve MV-131 and checking the temperature of this valve.

7. Time required to cool heat exchangers 3 and 4 from 300 to 80°K should be of the order of 1.5 hr with a flow rate of 8.3 g/sec of helium through the cold box. Observe the behavior of the liquid N_2 in heat exchanger 1 and keep level under control. Liquid N_2 consumption rate should be of the order of 90 liters/hr.

8. Start warm expander after heat exchanger 3 has been cooled (check at MV-131). Run expander at full speed to accelerate cooldown.

9. When exchanger 4 is cold open valve MV-152 and close valve MV-153. Control pressure (PI-153) with amount of opening of valve MV-152.

10. Low pressure gas is returned through the shell side of exchanger 2. When TI-206 and TI-208 start to indicate lower temperature, open EV-106 and MV-108 to keep TI-206 and TI-208 from dropping below 40°F. If necessary, reduce flow through EV-107. In general, high pressure flow should be balanced by manipulating valves EV-107, MV-108 and EV-106.

11. At this time in the cooldown process, it does not make much sense to operate the wet expander. It has a very low throughput and will make very little refrigeration.

12. Observe TI-132 and TI-241. When they come on scale, temperatures in lines 3, 4, 18 and 19 will be at 40°K or lower. Observe TI-152 and TI-252. When they come on scale, temperatures will be in the range of 4-20°K.

13. Start the wet expander when TI-152 and TI-252 come on scale. To start the wet engine, it is necessary to flow through the dewar connected to the cold box. If there is no dewar or if the dewar is cold, wet expander flow might be bypassed through a short spool piece, connecting bayonets F, G, R (one of these) and E, M, S (one of these).

14. When TI-151 indicates 5°K or less, MV-152 may be closed and all flow taken through the wet expander. TI-252 should read liquid temperature (2-4 psig).

C. STEADY STATE OPERATION

At this point, the system may be set up for steady state operation, as follows:

1. Compressor discharge pressure is maintained by PPIC-103, controlling flow through valve PV-103.

2. Liquid N_2 level in heat exchanger 1 is controlled by PLIC-111. Check proper functioning by reading TI-111 at 80°K ($\pm$.5°K).

3. Division of flow between exchangers 1 and 2 is controlled by valves EV-106 and EV-107. Proper division is indicated by measuring streams 14 and 25, relative to streams 1A, 1B and 26 temperatures. The difference between 1A, 1B and 14 should be of the order of 15-20°F. The difference between 25 and 26 should be 20-30°F.

4. Warm expander speed should be controlled to maintain TI-132 (TI-335) at approximately 25-28°K.

5. Wet expander speed should be controlled to keep valve PV-154 closed and PI-153 at approximately 280 psig. Too high a speed will lower this pressure and reduce output of the refrigerator.

6. Opening of valve PV-154 will reduce refrigeration capacity of the liquefier and may be corrected by increasing the speed of the wet expander.

Steady state without automatic controls for warm and wet expanders and valve PV-154 needs to be monitored.- Look for the following:

1. Too much refrigeration made by the machine will result in first instance in a lowering of the compressor suction pressure. PPIC-101 should control this by admitting gas from the LP or HP gas vessels.

2. Too little refrigeration will result in a rising suction pressure. Controller PPIC-102 will open valve PV-102 and return excess gas to the LP gas storage vessel.

3. When 1) and 2) above are not operative (no gas, for instance) controls at the cold end of the plant need to be adjusted.

4. Maximum refrigeration is obtained when valve PV-103 is closed, warm expander speed provides 25-28°K on TI-132 and wet expander speed maintains PI-153 at 279 psig. If the system load exceeds the maximum refrigeration level, compressor suction pressure (and dewar pressure) will rise. This in first instance provides more compressor flow to the cold box and allows an increase in both expander speeds. A further rise in suction pressure will remove gas from the system through PV-102 and result in consumption of liquid helium. It is possible to operate for extended periods of time in this mode. Liquid helium is being used up and changed into gaseous inventory.

Steady State Operation Variation Between:

1. All liquid production.
2. Liquid production and refrigeration.
3. Refrigeration only.
4. Exceeding refrigeration capacity of the machine.

The system will operate efficiently in any of the four modes. Following are the significant characteristics and control modes for each one:

1. All Liquid Production:

    a. Suction pressure tends to go low. Valve PV-101 adds gas to the system.

    b. Warm expander speed is high.

    c. Liquid nitrogen consumption is high.

    d. Wet expander speed is lowest.

    e. Warm end ΔT's of exchangers 1 and 2 will be low.

    Rate of liquefaction may be measured by gas flow rate from gas storage and level increase in the dewar. If both are measured accurately, one will find a discrepancy of approximately 15% between these rates. Level will increase faster. The discrepancy is caused by the fact that the machine still acts as a refrigerator and is turning the gas displaced by liquid in the dewar into liquid. The gas density is approximately 15% of that of liquid and this 15% provides the 15% reduction in gas flow to the machine.

2. Liquid Production and Refrigeration:

   a. Suction pressure tends to go low. Valve PV-101 adds gas to the system.

   b. Warm expander speed is lower than under 1) above.

   c. Liquid nitrogen consumption is lower than under 1) above.

   d. Wet expander speed is higher and inlet temperature will be lower.

   e. Warm end ΔT's of exchangers 1 and 2 will be somewhat higher.

3. Refrigeration Only:

   a. Valve PV-101 is closed.

   b. Warm expander speed is lower.

   c. Wet expander speed is higher.

   d. Liquid nitrogen consumption is lower.

   e. Warm end Δ T's of exchangers 1 and 2 are higher. It should be noted that refrigeration performance only occurs at maximum output of the machine, unless flow to the box is reduced. In other words, mode 2 occurs automatically in lieu of mode 3. To get from mode 2 to mode 3 requires reduction of flow to the box by opening valve PV-103 partially. This may be achieved automatically by closing valve PV-154 and decreasing wet and warm expander speeds.

4. Excess Refrigeration:

   This mode occurs when the capacity of the machine is exceeded.

   a. Suction pressure increases and gas needs to be diverted to gas storage through valve PV-102.

   b. Liquid helium level drops. To maintain liquid needs to be added from an external storage vessel.

   c. Warm expander speed drops. It may be at a very low level or stop altogether (TI-132 controls).

d. Wet expander runs at full speed.

e. Liquid nitrogen consumption is low and may go to zero.

f. Division of flow between exchangers 1 and 2 changes with less high pressure flow going through exchanger 1.

D. TROUBLESHOOTING WHEN OPERATING AT STEADY STATE

In order to determine whether the machine operates at steady state and full capacity, it is necessary to provide a number of parameters and their values at steady state. The most important parameters are:

1. Gas flow rate and pressure to the cold box.
2. Insulating vacuum of the cold box, transfer lines and expander cans.
3. Heat exchanger performance, primarily below 80°K (exchangers 3 and 4).
4. Expander performance.

1. Gas Flow and Pressure:

   These may be determined by a flow meter and pressure gauge. The flow meter may be a simple orifice plate. Its absolute reading is not important, as long as it is known what the reading should be at full output of the machine.

2. Insulating Vacuum:

   If vacuum gauges are used, they may be read. If not available, the temperature of the shells of vessels and lines is a good indication. Typically, 1°F difference between ambient temperature and wall temperature means a heat flux of .3 W/ft^2. The wall temperature of a couple of degrees (°F) below ambient may be recognized by alternately touching the vessel and a metal part, not part of the vacuum vessel.

3. Heat Exchanger Performance:

   Heat exchanger performance will be verified during checkout of the cold box. At that time it should be noted what typical temperature and pressure differences are as follows:

a. TI-206 and TI-208 against high pressure gas to the box.- This will determine liquid N_2 consumption in the box.

b. TI-111 and TI-122 against TI-222 and TI-223.- The difference should be of the order of 1°K, except for the excess refrigeration mode, where it will increase. The difference is then a function of the rate of liquid consumption. An increase in ΔT between TI-122 and TI-222 by 1°K at full flow rate of 38 g/sec means a load of 200 W on the warm expander.

c. TI-132 against TI-232.- The difference will vary between approximately 4 and 1.5°K, dependent on mode. The largest ΔT occurs in the 100% liquefier mode; the smallest in the excess refrigeration mode.

d. Total pressure drop between inlet to the box (   ) and gauges - PI-131 (warm expander inlet) and PI-153 (cold expander inlet).- An increase in pressure drop implies plugging and will result in lower expander output and possible reduced exchanger efficiency from maldistribution of flow.

4. Expander Performance:

Typical problem areas of the expander affecting performance are:

a. Valve leakage.- If the expander is equipped with a P-V display, valve leakage may be observed by the shape of the P-V diagram. Also, an increase of speed over the normal speed is necessary to maintain refrigeration level. To prevent scoring of the valves, the inlet gas to the machine should be filtered by a 50 μ nominal filter.

b. Inlet and discharge valve timing.- These should be set initially and should not provide problems afterwards.

c. Heat leak.- If the engine is not properly mounted in the vacuum vessel, it may be possible to churn gas on the discharge side. In that case, the warm top plate of the vessel will get cool. Changes in method of gas discharge and baffling are required to overcome this problem.

d. Ring friction.- This can only be detected by mounting a thermocouple on the cylinder wall of the engine.

e. Ring blowby.- A P-V diagram will show excessive leakage past the rings.