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## MODEL 1410 LIQUEFIER

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## MODEL 1410 LIQUEFIER

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## APPENDICES



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# SECTION 1

# INTRODUCTION

## 1.1 PURPOSE AND SCOPE OF THE MANUAL

This manual has been prepared for the general instruction of personnel in the technique of installing, operating and maintaining the Model 1410 Helium Liquefier. It also serves as a reference for standard operating procedures and contains troubleshooting procedures for determining the probable cause and correction of the most common types of malfunction.

These instructions are not intended to be complete enough to permit operation of the system by previously untrained personnel. Those responsible for installation, operation, and maintenance should be experienced in the fundamentals involved in the care of machinery of a similar complexity and also should have some special training by representatives of Linde Cryogenics or by personnel otherwise specifically qualified.

An effort is made to cover the subject in a manner that will make the operator familiar with the equipment and with the purpose of each operation and function. This will improve his ability to cope with unusual situations or trouble arising from minor equipment failure or malfunction.

## 1.2 INTRODUCTION TO THE MODEL 1410 SYSTEM

The Model 1410 Liquefier is used primarily to produce liquid helium. It has a built-in automatic purification system, which allows the economical production of liquid helium using recovered air contaminated helium gas.

The principal components for the complete system are the Model 1410 Helium Liquefier module, a delivery tube, one or more Model 1400 Compressors, or a Model RS Compressor.

This system can be operated with one RS Compressor. (Compressors are described in a separate manual.)

The system has a wide range of performance that can be simply adjusted. Operation is economical because the system is operable with or without liquid nitrogen precooling depending on liquid helium production requirements.

## 1.3 OPERATING PRINCIPLE

In operation, helium gas is compressed and delivered to the liquefier module at approximately 16.5 bar (240 psig).

The gas is cooled in the liquefier by:

1. Liquid nitrogen when the precooler is used;
2. Heat transfer in the main heat exchanger;
3. Isentropic work extraction in the two expansion engines;
4. Isenthalpic expansion in the Joule-Thomson valve.

All of these processes take place in a high vacuum insulated chamber. The liquid helium produced is delivered to an externally located liquefaction dewar via a removable vacuum insulated delivery tube.

The integral, automatic, freeze out purifier in the Model 1410 Liquefier module allows operation using helium gas with up to 10% air impurities with minimal inlet pressure of 34.5 bar (500 psig). The system purifies by condensing and/or freezing out the impurities then by automatically discharging them to the atmosphere. Refrigeration is provided by cold helium gas from the liquefier, and no liquid nitrogen is required.

# SECTION 2

# DESCRIPTION

This section describes the basic components of the standard Model 1410 Helium Liquefier module. Also included is a description of the important optional modules used to expand or complement the M1410 system.

## 2.1 MODEL 1410 LIQUEFIER MODULE

**Note:** Refer to the Flow Diagram drawing in Section 4 for details of helium gas flow through the Model 1410 Liquefier module. Refer to System Equipment Installation / Interface drawing in Section 4 for a flow diagram of a typical complete liquefier system.

The Model 1410 Liquefier module consists essentially of the following components:

Main Heat Exchanger (E30, E31, E32, E33, E34)
Precooler (E81) / Boiler (E83)
Expansion Engine Charcoal Adsorbers (E36, E38)
Joule-Thomson Charcoal Adsorber (E41)
Expansion Engines (E37, E39)
Brake Assembly
Joule-Thomson Valve (JT307)
Return Valve (V308)
Delivery Tube Gland
Vacuum System
Control Panels
Piping and Electrical Components
Automatic Purifier (E60, E62, E67)
External Bypass Regulator (V345)

Helium gas is initially compressed to approximately 17.2 bar (250 psig) by the compressor module(s) and delivered to the liquefier module. At this point, the gas stream is split into two parts. One portion is delivered to the first section of the main heat exchanger (E30) where it is cooled by the countercurrent, low-pressure, helium return gas.

The second portion of the compressed stream flows through the precooler heat exchanger (E81) and boiler heat exchanger (E83) where it is cooled by counterflowing cold nitrogen vapor and a liquid nitrogen pool, respectively.

This precooled helium stream then rejoins the main stream. This combined stream continues through the second heat exchanger section (E31) and then through the No. 1 engine charcoal adsorber (E36) for removal of trace air contaminants. The stream again splits into two parts. One part flows through the No. 1 expansion engine (E37) where it is cooled by isentropic expansion and then exhausted to the low-pressure return stream at nearly atmospheric pressure. Part two of the stream, still at high-pressure, flows through the third and fourth sections of the heat exchanger (E32, E33) where it is further cooled and then into the No. 2 engine charcoal adsorber (E38) for removal of lower boiling point contaminants. The stream again splits. Part one flows through the No. 2 expansion engine (E39) where it is cooled isentropically and exhausted to the low-pressure return stream; part two flows through the final section of the heat exchanger (E34). The stream is then throttled to nearly atmospheric pressure by the Joule-Thomson valve (JT307). Isenthalpic expansion through the J-T valve further cools the gas and a fraction is liquefied.

The low-pressure liquid / gas mixture flows through the inner channel of the triaxial delivery tube and into a dewar where liquid helium separates and collects. The remaining vapor, along with dewar boil-off and any vapor being displaced from liquid level rise, returns to the heat exchanger through the annular channel of the delivery tube and return valve V308. The low-pressure stream combines with the expanded engine streams within the heat exchanger and cools the incoming high-pressure gas. It is thus warmed to ambient temperature and returns to the compressor for recycle.

### 2.1.1 Internal Charcoal Adsorbers

#### 2.1.1.1 Expansion Engine Charcoal Adsorbers (E36, E38)

The function of the expansion engine charcoal adsorbers, located within the vacuum chamber, is to adsorb impurities that may enter the liquefier. All gas entering the No. 1 engine (E37) passes through the No. 1 engine charcoal adsorber (E36). All gas entering the No. 2 engine (E39) passes through the No. 1 engine charcoal adsorber and the No. 2 engine charcoal adsorber (E38). The element of each adsorber is a specially treated activated charcoal. Fiberglass filters contained at the outlet of each adsorber prevent migration of charcoal particles.

The No. 1 engine charcoal adsorber operates at less than 80°K and adsorbs $O_2$ and $N_2$. The No. 2 engine adsorber normally operates at less than 20°K and removes $H_2$ and Ne.

### 2.1.1.2 Joule-Thomson Charcoal Adsorber (E41)

The Joule-Thomson charcoal adsorber (E41), located within the vacuum chamber, operates at approximately 8°K and protects the J-T valve from any remaining contamination or particles that could obstruct the valve orifice. The construction of the adsorber is similar to that of the expansion engine charcoal adsorbers.

### 2.1.2 Main Heat Exchanger (E30, E31, E32, E33, E34)

The main heat exchanger, located within the vacuum chamber, cools incoming, compressed helium gas with the expanded, low-pressure return helium gas. It consists of five concentric sections. Each section is constructed with finned tubing wound around an inner shell and enclosed by an outer shell. The incoming compressed helium flows through the finned tubing; the expanded return gas counterflows across the fins.

### 2.1.3 Expansion Engine (E37, E39)

The function of the expansion engines is to provide refrigeration by isentropic work extraction. There are two expansion engines, each one consisting of a piston, cylinder, crosshead and valves operated through cranks and valve cams and connected to a flywheel. Both engines have a piston stroke of 50.8 mm (2 inches). The No. 1 engine (E37) has a 76.2 mm piston diameter (3" OD) and normally operates with an inlet temperature of less than 80°K; the No. 2 engine (E39) has a 50.8 mm piston diameter (2" OD) and operates at less than 20°K.

### 2.1.3.1 Piston, Cylinder and Crosshead

**Note:** Refer to Figure 5-1.

The expansion engine piston (2) is made of phenolic plastic. The cylinder (1) is stainless steel.

The crosshead (7) is made of aluminum and moves within the cast iron crosshead guide (11). It is connected to the piston with a locking screw (5). O-rings (6), located in grooves in the outside of the crosshead, seal the internal assembly to the crosshead guide. Lubrication for the O-rings is supplied by felt washers (45) which are impregnated with lubricant and installed in grooves near the O-ring seals on the circumference of the crosshead.

A connecting rod (14) connects the crosshead to the driveshaft crankpiece (23).

Two O-rings (8, 9) act as static seals between the cylinder and the cover plate (44), and the cylinder and the crosshead guide. A Teflon gasket (4) also seals between the cylinder and the crosshead guide. A sealing washer (3) prevents leakage around the locking screw.

### 2.1.3.2 Valve Assemblies

**Note:** Refer to Figure 5-1.

Each stainless steel valve has a plastic valve seal (54) and is guided within the valve sheath (51) by phenolic plastic spacers (49, 52, 53). Since the valve is closed by the springs, the valve rod (48) serves only to open the valve and experiences only tensile forces. The springs (50) do not come in contact with any metallic part, thus no metal particles are formed as a result of wear. The static and dynamic seals for the valves are lubricated O-rings (43, 41). Lubrication for the dynamic O-ring is provided by a felt (40) that has been vacuum impregnated with a lubricant. The knurled cap (39) retains the valve parts within the sheath tube. The valve assembly can be removed from the sheath tube for service or inspection.

### 2.1.3.3 Flywheel and Cam Assembly

**Note:** Refer to Figure 5-1.

The driveshaft (22) is supported and held in place by the two main bearings (24) that are mounted on the frame casting (30). The flywheel (29) is locked to the center of the driveshaft between the two main bearings. At each end of the driveshaft is mounted a crankpiece (23). The orientation of the crankpieces is such that the crankpins are 180° apart. Attached to each crankpiece are the inlet and exhaust cams (15, 17 and 37, 38) that operate the valves by means of the valve arms and the piston connecting rod. The inlet cams may be adjusted for optimum performance (See Table 4-1).

The valve arms (25, 28, 31, 35) are attached to the frame casting with shoulder bolts that allow the arms to oscillate as the cam followers (32, 34) ride on the cam surfaces. The intake and exhaust valve rods are attached to their respective valve arms by clamp assemblies (27). The upward motion of the valve arms opens the valves; the valves are closed by the action of the valve springs.

### 2.1.3.4 Expansion Engine Cycle

As the piston nears the bottom of its stroke, the intake valve opens and compressed helium gas flows into the cylinder. The gas exerts a force against the face of the piston and drives the piston upward. The gas continues to enter the cylinder at nearly constant pressure until the intake valve closes at cutoff. After cutoff, the gas in the cylinder continues to force the piston upward as the gas expands. Work is performed by the gas, and its temperature is progressively lowered; the pressure decreases almost to atmospheric pressure.

During the upward stroke of the piston, energy is stored in the flywheel. The energy is then used to move the piston downward for the exhaust stroke. The exhaust valve opens to expel the cold, expanded gas and when the piston has nearly reached the bottom of the cylinder, the exhaust valve closes and the intake valve reopens to begin the cycle again.

### 2.1.3.5 Brake Assembly

**Note:** Refer to Figure 2-1.

The brake has two main functions: (a) to absorb energy removed from the gas and (b), to control the speed of the expansion engines.

Four V-belts (16) connect the flywheel (1) to a sheave that is mounted on the jackshaft (5). A timing belt (6) connects a sprocket on one end of the jackshaft to a sprocket on the VFD driven motor (7). The speed is set automatically by the VFD. The output of the VFD is fed into two externally located resistors to dissipate the electrical energy produced.

### 2.1.3.6 Expansion Engine Inlet Pressure and Speed Control

The Model 1410 is equipped with an automatic heat exchanger inlet pressure and engine speed control system. The system is designed to provide optimal performance by maximizing the use of available compressor capacity. This is accomplished by varying the engine speed to a maximum value at which the inlet pressure is equal to or greater than 15.9 bar (230 psig) and the engine speed does not exceed 230 rpm.

**Note:** Refer to Figure 2-12.

The pressure control is a PID control loop operated by the PLC (Programmable Logic Controller). The setpoint for this loop is 15.9 bar (230 psig) and the process variable (parameter which is being controlled) is the pressure coming from pressure transmitter PT-1. The output from this loop is sent to the VFD as the speed setpoint.

The control loop is direct acting; as the pressure rises, the output from this loop will also rise. The output from the loop, in the form of a 4-20 mA signal, is sent to the VFD. As its speed setpoint increases, the VFD increases the motor speed until SDP=PV.

The operator may choose **MANUAL** speed control if desired. In this mode the control loop is disabled and the speed setpoint is entered by the operator via the Operator Interface Terminal (OIT).

In the event of a power loss, the VFD will transform the rotating motor energy into internal braking torque. This feature, called a regenerative braking, slows the engines to a stop without the incoming electrical power.

### 2.1.3.7 Engine Brake Circuit Component Description

#### 2.1.3.7.1 Pressure Transmitter PT-1

PT-1 is a pressure transmitter located in the helium supply line between V323 and the first heat exchanger. Its input range is -1.0 to +19.6 bar (-15 to +285 psig) with a linear output of 4 to 20 mA. This output signal is sent to the PLC's analog input module.

#### 2.1.3.7.2 Speed Signal SI-1

Speed signal is supplied from the VFD. It is proportional as 4-20mA to 0-90 Hz of the VFD power which corresponds to 0-2700 rpm of the motor shaft.

#### 2.1.3.7.3 PLC Functions

The PLC performs all the control functions for the speed control loops. It monitors the pressure and speed analog inputs and executes a PID control algorithm to adjust its analog output, which is sent to SY-1 (VFD). The PLC monitors the OIT for operator commands and updates the display for monitoring the process.

The PLC also performs many safety checks during engine operation, such as high and low speed conditions, low pure gas supply pressure and transistor fuse status. In the event of an abnormal condition, the PLC will take action to correct the problem or shut the system down in an orderly manner.

#### 2.1.3.7.4 VFD SY-1

SY-1, located on the electrical subpanel, performs several functions. The basic is to control the motor speed to the setpoint. It also provides linear acceleration / deceleration of the motor at step changes of the setpoint. For detailed description of the VFD, please refer to Hitachi VFD manual.

### 2.1.3.8 Engine Overspeed Safety Device

The overspeed safety device consists of a spring loaded pin built into the flywheel and a switch mounted on the cover plate. This prevents the engines from overspeeding in the event the VFD does not act as a brake (e.g., belt or VFD failure). Centrifugal force compresses the spring and allows the pin to move beyond the outer circumference of the flywheel.

When the engine speed reaches approximately 350 rpm, the pin will protrude enough to trip the switch. The PLC will then close the helium supply solenoid (V323) which shuts off the gas supply to the engines and the engines will coast to a stop. The PLC will also stop any other functions related to engine operation, such as stopping the purifier and closing JT307.

After the cause of the overspeed has been corrected, the switch must be reset manually using the reset tool provided (P/N 3824375). An overspeed alarm will be displayed on the Operator Interface Terminal. After the switch has been reset, pressing the **ALARM RESET** button will disable the alarm.

### 2.1.4 Joule-Thomson (J-T) Valve (JT307)

The J-T valve liquefies helium into a customer-supplied external dewar. It is an actuated extended stem needle valve located within the vacuum chamber. The valve stem, enclosed in a stainless steel sheath, extends from the valve body up through the ambient temperature cover plate. The actuator that positions the valve is located on the cover plate.

The J-T valve position is automatically determined by the PLC and is based on the No. 2 engine inlet temperature. As the engine temperature drops, the J-T valve opens. Manual override of the position is provided.

### 2.1.5 Low Pressure Return Valve (V308)

The low-pressure return valve is an extended stem, piston operated, on/off shutoff valve located on the vacuum chamber cover plate. The valve isolates the low-pressure return gas to the heat exchanger in the Model 1410 Liquefier module.

### 2.1.6 Vacuum System

The vacuum system provides insulation for the cold parts of the liquefier and consists of the vacuum chamber, the vacuum pump (E40) and vacuum instrumentation (VT43, VT44).

#### 2.1.6.1 Vacuum Chamber

The vacuum chamber encloses the engines, heat exchangers, filters, cold valves, and cold piping of the liquefier. The internal piping arrangement is shown in Figure 2-2. At the top of this chamber is a collar through which the gas piping penetrates. The cover plate, attached to the collar, provides support for the engines, flywheel, J-T and cold gas control valves, and the delivery tube gland. An O-ring seals the interface between the collar and the vacuum chamber. The engines, charcoal adsorbers, heat exchangers and valves are designed to be readily removed as a unit from the vacuum chamber should the occasion arise for maintenance.

A relief valve (V346) at the bottom of the chamber protects against over-pressure in the event of a helium leak within the chamber.

#### 2.1.6.2 Vacuum Pump and Piping

The insulating vacuum is produced by the 5 $m^3$/hour (3 cfm) rotary vacuum pump (E40) and by cryopumping action. The vacuum pump reduces the pressure in the vacuum chamber to approximately 50 mTorr at ambient temperature. Cryopumping further reduces the pressure below $10^{-5}$ Torr as the liquefier cools. The control switch for operating the vacuum pump is located on the Operator Interface Terminal. The piping between the vacuum chamber and the pump contains a manual shut-off valve (V336) to isolate the vacuum pump. A normally closed solenoid valve (V348) prevents the back flow of pump oil into the vacuum chamber if there is a power interruption.

A connection is also provided at V352 to allow periodic evacuation of other components such as the Remote Delivery Tube.

#### 2.1.6.3 Vacuum Instrumentation

A thermocouple gauge tube / transmitter (VT43) is mounted in the vacuum piping between the vacuum pump (E40) and solenoid valves (V348) and (V350). A second thermocouple gauge tube / transmitter (VT44) is located on the vacuum jacket. Both may be read out on the Operator Interface Terminal.

### 2.1.7 Temperature Instrumentation

Silicon diodes and thermocouples are installed to provide an accurate means of temperature measurement for evaluating the operation of the liquefier. TE-A senses the temperature of the gas entering the No. 2 engine (E39). TE-B senses the temperature of the gas entering the J-T valve (JT307). TE-5 and TE-C, used in the automatic control of the purifier, are located on the purifier's cooling stream. TE-5 is located between heat exchangers E60 and E62, while TE-C is located between heat exchangers E62 and E67. TE-7, located on the bottom of the E60 purifier heat exchanger, monitors temperature at the water blowdown connection. TE-2 indicates the temperature of the return helium gas after passing through the last section of the heat exchanger (E30).

The diodes, tagged as TE-A through TE-C, are connected to temperature transmitter TJT-1. TJT-1 transmits these temperatures as individual 4-20 mA signals to the PLC analog input module. Thermocouples, designated as TE-1 through TE-7, are connected to a PLC thermocouple input module. The PLC uses these temperature inputs for control purposes and all temperatures are displayed on the Operator Interface Terminal. A redundant diode is provided at all diode locations and their wires are bundled near temperature transmitter TJT-1.

### 2.1.8 Control Panels

#### 2.1.8.1 The Main Control Panel

**Note:** Refer to Figure 2-3.

The main control panel is located along the front of the liquefier and contains the instrumentation and controls required for normal operation. All of the operator input and most of the machine status is incorporated in to the Operator Interface Terminal.

The main control panel also has two pressure gauges, heat exchanger supply pressure (PI-33) and the JT307 inlet pressure (PI-34).

An emergency stop push-button is also located on the main control panel. This illuminated push-button is normally in its extended (out) position with the light off. Pressing the button will latch it in its depressed position, the light will turn on, and all PLC outputs will de-energize. This will return all automatic valves to their fail-safe positions and the expansion engines will slow to a stop. The pilot light will also turn on if the PLC is not in its “run” mode. This happens briefly at power up and in the unlikely event of a PLC fault.

#### 2.1.8.2 Auxiliary Panels

Located behind the right front door is an auxiliary panel containing pressure gauges PI-32 (supply pressure to makeup regulator V370), PI-39 (pure helium supply pressure), PI-60 (impure supply pressure to the purifier), PI-35 (low-side pressure) and PI-308 (dewar / return pressure between RDT and V308).

Located behind the left front door is a bracket holding the engine run time meter ETM-1.

### 2.1.9 Precooler (E81) / Boiler (E83)

To obtain increased capacity, a liquid nitrogen precooler (E81) is installed within the vacuum chamber.

In operation, valve V808 is opened thus allowing a portion of the incoming helium stream to the precooler (E81) / boiler (E83). This stream is throttled by adjusting valve V806. The precooler is a counterflow heat exchanger that uses the latent and sensible heat in the liquid nitrogen to cool this throttled stream to about 95°K.

The nitrogen level is automatically controlled in the “keep full” manner by two sensors (LE-1, LE-2) located in the level control tube of the boiler. LE-1 is the low level and LE-2 the high level sensor. The $LN_2$ level will oscillate between these two points.

There is the check valve (V802) located in the gaseous nitrogen exhaust line. A liquid nitrogen supply pressure of 0.7 bar (10 psig) is necessary to insure sufficient precooler operation.

Temperature sensor TE-6, near the inlet to heat exchanger E31, can be used to indicate the helium flow through the precooler. Optimum precooler flow occurs when the E31 inlet temperature is approximately 95°K.

### 2.1.10 Automatic Purifier (E60, E62, E67)

**Note:** Refer to Figures 2-4A, B, C, D

The automatic purifier liquefies helium gas with up to 10 percent air impurity. The major components of the purifier are: multiple finned tube heat exchanger sections (E60, E62), a filter (E67), three extended stem pneumatically operated valves (V614, V615, V616), and three temperature sensors (TE-5, TE-7, TE-C). These components are located within the vacuum chamber of the liquefier where they are interconnected to each other as well as to the main heat exchanger. The PLC monitors the temperatures and pressure of the purifier and controls all valves required for automatic operation during cooldown, purification, and final shutdown with enhanced regeneration.

The purifier requires a minimum supply pressure of 31.0 bar (450 psig) of impure helium gas. A buffer volume of approximately 40 liters (1.5 cubic feet), the size of a typical high-pressure helium cylinder, is suggested to be connected to the impure gas supply line to minimize pressure fluctuations during operation.

An automated purifier purge utility is provided which can be initiated by the operator. During this process the purifier is pressurized to full compressor discharge pressure through valve V614 and subsequently purged through the water and liquid air blowdown valves, V632 and V609.

#### 2.1.10.1 Purifier Cycle

Counterflow heat exchangers (E60 and E62) are cooled by approximately 20°K helium gas taken from the main heat exchanger near the inlet of the No. 2 expansion engine (E39). The cooling stream is controlled by valve V635 when the purifier is first turned on during the initial cooldown and is then controlled by the makeup gas regulator V370 during all subsequent operation. Low-side pressure tends to drop as helium is liquefied and stored into the dewar, which causes V370 to open. Cooling stream flow is thus a function of the liquid helium production.

When the purifier heat exchangers are cooled below preset temperatures at TE-5 and TE-C (reference Table 2-1 for typical values) the impure helium supply solenoid valve (V624) opens. The incoming impure gas stream counterflows over the refrigerated finned tubing where impurities are condensed and collected. The maximum flow rate of the incoming gas is controlled by needle valve (V628) so that it is slightly greater than the flow of gas required for helium production. Incoming gas causes the heat exchanger temperature to rise.

As the control-point temperatures rise, the impure helium supply solenoid valve closes and the heat exchanger cools again. The impure-gas feed cycles continue until the collected impurities result in sufficient restriction in the heat exchangers thus causing the inlet pressure to increase significantly. The PLC monitors the inlet pressure using a pressure transmitter (PT-60).

When the inlet pressure reaches 24.1 bar (350 psig) the PLC initiates a regeneration cycle wherein the heat exchanger is warmed so that TE-C reaches approximately 90°K and the impurities are discarded automatically through solenoid blowdown valves V609 and V632. The gas used to warm the heat exchanger is taken directly from the high-pressure supply from the compressor. When the warm-up setpoint of TE-C is satisfied and impurities have been discarded, the regeneration cycle is ended and cooldown begins again. Total regeneration time is usually between 4 and 8 minutes.

Manual actuation of the regeneration cycle by the Operator is possible at any time.

**Note:** The inlet pressure of the purifier heat exchanger during purification and regeneration is plotted versus time in Figures 2-5 and 2-6.

### 2.1.10.2 Purifier Valve Sequence

The following valve sequence description applies when the main heat exchanger has cooled sufficiently to commence operation of the purifier. If the operator turns on the purifier when the main heat exchanger is too warm, the PLC will automatically delay cooldown of the purifier until TE-A is less than 23°K and TE-B is less than 8°K.

1. When the purifier is switched on, valves V614 and V616 open; valve V615 closes, and JT307 is set to a “cracked open” position. Heater E63 is enabled. Heater E72 is controlled by the PLC to maintain ambient temperature condition at the water discharge line. Valve V603 opens, starting cooling stream flow through valve V635. When TE-5 and TE-C are sufficiently cool (reference Table 2-1) valve V624 opens and the first cycle of impure feed initiates. When TE-5 or TE-C rises above the desired operating

temperature, valve V624 closes completing the first impure feed cycle.

2. After completion of the first impure feed cycle, valve JT307 is placed in automatic mode wherein its position is adjusted to maintain proper No. 2 engine inlet temperature. Valve V334 closes isolating the pure gas supply to the cold box. Valve V603 closes and valve V602 opens, allowing the cooling stream to be controlled by makeup regulator V370.

3. If at any time during purifying operation TE-5 drops below 60°K, a regeneration cycle is automatically initiated. Warm-up prevents the cooling stream exiting the purifier from becoming too cold and damaging soft seated valves. Pure makeup gas solenoid valve V334 is temporarily opened to permit stabilized recovery of low-side pressure.

4. As impurities build up and cause flow restriction, purifier inlet pressure increases when valve V624 opens. When the inlet pressure reaches 24.1 bar (350 psig) the PLC automatically starts a regeneration cycle. Valves V602, V614, V616, and V624 close. Valve JT307 is placed in a cracked open position in order to minimize helium liquefaction in the dewar during regeneration and yet maintain proper cold temperature in the RDT. Valves V615 and V622 open and the purifier pressure drops to 5.5 bar (80 psig) as gas is drained to the helium recovery system. Valve V617 opens and warm-up of the purifier begins.

5. When TE-C reaches approximately 80°K, water blowdown valve V632 is opened for 20 seconds to drain E60 of any water that melted during regeneration. The pressure in the purifier drops to 3.4 bar (50 psig). After 20 seconds, valve V632 closes.

6. Air blowdown valve V609 then opens for approximately 60 seconds to drain E62 of any liquid air that melted during regeneration. The pressure in the purifier drops to 1.4 bar (20 psig). After 60 seconds valve V609 closes.

7. Valves V617 and V615 close. Valves V602, V614, and V616 open. The JT valve is placed back in auto position control mode. The purifier heat exchanger backfills with cold clean helium gas from the inlet of the second engine through valve V614. Cooldown of the purifier commences and regeneration is now complete.

8. When the purifier is shutdown (either by the Operator or automatically if PALL-65 is triggered by low-pressure), an enhanced regeneration (or final regeneration) is initiated. An enhanced regeneration is the same as the standard regeneration described above, except the setpoint for TE-C is 150°K instead of 80°K. After the enhanced regeneration is complete, the purifier is backfilled via valve V614 and blown down through valves V632 and V609 again.

#### 2.1.10.3 Purifier System Controls

Automatic operation of the purifier is governed by the PLC, which monitors temperature sensors TE-5 and TE-C and impure inlet pressure transmitter PT-60.

**1. Starting the Purifier**

Turning ON the purifier (using the Operator Interface Terminal (OIT) located on the main control panel) enables purifier operation if there is sufficient impure gas pressure detected by PT-65. Both the No. 2 Engine inlet temperature (TE-A) and the J-T valve inlet temperature (TE-B) must be sufficiently cold (approximately 23°K and 8°K respectively) before initial cooldown can start. The PLC will automatically start initial cooldown of the purifier after the cold temperature requirements are met.

**2. Temperature Control** (Reference Table 2-1)

Diode and thermocouple temperature elements provide input signals which in turn are monitored by the PLC such that:

a. Solenoid valve V624 opens to introduce impure gas when TE-5 and TE-C "Impure Feed" setpoints are both satisfied.

b. Solenoid valve V624 closes to stop flow of impure helium gas when either of the TE-5 or TE-C "Impure Feed" setpoints are not satisfied.

c. The regeneration cycle is completed when the TE-C "Regeneration Complete" setpoint is satisfied.

d. The enhanced regeneration cycle is completed when the TE-C “Enhanced Regeneration Complete” setpoint is satisfied.

### 3. Purifier Pressure Control

A pressure transmitter (PT-60) allows the inlet pressure of the purifier to be monitored by the PLC. When the contamination build-up is sufficient such that the inlet pressure reaches 24.1 bar (350 psig) a regeneration cycle is automatically initiated.

### 4. Initial Cooldown Cooling Stream Flow Control (V635)

Valve V635 controls the flow of the pure gas cooling stream from the purifier to the compressor suction return line during the first cooldown of the purifier. Valve V635 should be set so as to prevent the No. 2 engine from warming above 16°K during the initial purifier cooldown. Valve V635 is equipped with a micrometer handle. Typically a setting of 5 turns open is adequate.

### 5. Impure Feed Flow Control (V628)

Valve V628 limits the maximum impure gas feed-in rate so as to prevent temperature overshoot. Valve V628 is equipped with a micrometer handle. The setting of this valve is dependent on the liquefaction capacity of the M1410 Liquefier. Appropriate settings are typically 7 turns open for use with one RS Compressor without $LN_2$ precooling, and fully open for use with one RS Compressor with precooling.

### 6. Purifier Shutdown

Orderly shutdown of the purifier occurs when the operator turns off the purifier via the Operator Interface Terminal or if the impure gas supply pressure drops too low, thereby triggering PALL-65 (PT-65).

### 7. Purifier Purge

A Purifier Purge can be turned on at the operator's discretion and is generally used after an extended shutdown. The automated purifier purge cycle can be activated anytime a compressor is running. (The liquefier can be either on or off.) Pressing the “**OFF**” button terminates the purge sequence. A purifier purge is more effective when the cold box is warm.

The valve sequence for the automated purge cycle is as follows:

1. If the liquefier is not running, valve V323 is opened, pressurizing the main heat exchanger.
2. Valve V614 opens for 15 seconds to pressurize the purifier and then closes.
3. The liquid air blowdown valve V609 opens for 15 seconds and then closes.
4. The purifier is repressurized through valve V614 for 15 seconds.
5. The water blowdown valve V632 opens for 15 seconds and then closes.
6. Steps 2 through 5 are repeated two more times.
7. Valve V323 closes if the liquefier is not operating.

#### 2.1.10.4 Purifier Faults

A pressure transmitter is provided to stop the purifier upon loss of the impure gas supply. Orderly shutdown of the purifier occurs when the pressure of the impure gas supply, as sensed by PT-65, falls below the minimum operating limit of 31.0 bar (450 psig).

During operation, the impure supply pressure transmitter (PT-65) is set to close on decreasing pressure at 31.0 bar (450 psig). When the pressure falls below that setpoint, the purifier shuts off and the makeup gas source reverts to the pure gas supply. An alarm indication is provided on the Operator Interface Terminal.

To reset the impure supply interlock, the alarm indication must be reset and the purifier must be switched off, then on.

A pressure transmitter (PT-32) is located in the pure gas supply line. If the pressure falls below the setpoint, the purifier will shut off and the liquefier will shut down.

### 2.1.11 The Piping and Electrical Connections

The liquefier piping and electrical connections are located in the cabinet. The bottom fixed panel on the rear of the cabinet contains all the couplings and disconnects for the piping. The electrical connections are located on the interior electrical control panel located at the left side of the unit.

Behind the doors on the front right side of the cabinet are located control valves, regulators, control piping, and vacuum pump. The electrical subpanel, located inside a locking panel at the left end of the module, contains all relays, fuses, transformers, circuitry, etc. necessary for the operation of the control circuit.

### 2.1.12 Safeties and Alarms

The liquefier is designed for unattended, continuous duty. Electrical safety switches and controls automatically shut the system down if a malfunction occurs. Relief valves are provided to prevent excessive pressure buildup. Routine operator checks are recommended to maintain optimum performance and data logs.

### 2.1.13 External Bypass Regulator (V345)

This regulator serves to relieve the excess high-pressure gas being delivered by the compressor to the liquefier during certain periods of operation. It does so by bypassing the extra gas to the compressor suction. It is located on the external piping and is supplied by Linde Cryogenics.

### 2.1.14 Programmable Logic Controller

#### 2.1.14.1 Description

The Model 1410 has a programmable logic controller (PLC) that controls all functions of the liquefier. The PLC monitors all data from the Operator Interface Terminal, as well as inputs from pressure transmitters, temperature sensors and discrete switches. The heat exchanger inlet pressure, expansion engine speed and the J-T valve (JT307) position are all automatically controlled by the PLC's internal control loops. The PLC properly sequences all valves and updates the operator terminal to provide a complete control package.

The PLC is located on the electrical subpanel found behind a locking panel on the left side of the liquefier.

### 2.1.14.2 PLC Program

The Programmable Logic Controller (PLC) executes instructions contained in the ladder logic program.

**WARNING! Do not remove the PLC battery with power turned off. The PLC program will be lost!**

**WARNING! Do not attempt to modify or alter the PLC program in any way. Unpredictable machine operation may occur, resulting in undesirable actions and possible physical damage!**

## 2.1.15 Operator Interface Terminal (OIT)

### 2.1.15.1 General

The Operator Interface Terminal (OIT) is located on the main instrument panel on the front of the liquefier. The OIT allows the operator to monitor and control most of the liquefier functions, only some manual valves and pressure gauges are not accessible through the OIT. The OIT has a display area with touch sensitive screen and presents information in a multi-page format. The M1410 OIT can use up to 10 pages (page 00 through page 09), and allows the operator to view one page at a time.

The display has two primary regions, the template region and the control button region. A template is a graphical representation of conventional operator devices such as status indicators (pilot lights) and numeric displays. There are 15 template cells in the template region, 3 rows of 5 columns, allowing for up to 15 templates per page, although some templates may occupy more than one cell. Along the right side of the template region is the control button region. A control button is a graphical representation of a conventional momentary pushbutton. Up to four control buttons can appear vertically in the control button region.

### 2.1.15.2 Operation

To perform any OIT operation, the operator must go to the proper page, activate the appropriate template, and press the desired control button. For example, to start compressor #2 the operator would follow this sequence:

1. From the main menu (Page 01), press the **Page 02** button to bring up the compressor control page.

2. From other pages press the **GO TO PAGE** control button to bring up the numeric keypad. Press the **DIR** (directory) button to display a list of the OIT pages if you don't know which page contains the appropriate templates. All pages use two digits, the operator must use the preceding 0 (00, 01, 02...09). Press **02** to go to page 02, the location of the compressor templates.

3. Activate the compressor #2 template by touching the #2 template. The control buttons will now appear in the control button region.

4. Press the top control button, **START COMPRESSOR #2,** to start the compressor. At this point the compressor #2 template would change from OFF to ON.

5. The operator can press the **CANCEL** button at the top of the display to deactivate the template, or the template will automatically deactivate after a short time delay.

With the exception of the page change buttons, activating just a template will not result in any action on the M1410, the operator must also press the control button (once the template is active) to initiate any command. This two step process provides a safe control system, eliminating inadvertent operation.

#### 2.1.15.3 Organization

Each OIT page has a group of related control functions. The 10 pages for the M1410 OIT are organized as follows:

#### 2.1.15.3.0 Page 00 Linde Logo

Page 00 contains the Linde company logo and is displayed after control power is turned on. Press the logo to bring up the main menu, page 01.

#### 2.1.15.3.1 Page 01 Main Menu (Data Table and Status)

Page 01 contains a data table that displays all the M1410 operation parameters as well as a region that displays the discrete status of other M1410 functions. There is no control from this page, although the operator can utilize the buttons in the right hand column to go directly to the page that provides the desired control functions.

#### 2.1.15.3.2 Page 02 Compressor Control

Page 02 contains the templates for remote control of up to three compressors; each compressor has its own template.

#### 2.1.15.3.3 Page 03 Expansion Engine, V323

Page 03 has the controls for the expansion engine operation. This includes the engine start and stop functions as well as the engine auto / manual speed control selection. There is also a template for control of the helium isolation valve V323.

#### 2.1.15.3.4 Page 04 JT307 and V308 Control

Page 04 contains the templates for control and indication of valves JT307 and V308.

#### 2.1.15.3.5 Page 05 Purifier Control

Page 05 contains the templates for control of the M1410 purifier.

#### 2.1.15.3.6 Page 06 Vacuum Pump and $LN_2$ Control

Page 06 contains the templates for controlling the vacuum pump and vacuum valves. A second template is used for liquid nitrogen control. A third template, COLD BOX CLEANUP, allows the operator to put the liquefier in the cleanup mode.

#### 2.1.15.3.7 Page 07 Digital Input Status

Page 07 displays the status of certain digital signals provided to the PLC, such as pressure switch contact signals. This page is provided as a convenient means for observing these signals. Normal operation of the cold box does not typically require monitoring of this information by the operator.

#### 2.1.15.3.8 Page 08

OIT page 08 is not currently used by the M1410.

#### 2.1.15.3.9 Page 09 PLC Operational Parameters

Page 09 contains templates that allow for adjustments of various M1410 operation parameters. These parameters have been set at the CPS test facility and should not require further adjustments by the customer.

**<u>WARNING!</u> Improper setting or adjustment of these parameters may result in undesirable machine operation, which can lead to poor system performance, machine damage or personal injury!**

The parameter values are stored in the PLC memory and will automatically be saved when the M1410 has no control power applied.

#### 2.1.15.4 Alarms / Fault Conditions

The OIT generates alarms to bring operator attention to an abnormal operating condition. Alarms are visually displayed at the top of each page of the OIT in the order that they occurred. Descriptions of the cause of the alarm, along with the alarm status, are provided in the display. A speaker also provides an audio signal that an alarm has occurred. An OIT page number is also indicated to reference the source of the alarm.

Alarm status can be either active or non-active, and acknowledged or not acknowledged. If the cause of an alarm is still present, for example impure gas supply pressure is still too low, the alarm remains active. If the cause of the alarm was only temporary (in the previous example, the impure gas supply pressure has returned to normal), then the alarm is non-active. Acknowledgment of an alarm occurs by the operator pressing the alarm acknowledge button on the OIT.

Fault conditions result in a device being removed from operation. Typically a fault condition for a device has to be manually reset from the appropriate page of the OIT, although some exceptions exist. If a device is in fault, for example a fuse has blown on the vacuum pump, a fault indication will appear on the OIT page that controls the vacuum pump.

Some alarm conditions will require a reset button being pressed on the appropriate page, so that the PLC will recognize acknowledgment by the operator of the fault condition having occurred.

Refer to Table 2-1 for a list and description of alarms and fault conditions.

### 2.1.16 Low-Side Pressure Control System

Low-side pressure control consists of two essential functions: (a) gas recovery to storage when low-side pressure is high; and (b) makeup gas requirements when low-side pressure is low. The pressure transmitter PT-2 provides a 4-20 mA signal to the PLC that corresponds to low-side pressure. The PLC monitors this signal and also re-transmits it as a process variable to the internal PID process controller that controls low-side pressure makeup valve V370.

If the low-side pressure rises above 0.21 bar (3.0 psig), and a compressor is operating, the PLC will automatically open valve V378 to recover gas to pure helium storage at connection “G”. When low-side pressure drops below 0.19 bar (2.8 psig) V378 is closed. An operating compressor is required for automatic gas recovery operation.

Makeup gas requirements are controlled by a dome-loaded regulator V370. The dome pressure, which controls the opening of the valve, is determined by an internal control loop. The output of the control loop is a 4-20 mA signal that is converted to a pressure signal by PY370. PY370 automatically pressurizes the dome with instrument air as required. The setpoint for low-side pressure is factory established and is typically set to provide 0.07 bar (1.0 psig) operating pressure to the compressor.

## 2.2 DELIVERY TUBE

The delivery tube (Figure 2-8) is a rigid, triaxial stainless steel tube assembly with two concentric gas passages surrounded by a superinsulated vacuum space. The inner passage carries the two-phase mixture to the external dewar. Uncondensed helium gas and boil-off gas return through the outer passage to the return side of the heat exchanger (E34) through the return valve (V308). The delivery tube has a 12.7 mm diameter (1/2” OD) vertical tube section for connection to the liquefaction dewar. The tube is removable for convenience in positioning the dewar. An adapter containing a relief valve supplied by LC must be in the delivery tube port on the liquefier whenever the delivery tube has been removed.

## 2.3 OPTIONAL EQUIPMENT

**Note:** Refer to System Equipment Installation / Interface drawing in Section 4.

### 2.3.1 Additional Compressor Units

A second or third M1400 Compressor unit or an RS Compressor may be used with the M1410 Liquefier. Multiple compressor units operate in parallel with common inlet and discharge lines. Refer to manual material supplied with compressor(s).

### 2.3.2 Storage Tank

A tank, having a minimum capacity of 14 cubic meters (500 scf) at 16 atmospheres, should be connected into the system, as shown in Section 4 drawings, and is used to recover and store pure helium gas. If the tank is not available, helium must be vented to the atmosphere or gas bag via connection "G".

### 2.3.3 Helium Liquefaction Dewars

Double ported liquefaction dewars of 100, 250, 500 and 1,000 liter capacity are typically used with the liquefier. One port, with a gland of 12.7 mm outside diameter (1/2" OD), is required for the delivery tube; the other port, typically 15.9 mm outside diameter (5/8" OD), is for a transfer tube.

### 2.3.4 Liquid Helium Transfer Tube

The transfer tube is used to transfer liquid helium from the liquefaction dewar to a storage dewar or experimental apparatus.

### 2.3.5 Cryogenic Adsorber

The cryogenic adsorber, basically a maintenance tool, is effective for the removal of nitrogen and other gaseous impurities having a freezing point higher than the temperature of liquid nitrogen. It is used to remove air and water contaminants from the compressor and to clean up the refrigerator piping and heat exchangers after maintenance. (The cryogenic adsorber is described in a separate manual).

### 2.3.6 Gas Manifold(s)

Multi-station manifold sections are used for connecting high-pressure gas cylinders into the liquefaction system. A regulating valve (V351) with a relief valve (V395) is supplied by Linde Cryogenics for use on the pure gas manifold. An additional regulator (V629) and relief valve (V641) are supplied by Linde Cryogenics for use on the impure gas manifold.

### 2.3.7 Ballast Tank

A tank, having a minimum capacity of 1.5-2.0 cubic meters (50-70 scf) at 16 atmospheres is used for ballast for the automatic purifier. It is connected directly into the supply line. Gas is taken from the tank when the purifier is being regenerated and replenished by makeup gas from the compressor when normal purifier operation resumes.

### 2.3.8 Surge Tank

A tank is connected directly into the impure helium gas supply line. It is used during purifier operation to adsorb any shock in the line when purifier solenoid valve V624 cycles.

### 2.3.9 High Pressure Helium Recovery Compressor

The high-pressure recovery compressor is used to pump gas from the gas bag into high-pressure storage cylinders. (The recovery compressor is described in a separate manual).

### 2.3.10 Gas Bag

The gas bag is a flexible container made from laminated plastic. It is used to collect boil-off gas and has a control to operate a high-pressure, helium recovery compressor.

## SECTION 3

## INSPECTION AND INSTALLATION

The following section covers inspection and installation of the Model 1410 Liquefier module. The steps performed by the User are to be completed before arrival of the Field Service Representative.

### 3.1 INSPECTION

**Note: If any damage is noted, contact transportation carrier and the Field Service Representative immediately for instructions.**

#### 3.1.1 Inspecting the Liquefier

1. Remove the crating and packing material.

**WARNING! Transport of liquefier module is from the bottom of the skid only, at the forklift truck pockets provided.**

2. Inspect the exterior of the liquefier module for evidence of physical damage.

3. Record pressures indicated on pressure gauges PI-33 and PI-34.

**Note: If either pressure gauge reads zero, contact the Field Service Representative for instructions.**

#### 3.1.2 Inspecting Remote Delivery Tubes (RDT)

Remove from the crate and inspect the exterior surface for any physical damage. Make certain the leg portions of the RDT are not deformed.

## 3.2 INSTALLATION

1. Mechanical and electrical installation drawings of the liquefier module are included as part of this manual. These drawings contain details of the system provided.

**Note: The information on these drawings supersedes any preliminary information received prior to the receipt of the shipment or this operating manual.**

Typical list of System Installation Data:

a. System Equipment Installation / Interface Drawing

b. System Electrical Installation / Interface Drawing

c. System Flow Diagram

d. Control System Schematic(s)

e. 1410 Helium Liquefier Installation / Interface Drawing

f. Compressor Installation / Interface Drawing (optional)

g. Regulator / Relief Valve Detail(s)

h. Model 1410 Helium Liquefier Operator's Manual

2. It is the User's responsibility to securely mount the liquefier. Also, to install all electrical and piping interconnections including evacuation valves, bypass valves and bypass regulator (V345). Do not install the delivery tube at this time.

3. Any questions arising during installation should be discussed and resolved prior to the arrival of the Field Service Representative for final checkout.

4. It is essential that at least 1 meter (3 feet) of working space be provided around the liquefier. Overhead clearance required is approximately 3 meters (10 feet).

5. Power requirements for the liquefier module are identified in Model 1410 Utility Requirements (Table 1-2).

6. Before shipping, the liquefier was purged and back filled with pure helium gas.

### 3.2.1 Materials

#### 3.2.1.1 Interconnecting Piping and Fittings

LC suggests copper tube Type L is used for interconnecting the ambient temperature piping between the liquefier and its related components. Fittings should be of the Wrought copper type suitable for brazing. **Do not use cast brass.**

#### 3.2.1.2 Vibration Eliminators

The use of vibration eliminators is recommended for connecting to the fittings provided on the liquefier module and on the compressor(s). These allow for some flexibility in the piping for connecting the self-sealing couplings and other fittings supplied on the equipment. It is suggested that the vibration eliminators be positioned at 90° with the axis of the fittings on the equipment for ease of assembly and disassembly. Refer to the System Equipment Installation / Interface drawings provided with the equipment for recommendations concerning vibration eliminators.

#### 3.2.1.3 Brazing Alloys

1. For brazing copper to copper or brass to copper
   a. Brazing alloy: BAg-5
   b. Flux: 4A, White flux
   c. Brazing temperature range: 743°C-843°C
      (1370°F-1550°F)
2. For brazing copper to stainless steel or brass to stainless steel
   a. Brazing alloy: BAg-24
   b. Flux: 3A, Black flux
   c. Brazing temperature range: 707°C-843°C
      (1305°F-1550°F)

3. For brazing copper to copper only

   a. Brazing alloy BCuP-5

   b. Flux: No flux required

   c. Brazing temperature range: 704°C-815°C (1300°F-1500°F)

### 3.2.1.4 Joint Compounds

All pipe joints should be made up using an appropriate pipe joint compound applied to the male pipe member only. Epoxy or Neolube® may be used if available.

### 3.2.1.5 Service Valves

Service valves are required for evacuation and back fill of the system interconnecting piping. For this application, helium leak tight quality ball valves are ideal. All evacuation valves should be 1/2”-IPS minimum and rated for the positive pressure of the line.

### 3.2.2 Installing the Liquefier

1. A flat foundation or floor which can support the weight of the equipment, which is approximately 1000 kg (2200 lbs.), must be provided since the unit must be level for proper operation. When installing the unit, shim the base as necessary to ensure that the unit is level and properly supported.

2. Securely fasten the unit to the floor or foundation using the holes provided on the unit. Refer to installation / interface drawing supplied.

3. The unit is shipped from LC evacuated and back filled with pure helium gas to a positive pressure. This condition must be maintained during installation, testing and back filling of the interconnecting piping.

   Some of the more important piping connections at the rear of the unit contain the male portion of self-sealing couplings. (Aeroquip Inc. - Refer to manufacturer's literature located in the appendix.) LC supplies the mating female self-sealing couplings.

The mating female self-sealing coupling halves for the interconnecting piping must be disassembled so that only the outer body will be connected for aligning interconnecting piping. If the internal components of the coupling half are installed, the coupling seal on the liquefier unit will engage, and become contaminated with air. After aligning and making up the interconnecting piping, the body of the female coupling must be separated from the male mating fittings on the M1410, and its internals reassembled prior to evacuation of interconnecting piping.

The remainder of the connections are of the compression fitting type and may be made up during piping installation.

### 3.2.3 Installing the Interconnecting Piping

Refer to the System Equipment Installation / Interface drawing provided with the equipment.

When installing the interconnecting piping, ensure sufficient flexibility to allow the couplings to be disengaged without having to move the equipment. To minimize pressure drops, helium lines should be as short and direct as possible. Plan piping for a minimum number of joints using as few elbows and other fittings as possible. However, make sure to provide sufficient flexibility to absorb any vibration. Locations where tubing will be exposed to mechanical damage should be avoided. If it is necessary to use such locations, the tubing should be enclosed in protective conduit. Where considerable traffic is adjacent, it is necessary to provide protection against impact from carelessly handled hand trucks, overhanging loads, ladders, etc.

All helium piping practices must be in accordance with local codes and the latest standard of ANSI/ASME B31.5 Refrigeration Piping Code. To ensure trouble-free operation, the following conditions should be observed:

a. When brazing or soldering, valves are to be disassembled, or wrapped in a wet cloth to prevent damage by heat. To prevent formation of oxide on the inside of the copper tubing, nitrogen or inert gas must be passed through the piping continuously while brazing joints.

b. If tubing or pipes are cut from open stock, they should be thoroughly cleaned and deburred before they are fitted. All lines should be flushed with a suitable cleaner / solvent (Table 5-3) and dried out using dry nitrogen gas.

c. Never leave a dehydrated line exposed to the atmosphere longer than is absolutely necessary for the installation.

Contamination often results from carelessness or mishandling during storage or assembly of the tubing and components. All filings, chips, flux, scale, dust and dirt must be periodically cleaned from the piping during assembly and thoroughly cleaned after final assembly.

For information concerning the self-sealing couplings, refer to Section 3.2.2 and manufacturer's literature located in the appendix.

### 3.2.4 Leak Check of Interconnecting Piping

All piping that is to be used to interconnect the liquefier module with other components must be leak checked before it is interconnected.

**Note: See Table 5-4, Maximum Test Pressure**

If no leak is found during pressure testing, evacuate the system by using a clean vacuum pump.

If the system is properly evacuated, the air contaminants are eliminated before the system is started.

A vacuum pump which can operate below 50 mTorr at 3.5 $m^3$/hour (2 cfm) displacement or better, and has an electronic gauge, is desirable and is highly recommended for this procedure. To properly evacuate a system and ensure maximum removal of air and water vapor, connect the vacuum pump to the evacuation port and open all valves in the system. Do not use too small a connecting line between the system piping and the vacuum pump, as it will restrict flow (minimum line size 15.9mm, 5/8 inch).

To use the vacuum pump most efficiently, a triple evacuation procedure is recommended. This involves evacuating and back filling the system with a dry gas three times. Warming the system piping to approximately 38°C (100ºF) while evacuating will help to dehydrate the system. The vacuum should be broken with dry nitrogen or helium. After a final evacuation, the vacuum pump should then be shut down and the vacuum held for approximately 12 hours. The level of vacuum should not rise beyond 500 mTorr.

If the system does not meet the standards above, piping should be rechecked for small leaks, repaired and the above procedure repeated. Finally, the piping must be charged with clean helium gas to a positive (0.07 bar, 1.0 psig) pressure. The piping will then be ready for interconnecting with the leak tight and purged liquefier.

**Note: Final interconnections should not be made to the cold box module or compressor(s) before the arrival of the Field Service Representative.**

Besides being sure that the connecting line between the vacuum pump and the refrigeration system is sufficiently large enough to prevent pressure drop, there are other precautions to be kept in mind.

1. An ordinary compound gauge is worthless in the pressure range of interest. It is absolutely necessary to use an electronic gauge capable of reading in mTorr.
2. A good vacuum pump may pump faster than a small leak.
3. Initial evacuations of the interconnecting piping may result in water contamination of the vacuum pump oil, severely degrading the performance of the vacuum pump. Proper ballast procedures should be employed. Refer to the vacuum pump manufacturer's literature.

### 3.2.5 Installation Wiring

Field wiring drawings for each system are provided with the equipment. The information on these drawings supersedes any preliminary information received prior to the receipt of the shipment or this operating manual. All wiring must conform with the National Electric Code (USA) and/or equivalent Federal, National, State, Provincial, or Local codes.

#### 3.2.5.1 Compressor Control Wiring

The liquefier is equipped with local compressor start / stop controls. Field wiring is required between the liquefier and the compressor starter box for these switches to operate.

## 3.3 INSPECTING THE INSTALLATION

A Field Service Representative will inspect the installation before the final interconnections between the liquefier, compressor, and related components are made.  Evidence of the pressure integrity of the interconnecting piping must be shown at the time (i.e., pressure tested according to Table 5-4 with no overnight pressure decay).

When pressure integrity is demonstrated, the components should be interconnected under the direction of the Field Service Representative, who will make all necessary adjustments to the liquefier prior to operation.

The Field Service Representative will perform an electrical checkout of the basic control circuit during commissioning of the system.

# SECTION 4

# OPERATION

The following operating procedures are intended to supplement on-site instructions provided by the Field Service Representative. They also describe some of the more frequently encountered operating conditions that may require adjustment.

> **Note:** Refer to the drawings provided in this section for a Flow Diagram of the Model 1410 Liquefier and to the System Equipment Installation / Interface drawing for a flow diagram of the complete liquefier system.

## 4.1 PRELIMINARY CHECKS

1. Verify the conditions as listed below and make the necessary corrections as required:

    a. All piping interconnections are complete.

    b. The system has been decontaminated in accordance with Section 5.5.

    c. The control wiring to the liquefier has been connected and the fused disconnect has been engaged.

    d. The three phase power supply circuits are on.

    e. The vacuum jacket pressure is less than 100 mTorr as indicated on the Operator Interface Terminal.

    f. The valve clamp clearance on the engine valves is set in accordance with Section 5.2.13.

    g. Refer to Table 4-1 for position of inlet cams.

    h. The toothed timing belt has been tightened to deflect about 3 mm (1/8 inch) with a moderate force of about 4.5 kg (10 pounds) at mid-span.

    i. The external manual bypass valve is closed.

    j. The air supply regulator (V306) is set at 4.1 bar (60 psig) and its water drain has been blown down.

2. When using liquid nitrogen for precooling, ensure that the $LN_2$ supply is between 0.7 and 2.0 bar (10 and 30 psig) and ready for use, and that the supply valve is closed.

**<u>WARNING!</u> Do not allow Nitrogen Supply Pressure to exceed 2.4 bar (35 psig).**

3. Determine correct valve positions as follows:

   a. The JT307 and V308 valves are in the "**AUTO**" control mode.

   b. Valves V312, V339, V397, V396 and V341 are closed.

   c. Vacuum jacket pressure is below 100 mTorr and vacuum valve V336 is closed.

   d. A pure helium, makeup gas source is open with a minimum pressure of 6.9 bar (100 psig).

## 4.2 BLOWDOWN OF THE HEAT EXCHANGER

The main heat exchanger should be blown down if the liquefier has not been operated for an extended period of time and the temperatures are near ambient. This procedure will remove any moisture that has collected in the first heat exchanger and in the precooler heat exchanger. The purifier should also be blown down if it is to be used.

1. Open valve V312 and decrease the pressure in the liquefier to approximately 0.34 bar (5 psig) as shown on pressure gauge PI-34.

2. Install the locking bar in the flywheel.

3. Open valve V806.

4. Start a compressor.

5. Press the "**HX FILL**" button to energize solenoid valve V323 and allow gas to pressurize the system to operating pressure. Valve V323 will automatically close after approximately 10 seconds.

6. Open valve V312 to one-half (1/2) turn to blow down main heat exchanger. Watch for signs of moisture.

7. Close valve V312 when PI-34 reaches 1.4 bar (20 psig).

   **Note:** If there is any possibility that water still remains in the heat exchanger, repeat steps 5 and 6.

8. If the purifier has been in operation, press the purifier "**PURGE**" button to automatically blow down the purifier heat exchangers through the water and liquid air blowdown valves.

## 4.3 COOLDOWN OF THE MODEL 1410 LIQUEFIER

Cooldown of the liquefier and subsequent liquid production is an automatic process when the helium dewar is kept at cold temperature and contains some liquid helium. In this situation operator requirements are minimal: Starting and Stopping the unit, and periodic monitoring for safe operation of the cryogenic system.

Cooldown with a warm liquid helium dewar is occasionally necessary. In this situation some manual intervention in the operation of the J-T valve and the dewar return valve V308 is required.

### 4.3.1 Cooldown Using A Cold Liquid Helium Dewar

1. Confirm that all conditions in Section 4.1 exist.

2. Start a compressor.

3. Observe that the compressor starts and the supply pressure gauge PI-33 reads the setpoint pressure of the external bypass regulator V345.

   **Note:** It may be necessary to readjust regulator V345 to obtain a 16.5 bar (240 psig) reading at PI-33.

4. Verify positive pressure in the low-side at PI-35.

5. Manually open return valve V308. Regulator V370 should open and helium gas should flow out the RDT port.

6. Insert the delivery tube in the RDT port sealing gland on the liquefier, taking care not to engage the cold seal in the liquefier. Do not insert the dewar end of the delivery tube into the dewar. Tighten the sealing gland. Verify that gas is flowing out both passages of the delivery tube. Allow purge to continue for at least 60 seconds.

7. Insert the Remote Delivery Tube (RDT) into the 12.7 mm (1/2" OD) gland of the dewar.

**WARNING!** **Do not remove the dewar gland plug until the pressure in the dewar has been bled down to 0.0 bar (0.0 psig).**

8. Set the delivery tube into its operating position and tighten glands on both dewar and liquefier making sure that the cold seal nut is tightened. Recheck after cooldown to make sure that the nut is still tight.

9. Close valve V308. After closing valve V308, ensure that it is reset to the "**AUTO**" control mode.

10. If precooling is desired, turn on the $LN_2$ Control at the Operator Interface Terminal and open the $LN_2$ supply valve to the cold box.

11. Verify that the high-side pressure inside the heat exchanger is less than 3.4 bar (50 psig) at PI-34. Open manual valve V312 if necessary to drain pressure.

12. Remove the locking bar and reinstall the engine covers.

**WARNING!** **Do not operate liquefier module without the engine covers in place.**

13. Start your engines. The heat exchanger will pressurize and the engines start turning, gradually increasing in speed to a maximum 230 rpm.

    **Note:** For the initial 30 to 60 minutes, a significant portion of the compressed gas will bypass directly into the return line via external bypass regulator V345. As the heat exchanger cools, the mass flow through the engines will increase and eventually the engine may automatically start to slow down to maintain supply pressure.

14. When the No. 2 engine reaches 100°K, the J-T valve will automatically start ramping open.

15. When the J-T inlet temperature reaches 30°K, the J-T valve will automatically control to maintain the No. 2 engine inlet temperature setpoint.

16. Adjust valve V806 to control return temperature TE-2 at approximately 278°K. This may take some time to reach equilibrium. Final adjustment should be made after the liquefier is cooled down and liquefying into the dewar.

    **Note:** The setting of valve V806 is dependent primarily on the compressor flow capacity of the liquefier system. Subsequent startups should require no further adjustment.

    The liquefier may be left unattended for extended periods; however, the periodic tabulating of data is encouraged to monitor the condition of the system. (Refer to the performance data sheet in the appendix.)

### 4.3.2 Cooldown Using A Warm Liquid Helium Dewar

1. Confirm that all conditions in Section 4.1 exist.

2. Check the dewar to see if it is decontaminated (refer to dewar manual) and that the transfer tube is in place.

3. Start a compressor.

4. Observe that the compressor starts and the supply pressure gauge (PI-33) reads the setpoint pressure of the external bypass regulator (V345).

    **Note:** It may be necessary to readjust regulator V345 to obtain a 16.5 bar (240 psig) reading at PI-33.

5. Verify a positive low-side pressure indication at PI-35 greater than or equal to 0.07 bar (1.0 psig).

6. Manually open return valve V308. Helium gas should flow out the RDT port.

7. Insert the delivery tube in the RDT port sealing gland on the liquefier, taking care not to engage the cold seal in the liquefier. Do not insert the dewar end of the delivery tube

into the dewar. Tighten the sealing gland. Verify that gas is flowing out both passages of the delivery tube. Allow purge to continue for at least 60 seconds.

8. Loosen the sealing gland on the RDT port and continue inserting the delivery tube into both the liquefier and the dewar. Insert the delivery tube 25 mm (1 inch) above its normal position.

9. Tighten the sealing glands at the dewar and at the RDT port. Do not engage the cold seal of the delivery tube.

10. Using 9.5 mm (3/8” ID) surgical rubber tubing, connect exhaust end of the transfer tube, dewar service valve and dewar shield flow valve with valve V339 port at rear of liquefier. Engage the foot valve on LC Transfer Tubes.

    **Note:** Whenever connecting a transfer tube, or section of surgical tubing to a clean system, it is necessary to purge lines and connectors from both sources. Final connection should be made with a positive flow from each source, if possible.

11. Close valve V308. Leave valve V308 in “**MANUAL**” control mode.

12. Place the J-T valve in “**MANUAL**” control mode, with the valve in the closed (0% open) position.

13. During dewar cooldown, all gas from the dewar must be returned through the hose to the liquefier via valve V339.

14. Open liquid nitrogen supply if precooling is desired and turn on the $LN_2$ Control on the OIT.

15. Verify that the high-side pressure inside the heat exchanger is less than 3.4 bar (50 psig) at PI-34. Open manual valve V312 if necessary to drain pressure.

16. Remove the locking bar, install the engine covers and start your engines.

**WARNING!** **Do not operate liquefier module without the engine covers in place.**

**Note:** For the initial 30 to 60 minutes, a significant portion of the compressed gas will bypass directly into the return line via external bypass regulator V345. As the heat exchanger cools, the mass flow through the engines will increase and eventually the engine may automatically start to slow down to maintain supply pressure.

17. During cooldown, valve V806 may be adjusted one turn at a time so that the return temperature at TE-2 indicates 278°K. This may take several hours to reach steady state during cooldown with a warm dewar.

**Note:** Helium flow through the precooler (E81) controls the $GN_2$ return gas temperature. Very high flow through the precooler can waste $LN_2$.

18. If more than one compressor is to be used, start the other compressor when the engine speed falls below 220 rpm. An alternate procedure is to start with two compressors if economy is not a consideration or if the Operator has other duties.

19. As the No. 2 engine inlet temperature (TE-A) approaches 19°K, manually open JT307 and maintain the engine temperature to approximately 19-20°K.

**Note:** Ensure that the delivery tube is installed in the liquefier gland 12 mm (1/2 inch) above its normal position, thus allowing cold gas to flow in the normal return passage. This will hasten cryopumping of the delivery tube vacuum space.

20. When liquid air begins to form at the end of the transfer line, seat the delivery tube in its normal position and tighten the gland nut to engage the cold seal securely, then open valve V308 and close the transfer tube manual valve and the dewar service valve.

21. Adjust the JT307 to achieve and maintain the No. 2 engine inlet temperature (TE-A) in the range of 19-20°K. However, if the dewar pressure increases to above 0.34 bar (5 psig), reduce the J-T opening to lower that pressure, using the Operator Interface Terminal. As the dewar pressure falls below 0.28 bar (4 psig), reopen the J-T valve.

**Note:** If J-T valve inlet temperature TE-B exceeds 20°K, reopen the transfer tube manual valve and dewar service valve to bypass gas flow and lower the temperature.

22. When the bypass flow is stopped, and the J-T temperature is less than 10°K, cooldown is complete, close valve V339.

23. Place the J-T and V308 valves in "**AUTO**" control mode.

## 4.4 OPERATING THE PURIFIER

The purifier can be turned on at any time during operation of the liquefier. Actual cooldown of the purifier will not commence until the No. 2 engine is less than 23°K and the J-T inlet temperature is less than 8°K. This will ensure liquefying conditions exist for proper operation of the purifier. The "**ON**" button can be pressed before these temperature conditions are satisfied, and the PLC will automatically start the purifier cooldown sequence after cold box temperatures are sufficiently cool.

### 4.4.1 Purging the Purifier

The purifier may be purged at the operator's discretion while the engines are running. Purging the purifier may be desired if the unit was previously operated with a high impurity content and has since warmed to near ambient condition.

To purge the purifier, press the purifier "**PURGE**" button on the Operator Interface Terminal. Purging will be complete in approximately 3 minutes.

Optimal purging occurs when the main heat exchanger is near ambient temperature.

### 4.4.2 Starting the Purifier

The purifier "**ON**" button can be pressed any time after the engines have started. If the No. 2 engine and the J-T valve temperatures are too warm, the PLC will wait until the temperatures are satisfied and then automatically initiate the cooldown sequence.

1. Verify that valve V341 is closed.

2. Verify that valves V628 and V635 are open. Refer to Section 2.1.10.3 for nominal settings.

3. Check the impure helium supply to be sure that is regulated at 34.5 bar (500 psig), and that there is adequate gas for the intended period of operation.

4. Turn on the purifier.

### 4.4.3 Manual Regeneration of the Purifier

Manual regeneration of the purifier can be initiated at any time at the discretion of the operator, however it is not required for normal operation. Pressing the "**MANUAL REGEN**" button will initiate a regeneration sequence equal to the automatically initiated sequence. The most common need for a manual regeneration is just prior to a liquid helium transfer from the storage dewar.

### 4.4.4 Measuring Liquid Helium Production

Measurement of liquid helium production when operating with purifier can only be made by observing the liquid level in the dewar.

## 4.5 TRANSFER OF LIQUID HELIUM

There are two requirements for transferring liquid helium from the supply dewar to the receiving dewar:

(1) An insulated transfer tube through which the liquid helium may be conducted.

(2) A pressure within the supply dewar which is higher than the pressure at the delivery end of the transfer tube.

The following sections describe the procedures for depressurizing the dewar and the proper use of the LC Transfer Tube.

### 4.5.1 Preparing the Transfer Tube

1. Inspect the foot valve of the transfer tube to make sure that it is clean and dry; if necessary, use a hot-air blower to remove any traces of moisture. Then connect a purging line from a source of low-pressure (0.07 to 0.34 bar, 1 to 5 psig) helium to the end of the transfer tube (the end without the foot valve).

2. Open the transfer tube manual valve and pressurize the tubing with helium gas. Next, open the foot valve by depressing the plunger. Helium gas should flow through the transfer tube, purging it of all contaminants. When purging has been completed, close the foot valve, then close the transfer tube manual valve, and finally turn off the helium gas supply. Remove the rubber tubing from the transfer tube.

### 4.5.2 Insertion of Transfer Tube to the Liquid Helium Supply Dewar

**WARNING!** **Use appropriate Personal Protective Equipment (PPE) when performing transfer tube insertion or removal. Very cold gas will blow from the dewar port when the plug is opened.**

The pressure within the supply dewar should be reduced to less than 0.07 bar (1.0 psig) prior to inserting the transfer tube. Then perform the following:

1. If the dewar is connected to a LC helium liquefier, verify that low-pressure return valve V308 and JT307 are manually closed.

2. Connect the supply dewar service valve to a suitable helium recovery system.

3. Fully open the service valve to vent dewar gas to the recovery system.

4. After the dewar pressure falls below 0.07 bar (1.0 psig), use insulated gloves to loosen the gland on the dewar cap and remove the plug from the opening into which the transfer tube is to be inserted. Insert the transfer tube promptly, but do not push it to the bottom of the dewar so that the foot valve will remain closed. Tighten the gland nut.

### 4.5.3 Pressurization of the Supply Dewar

When the supply dewar is connected to a liquefier and the liquefier is running, transfers can generally be performed with the pressure available. It is not necessary to shut off the liquefier.

If the liquefier is shut off, perform the following:

1. Open valves V341 and V308.

2. Set the regulating valve V370 suction pressure at its normal setting.

3. Close all liquefaction dewar neck port valves, including the flow meter and service valves. Building pressure in the liquefaction dewar is necessary in order to transfer the liquid helium to the receiving dewar.

When the supply dewar is not pressurized by a liquefier, the operator must use an external low-pressure (0.21 to 0.34 bar, 3 to 5 psig) source of clean dry helium to pressurize the supply dewar.

To pressurize from an external source, purge the pressurizing line to the service valve on the dewar neck. Open the service valve momentarily to pressurize the dewar to 0.21 - 0.28 bar (3 - 4 psig).

As the transfer proceeds, the operator may find it necessary to admit additional gas so as to maintain the supply dewar pressure at the desired level. The gas used to pressurize the dewar carries heat into the dewar. This heat eventually results in additional boil-off losses. Hence, the minimum amount of gas and the minimum practical pressure should be used.

### 4.5.4 Preparing a Receiving Dewar with Multiple Service Ports

**<u>WARNING!</u> Do not use liquid nitrogen to pre-cool a warm dewar. Nitrogen may plug the liquid helium gauge system, the dewar vent line, or both. Cooldown must be accomplished either by transferring liquid helium into the dewar or by using a LC Helium Liquefier equipped with an RDT.**

1. Move the receiving dewar into position beneath the discharge end of the transfer tube.

2. Lower the transfer tube with extension piece attached into the receiving dewar. It may be necessary to loosen the gland seal on the supply dewar so that the transfer tube can easily slide in. Do not seat the foot valve on the bottom of the supply dewar. Tighten the gland nuts on both dewars after insertion. The extension piece of the transfer tube should be lowered to the bottom of the receiving dewar.

3. Evacuate and purge the receiving dewar with pure helium gas to remove all air. Purging the dewar should be done by flowing the helium gas into a dewar neck port at low pressure. After purging, close all open valves on dewar neck ports and leave approximately 0.14 bar (2.0 psig) of helium gas pressure in the dewar.

4. Attach a vent line from the dewar neck port to either the LC Liquefier low-pressure tap at connection “Y” or the helium recovery system.

### 4.5.5 Preparing a Receiving Dewar with a Single Neck Port

1. Move the receiving dewar into position beneath the discharge end of the transfer tube.

2. Remove the vent adapter from the extension tube and clamp the bottom of the vent adapter to the outside of the neck port of the receiving dewar.

3. Lower the transfer tube with extension piece attached into the receiving dewar. It may be necessary to loosen the gland seal on the supply dewar so that the transfer tube can easily slide in. Do not seat the foot valve on the bottom of the supply dewar. Tighten the gland nut on the supply dewar after insertion.

   The bottom of the extension tube should be located near the bottom of the receiving dewar. A gap must exist between the transfer tube and neck port so that gas can exhaust out of the transport dewar. This gas will vent through the vent adapter during transfer. Clamp the top of the vent adapter to the transfer tube extension.

   **Note:** The discharge end of the transfer tube should enter at least 150 mm (6 inches) into the neck of the transport dewar to prevent excessive transfer losses. If necessary, raise the transport dewar with a hoist. Ideally, the extension tube should be located near the bottom of the receiving dewar.

4. Connect a gas recovery line to the vent adapter. The recovery line should be connected to a helium gas recovery system.

### 4.5.6 Transfer of Liquid Helium Into the Receiving Dewar

1. Lower the transfer tube and engage the foot valve on the bottom of the supply dewar. Be certain a helium gas recovery vent line is open from the receiving dewar to the liquefier or recovery system.

2. Open the manual valve of the transfer tube so as to allow liquid helium to flow from the supply dewar to the receiving dewar.

3. Insure that the boil-off gas is being properly recovered.

4. When the transport dewar has been filled, the gauge on the extension tube will show a sharp increase in pressure. At this time, close the manual valve.

5. As the pressure in the transport dewar falls, the liquid helium within it will become more dense and will occupy less volume. Opening the manual valve again briefly to admit some additional liquid helium will top it off.

6. Disconnect the recovery line from the recovery connection after transfer is complete and the pressure in the receiving dewar is less than 0.07 bar (1.0 psig).

**WARNING! Use Personal Protective Equipment (PPE) when performing transfer tube insertion or removal. Very cold gas may blow from the dewar port when the plug is opened.**

7. When the neck of the dewar or vent adapter is warm (a hot-air blower may be used to hasten warm-up), raise the transfer tube and remove the extension tube and the vent adapter. Be certain pressure in the receiving dewar is less than 0.07 bar (1.0 psig) before opening the neck port to atmosphere.

8. Replace the plug on the receiving dewar neck.

9. Lift the transfer tube in the supply dewar above the liquid helium level.

## 4.6 SHUTDOWN

To shutdown the system perform the following:

1. Turn off the Purifier if it is running. Turning off the purifier will initiate an enhanced regeneration that will take about 5 minutes to complete.

2. After the purifier has shut down, turn off the liquefier. Valve V323 will close and the engines will coast to a stop. Low-side pressure may start to rise at which point the low-side pressure setpoints of the PLC will control gas recovery through valve V378 to the storage tank.

3. After the engines have stopped rotating, stop all compressors.

4. Install the flywheel locking bar.

# SECTION 5

# MAINTENANCE

This section contains certain procedures for the maintenance of the Model 1410 Helium Liquefier module. A Lubricant Guide (Table 5-1) and a Preventive Maintenance Schedule (Table 5-2) give the service interval of those procedures that must be performed periodically, and are listed at the end of this section. To order replacement parts that may be required to perform the maintenance or repairs described in this section, refer to Section 7.

## 5.1 LIQUEFIER WARMUP

Normally, the liquefier is left at normal operating temperature at shutdown. Subsequent cooldown time is reduced, particularly if the off period is short. To rapidly warm the system for certain maintenance procedures, it is necessary to break the vacuum in the vacuum jacket to warm the liquefier to room temperature.

**Note:** The vacuum jacket temperature must be above 80°K before breaking the vacuum with nitrogen gas. Allow time for the cold box to warm and break the vacuum to 100 mTorr only.

To break the vacuum:

1. Connect 9.5 mm (3/8” ID) surgical rubber tubing to an external source of low-pressure (0.07-0.21 bar, 1-3 psig), clean, dry, ambient-temperature nitrogen gas and purge the tubing for at least 60 seconds. Nitrogen gas is preferred for back-filling the vacuum jacket to aid the re-evacuation process and facilitate any leak testing that may be required.

2. Connect the other end of the tubing to the vacuum jacket bleed in valve V335 and pinch off the tube approximately 300 mm (12 inches) from valve V335.

3. Slowly, open and close bleed in valve V335 thus collapsing the surgical rubber tubing.

4. Observe the vacuum jacket pressure on the Operator Interface Terminal and verify that it reads 100 mTorr. If the reading is less than 100 mTorr, repeat step 3. The system will warm to approximately 200°K in 16 hours and to room temperature in approximately 40 hours.

## 5.2 LIQUEFIER MAINTENANCE

### 5.2.1 Disassembly of the Engine

1. Remove the engine covers.

**WARNING!** **All electrical power and helium gas connections must be removed from the liquefier module.**

   A. Do not dismantle the engine assembly until the liquefier is at room temperature, atmospheric pressure, and disconnected from both the interconnecting piping and the electrical power sources.

   The self-sealing couplings must be capped.

   B. Open valves V312 and V396 and leave open.

   C. Open all four engine valves with the valve jack tools, P/N 3824465 and P/N 3824466.

   D. Check that gauges PI-33, PI-34, and PI-35 all read zero pressure. (Verify that the snubber valves V366, V349, and V347 are open.)

2. Loosen the adjusting nuts on the motor support rod.

3. Remove the clevis pin from the motor support rod.

4. Lift the VFD motor (7, Figure 2-1) and remove the toothed belt (6, Figure 2-1).

5. Rest the VFD motor on the support provided.

6. Remove the two socket-head cap screws (16, Figure 5-1) that secure each connecting rod to its crankpin; then, remove each connecting rod cap (20, Figure 5-1) and outer retaining ring (19, Figure 5-1). The crankpin bearing (18, Figure 5-1) and inner retaining ring (62, Figure 5-1) remain on the crankpiece.

   **Note:** Piston should drop to bottom of cylinders. There may be pressure inside the piston cylinders if the engine valves are not properly opened (see Section 5.2.1 C).

7. Loosen the eight clamp assemblies (27, Figure 5-1) that secure the valve rods to the valve arms, then remove each clamp and valve rod guide (26, Figure 5-1).

   **Note:** Do not bend the valve rods.

8. Remove the valve arms from the frame casting by unscrewing the shoulder bolts (17, Figure 2-1).

9. Remove the four long hold-down bolts (21, Figure 5-1) that attach the frame casting to the cover plate. Do not remove the hex screws (60, Figure 5-1) on the main bearing mounts.

10. Insert the lifting bar P/N 3824271P2 in the hole located in the side of the main casting just below one of the main bearings. (Refer to Figure 5-2).

11. Lift the casting about its pivot point until it rests on the cover plate as shown in Figure 5-2.

12. The piston and valve assemblies can now be removed according to Sections 5.2.2 and 5.2.3.

### 5.2.2 Removing the Pistons

**WARNING! Do not dismantle the piston assembly until the liquefier is at room temperature, atmospheric pressure and disconnected from both the interconnecting piping and the electrical power sources.**

Before the pistons can be withdrawn, it is necessary to perform the preliminary disassembly as described in Section 5.2.1. This procedure will allow air to enter each cylinder to equalize suction pressure as the pistons are pulled out.

1. Slip the small end of the valve spring compression tool (LC P/N 3824275) over one of the engine valve rods, and slide the tool down to the knurled cap (39, Figure 5-1).

2. Slide a split clamp down to the top of the valve spring compression tool.

3. Tighten the split clamp on the valve rod.

4. Unscrew the valve spring compression tool. This will compress the valve springs and open the valve. Push the valve assembly down and remove the valve retainer.

5. Note the location of grease fittings so that the piston assembly can be installed with the same orientation.

6. Withdraw the piston assembly from the cylinder.

   **Note:** Take care to lift the piston assembly in a straight line to prevent damage.

7. Loosen the split clamp from the valve rod and remove it along with the valve spring compression tool.

8. Repeat steps (1) through (7) on the other piston.

9. Inspect and perform maintenance on the pistons according to Section 5.2.8.

10. Remove the valve assemblies according to Section 5.2.3.

### 5.2.3 Removing the Valves

**WARNING! Do not dismantle the valve assemblies until the liquefier is at room temperature, atmospheric pressure and disconnected from both the interconnecting piping and the electrical power sources.**

1. Before the valves can be withdrawn, it is necessary to perform the preliminary disassembly of the engine as described in Section 5.2.1.

2. Remove each valve retainer (39, Figure 5-1) by using the valve spring compression tool (P/N 3824275) and a split clamp. Compress the valve springs about 3mm (1/8 inch) and then slide the valve retainer off.

3. Carefully withdraw each valve assembly from its sheath tube.

   **Note**: Inlet and Exhaust Valves differ slightly. Note their proper location for reassembly.

4. Insert a stopper in valve sheath tube to trap gas as valve assembly is removed.

5. Perform inspection and maintenance of the valve assemblies according to Section 5.2.5.

### 5.2.4 Cleaning the Cylinders and Valve Sheath Tubes

1. Remove the pistons and valves according to Sections 5.2.2 and 5.2.3.

2. Clean the inside of the cylinders, crosshead guides and valve sheath tubes using clean cloths dampened in solvent. Refer to Solvent Guide in Table 5-3.

   **Note:** Avoid using excessive solvent to prevent it from draining into the heat exchanger.

   **Note:** If a rod is used to aid in cleaning, the rod must be wood or plastic, not metallic.

   Wipe away all traces of oil and solvent from the walls of the cylinders and sheath tubes using a clean, dry, lint-free cloth.

3. Cover the tops of the cylinders and valve sheath tubes to exclude foreign matter.

### 5.2.5 Maintenance of the Valve Assemblies

1. Remove the valve assemblies separately according to Section 5.2.3.

2. Disassemble each valve rod assembly separately and discard the lubricating felt, O-rings, valve seal, and nylok screw (40, 41, 43, 54, 55, Figure 5-1).

3. Clean the valve rod, pilots, pilot washer, spacers, and valve springs with solvent. Wipe away all traces of the solvent. (Refer to Table 5-3.)

4. Inspect each valve rod for signs of wear in the area sealed by the O-ring. If there are signs of scratches on the rod, replace the rod.

5. Reassemble each valve assembly separately (Figure 7-5 and 7-6) using new O-rings, felt, valve seal and nylok screw.

   **Note:** Use only dynamic O-ring seal grease (P/N A3542467) on O-rings and felts.

6. Reinstall the valve assemblies in the sheath tubes according to Section 5.2.7.

### 5.2.6 Replacing the Cam Followers

1. Remove the eight split clamps and four valve rod guides (26, 27, Figure 5-1).

2. Remove the valve arms from the frame casting by unscrewing the shoulder bolts (17, Figure 2-1).

3. Using a wrench, remove the nut that secures the cam follower to the valve arm.

4. Remove the cam followers from the valve arms by pressing the stud out of the arm with an arbor press, a vise, or with a plastic hammer.

   **Note:** Support the valve arm properly to prevent bending or physical damage.

5. Install replacement cam followers (see Figure 7-4) making certain that the rollers are on the proper side of the valve arm (see Figure 5-1) and that they are properly aligned before pressing.

6. Using an arbor press or vise, press the stud into the arm.

   **Note:** Support the valve arm properly and do not damage the grease fittings on the cam followers. A small hex nut placed over the grease fitting will provide protection while applying pressure.

   An alternate method of installation is to use a plastic hammer to tap the stud into the valve arm far enough to allow the nut to be started on the threads of the stud.  The stud can then be pulled into the valve arm by tightening the nut.

### 5.2.7 Reinstalling the Valve Assemblies

1. Install the valve assemblies into their sheath tubes.

   **Note**: Inlet and Exhaust Valves differ slightly. Note proper location before installation.

2. Compress the valve springs of each valve in turn, as described in Section 5.2.2, steps 1 through 4, and install the valve retainers.

3. If the frame casting is bolted in its operating position, reinstall the valve arms according to steps 8, 9, and 10 of Section 5.2.12.

### 5.2.8 Maintenance of the Piston Assemblies

#### 5.2.8.1 Inspection

**Note:** Long exposure to moisture will allow the phenolic to swell.

1. Remove each piston assembly according to Section 5.2.2.

2. Remove and discard the two lubricating felts and two O-rings (45, 6, Figure 5-1) from each crosshead (7, Figure 5-1).

3. Using a clean, lint-free cloth moistened with solvent, clean all the surfaces of the piston assembly. (Refer to Table 5-3.)

4. Inspect the outside surfaces of the piston assemblies and seal grooves for scratches and other signs of abnormal wear. Remove all particles of foreign material and smooth out any scratches on the phenolic-plastic pistons using fine emery cloth.

5. Loosen the set-screw on the connecting rod that secures the wrist pin (accessed through the small hole in the crosshead).

6. Remove the wrist pin (12, Figure 5-1) by placing the assembly in an Arbor Press. Insert a 15 mm X 100 mm (5/8" OD x 4 inch) steel pin into the wrist pin bearing with cover removed. Press the wrist pin out.

   **Note:** Opposite bearing may come out. Remove connecting rod from inside the crosshead. Using the proper wrist pin bearing tool, press out the wrist pin bearings.

7. Refer to Section 5.2.9 for Wrist Pin and Wrist Pin Bearing Installation.

### 5.2.8.2 Reinstalling Piston Felts and O-Rings

1. Install lubricating felt strips (45, Figure 5-1) in each of the two inner grooves. Press the strips into each groove until they are firmly seated around the entire diameter of the crosshead (7, Figure 5-1). Overlap the starting end of each strip with the finishing end; then make a diagonal cut of the finishing end with a sharp knife so that the two ends come together flush in the groove. No portion of the felt strip should protrude above the groove.

2. After fitting the felts on the crosshead, construct a sheath tube from a 0.8 mm (1/32 inch) thick manila folder (or material with equivalent smoothness and stiffness) with a length of 100 mm (4 inches) to wrap around the piston and slide over the felts. This will let you know if the felts are installed correctly. Remove any extra felt material that is not in the felt groove of the crosshead.

3. Install two new O-rings (6, Figure 5-1) on each crosshead using the following procedure:

   a. Stand the piston assembly on a flat work surface with the crosshead end down.

   b. Construct a sheath tube from a 0.8 mm (1/32 inch) thick manila folder (or material with equivalent smoothness and stiffness) long enough to encircle the piston and a length of at least 150 mm (6 inches).

   c. Slide the two O-rings over the top of the phenolic piston (2, Figure 5-1).

   d. Wrap the sheath around the piston and slide O-rings onto the sheath tube.

   e. Slide the sheath tube with the two O-rings over the crosshead until the sheath tube covers the crosshead grooves.

f. Push the O-rings off each end of the sheath so that they are beyond the outer O-ring grooves. Remove the sheath tube.

g. Invert the piston assembly on the work surface so that the crosshead end is up.

h. Partially fill O-ring grooves with O-ring grease (P/N A3542467).

i. Slide the two O-rings into the two outer O-ring grooves on the crosshead. Using the stick end of a cotton swab or equal, get in back of the O-ring lifting the O-ring from its groove. Slide the stick around the inside diameter of the O-ring approximately two times. This will assist in removing any O-ring twist incurred during installation.

j. Lubricate the O-rings with grease (P/N A3542467).

k. Remove excess grease from felts and O-rings.

### 5.2.9 Installing the Wrist Pin and Wrist Pin Bearing

**Note:** Refer to Figure 5-3 for tools.

1. Using a heat gun, preheat the small end of connecting rod (14, Figure 5-1) for approximately 3 minutes.

2. Insert small end of connecting rod into crosshead and align wrist pin holes. Be sure the set-screw of the connecting rod is aligned with the access hole in the crosshead.

3. Support crosshead in a V-block and use an arbor press to press the wrist pin into the connecting rod until end of wrist pin is within about 6 mm (1/4 inch) of surface of crosshead.

4. Place the appropriate wrist pin inserting tool over the end of the wrist pin, and press on the tool until it rests against the side of the connecting rod. This will center the wrist pin in the connecting rod.

5. Remove all metal chips surrounding the wrist pin with dry compressed air.

**Note**: Check for proper alignment of wrist pin to connecting rod by using a grease gun containing Molub-Alloy grease (P/N A3542548). Grease the lube fitting on the connecting rod. Grease must exit through both end holes in the wrist pin.

6. Tighten the set-screw on the connecting rod to secure the wrist pin (accessed through the small hole in the crosshead).

7. Place the appropriate bearing locating tool so that the forked ends are down around the wrist pin between the connecting rod and the crosshead.

8. Pre-lubricate the needle bearings with Molub-Alloy grease (P/N A3542548). Place a needle bearing over one end of the wrist pin and press it into the crosshead. Use the appropriate wrist pin inserting tool and press the bearing in until it seats against the bearing locating tool.

9. Install the other needle bearing, using the above procedure.

10. Remove the bearing locating tools from the crosshead.

11. Check to ensure sufficient side-play between the connecting rod and sides of the crosshead. Approximately 1.5 mm (0.060 inch) clearance on each side of the connecting rod with the rod centered.

12. Grease the wrist pin bearings using a grease gun containing Molub-Alloy bearing grease (P/N A3542548). Remove excess grease.

### 5.2.10 Replacing the Crankpin Bearing

1. Remove the bearing retaining cap (36, Figure 5-1).

2. Using the crankpin bearing removal tool (P/N 3839217), remove the crankpin bearing (18, Figure 5-1).

   **Note:** Do not damage the crankpin.

3. Remove the spacer ring (61, Figure 5-1) and inner retaining ring (62, Figure 5-1).

4. Clean the crankpin thoroughly with solvent. Refer to Solvent Guide in Table 5-3.

**Note:** It may be necessary to polish the crankpin with very fine emery cloth so that the new bearing can be pressed onto it.

**Note:** Do not use lubricant when installing the bearing on the crankpin. The presence of oil or grease usually accelerates fretting corrosion.

5. Reinstall the spacer ring (61, Figure 5-1) with the chamfered side toward the crankpin.

6. Reinstall the inner retaining ring (62, Figure 5-1).

   **Note:** Inner retaining ring must not rest on the crankpin shaft when installing crankpin bearing.

7. Press on crankpin bearing (18, Figure 5-1), using the crankpin bearing installation tool (P/N 3839286).

8. Reinstall the bearing retaining cap (36, Figure 5-1).

### 5.2.11 Reinstalling the Piston Assemblies

1. Apply a light coating of Ronex MP or Lidok Grease (LC P/N A3542293) to the widest diameter of the crosshead. (The upper 76 mm or 3 inches of the crosshead only).

   **Note:** Use only Ronex MP or Lidok grease. Be sure that no other lubricant contacts the surfaces of the crosshead guides because wear will result.

2. Carefully insert the piston assembly into the cylinder with the grease fittings facing toward the valve assemblies.

   **Note:** When installing a new piston, it is imperative that a 0.30-0.50 mm (0.010-0.020 inch) clearance is established between end of piston and the cylinder bottom. Piston end must be machined to achieve the required clearance.

3. Lower both piston assemblies to their bottom position.

4. Using one finger, wipe the excess Ronex MP or Lidok Grease to the upper inner surface of each crosshead guide.

### 5.2.12 Final Reassembly of the Engines

1. Rest one connecting rod in the forward position in the crosshead guide, and the other connecting rod in the opposite direction in its crosshead guide.

2. Turn the flywheel so that each crankpin will be oriented with its mating connecting rod when the frame casting is rocked back to its normal operating position.

3. Using the lifting bar P/N 3824271P2, rock the frame casting forward about its pivot point until it rests on the cover plate.

   **Note:** When lowering the frame casting, observe each crankpin and its relationship to its mating connecting rod as they approach each other. Do not allow any interference.

4. Reinstall the four hold-down bolts (21, Figure 5-1) and torque them to 54 N·m (40 lb·ft).

5. Engage each crankpin with its connecting rod by rotating the flywheel. Reinstall the outer retaining ring (19, Figure 5-1).

6. Align the mark on each connecting rod cap with the corresponding mark on the connecting rod and fasten the cap to the rod with socket head cap screws (16, Figure 5-1).

7. Wipe all excess grease from the surfaces of the inlet and exhaust cams (15, 17, 37, 38, Figure 5-1) and cam followers (32, 34, Figure 5-1).

8. Slide each valve arm (25, 28, 31, 35, Figure 5-1) over its valve rod and attach it to the frame casting with the shoulder bolt. Be certain that the arms are in their correct locations. All valve rods should be vertical.

9. Install the valve rod guides and clamps (26, 27, Figure 5-1).

10. Set the valve clamp clearance according to Section 5.2.13.

11. Raise the VFD motor assembly (7, Figure 2-1) and install the toothed belt (6, Figure 2-1), making sure that the teeth engage all sprockets.

12. Position the motor support rod over the lug on the motor base; then, reinstall the clevis pin. Set belt tension so that the belt will deflect 3 mm (1/8 inch) with a moderate force of about 4.5 kg (10 pounds) at mid-span.

### 5.2.13 Setting the Valve Clamp Clearance

1. Push the **ENGINE STOP** button.

**<u>WARNING!</u> Do not rotate the flywheel if the engine pressure (PI-34) is above 0.7 bar (10 psig). Engines could start. Reduce the pressure using valve V312.**

2. Rotate the flywheel so that the cam follower is positioned on the flat of the cam.

3. Rotate flywheel manually and insert the proper valve setting shim between the bottom surface of the clamp and the upper surface of the valve rod guide. Ensure that a clearance of 0.20 to 0.35 mm (0.008 to 0.014 inches) exists when the unit is cold and 0.63 mm (0.025 inches) when the unit is warm.

   **Note:** Use valve setting shim P/N 3824270P2 (0.254 mm, 0.010 inches) when the unit is cold.
   Use valve setting shim P/N 3824270P1 (0.635 mm, 0.025 inches) when the unit is warm.

4. If the clearance is not correct, adjust the position of the split clamp as required.

   **Note:** Do not bend the valve rod.

5. Remove the valve setting shim when the valve clearance has been checked.

Use the above procedure to set the valve clamp clearance for each of the Inlet and Exhaust valves.

### 5.2.14 Lubricating the Engine Assembly

Using a grease gun filled with Molub-Alloy grease (P/N A3542548), lubricate the listed components as per the following schedule:

**LUBRICATION SCHEDULE**

| Component | Lube Fitting Location | (Hours Operation) |
|---|---|---|
| Crankpin Bearings | Connecting Rod | 250 |
| Wrist Pin Bearings | Connecting Rod | 250 |
| Cam Followers | Cam Follower Assembly | 250 |
| Main Bearings | Under Bearing Nameplate | 3000 |
| Jackshaft Bearings | Jackshaft Bearing Block | 3000 |

**Note:** Do not over lubricate the bearings. Wipe off excess grease from the cam followers.

Lubricate the valve arm bushings with light machine oil after every 1000 hours of operation. There is a 3 mm (1/8” OD) hole located on the top section of the valve arm where the shoulder bolt rests.

### 5.2.15 Lubricating the Crosshead Guide

If the engines are being operated at speeds of less than 200 rpm, grease must be applied to the crosshead guide after every 1000 hours of operation. If the engines are being operated at speeds greater than 200 rpm, grease must be applied after every 500 hours of operation.

The best way to lubricate the crosshead guide is to stop the engines and proceed as follows:

1. Open valve V312 to bleed down pressure at PI-34 to 0.3-0.7 bar (5-10 psig).

2. Turn the flywheel by hand until the piston reaches the bottom of its stroke.

3. Apply a light coat of Ronex MP or Lidok grease with fingers to the wall of the crosshead guide.

4. Perform steps 2 and 3 for the second Crosshead Guide.

**Note:** Use only Ronex MP or Lidok grease. Do not add an excessive amount of grease.

### 5.2.16 Checking Engine Valve Leakage

1. Push the **ENGINE STOP** button.

**<u>WARNING!</u> Do not rotate the flywheel to install the locking bar if the engine pressure (PI-34) is above 0.7 bar (10 psig). Engines could start. Reduce the pressure using valve V312.**

2. Rotate the flywheel so that the 15.9 mm (5/8" OD) diameter hole in the flywheel is aligned with the 15.9 mm (5/8" OD) diameter hole in the frame casting. Insert the flywheel locking bar P/N 3824271P1 through the holes, thus locking the flywheel.

3. Adjust the valve clearance using 0.635 mm (0.025 inches) valve setting shim so that all four valves are closed with the locking bar in place.

4. If the clearance is not correct, adjust the clamps.

**Note:** Do not bend the valve rod.

5. Remove the valve setting shim when the valve clearances have been checked.

6. Start a compressor. Press the **HX FILL** button. Valve V323 will open momentarily and increase high-side pressure.

7. Confirm valve V323 is closed.

8. Using the valve jacks P/N 3824465 and P/N 3824466, open the valves as indicated on Engine Valve Leak-Check Data sheet. Trial I, Table 5-5.

9. Using a stopwatch, record the data on a sheet similar to Table 5-5.

10. Repeat steps (6) through (9) for Trials II, III, IV, and V using Table 5-5, and record data.

11. Open valve V312 and bleed off the pressure, until PI-34 reaches 0.7 bar (10 psig).

12. Remove the flywheel locking bar.

13. Rotate the flywheel so that the cam follower is on the flat of the cam. Reset the valve clamp clearance as required per Section 5.2.13. Use this procedure for all valves.

14. If the engine valve needs replacement, use Section 5.2.5.

### 5.2.17 Checking Setting of the Overspeed Safety Device

The overspeed safety device pin assembly was set at the proper spring compression before shipment and normally it is not necessary to readjust it. However, check the setting in accordance with the following procedure.

1. Measure the force to compress the spring of the overspeed safety device to slightly displace the pin.

2. If the measured force equals approximately 2.04 kg (4.5 pounds), no adjustment is necessary. If the force is not equal to approximately 2.04 kg (4.5 pounds), readjust the preload on the spring.

   **Note:** The PLC is programmed to stop the flow of gas to the engines in the event that the flywheel overspeeds.

### 5.2.18 Resetting the Overspeed Shutdown Switch

The overspeed shutdown switch assembly (58, Figure 5-1) is mounted on the cover plate directly beneath the flywheel. It is set to trip at approximately 300 rpm. The end of the assembly may be viewed by removing the engine cover and looking under the flywheel from the left end of the liquefier or refrigerator. Use the reset tool P/N 3824375 provided for resetting the switch.

### 5.2.19 Maintenance of the Vacuum Pump (E40)

The oil level should be about midway on the sight gauge when the pump is at low inlet pressures. If the vacuum jacket has been opened to the atmosphere, a large quantity of moisture may enter the pump during pumpdown. If the oil becomes cloudy (mixed with moisture), open the gas ballast valve on top of the vacuum pump. If oil does not clear up while ballasting for 12 hours, change the oil. For detailed maintenance instructions, refer to the vendor's manual in the appendix.

### 5.2.20 Checking the Main Shaft Bearing Clearance

The main shaft bearing should be inspected every 3000 hours. If bearing play exceeds 0.13 mm (0.005 inches), replace the bearing. Clearance can best be checked by taking a dial indicator reading on the top cam surface while the No. 1 piston, and alternately the No. 2 piston, are forced upward by pressurizing the cylinder. Use Section 5.2.16 to pressurize the cylinders. Replace bearing per Section 5.2.21 if required.

### 5.2.21 Replacing the Main Bearing(s)

#### 5.2.21.1 Removing the Main Bearing(s)

1. Disassemble the engine as specified in Section 5.2.1.
2. Remove the crankpin retaining cap (36, Figure 5-1).
3. Remove the crankpin bearing (18, Figure 5-1) using crankpin bearing removal tool, P/N 3839217 (Figure 5-3).
4. Remove the crankpin bearing spacer ring (61, Figure 5-1) and the inner retaining ring (62, Figure 5-1).
5. Remove the four (4) socket head clamping screws that secure the exhaust cam and remove the exhaust cam (17, 37, Figure 5-1) from each engine.
6. Remove the inlet cam (15, 38, Figure 5-1) from each engine.
7. Remove the four (4) jackshaft assembly hold-down bolts (5, 8, Figure 7-8).

8. Separate the jackshaft V-belt sheave pulley from its hub. (Remove the two clamping screws located on the side of the V-belt pulley. Use one of the screws removed as a jacking screw by inserting it in the middle hole. Turn this screw clockwise, separating the pulley from its hub.)

9. Remove the jackshaft assembly by slipping the assembly under the flywheel V-belts.

10. Tilt engine frame casting back to its normal working position.

11. Remove two (2) socket head cap screws from each main bearing pillow block (18, Figure 7-7).

12. Lift the flywheel assembly from the frame and place on a bench. (Note the orientation of overspeed pin on flywheel.)

13. Remove four (4) hex screws (60, Figure 5-1) from each main bearing pillow block cap. (Note: Mark orientation of pillow block housing with frame.)

14. Remove the pillow block cap and saddle from each bearing (24, Figure 5-1).

15. Remove flat head screw from each crankpiece.

16. Remove each crankpiece (23, Figure 5-1) using a wheel or gear puller (apply heat to crankpiece as needed). Remove woodruff keys from driveshaft (22, Figure 5-1).

17. Remove two (2) set screws from each bearing collar. Remove the collar from each bearing.

18. Measure and record the distance between the end of the shaft and inner race face of each main bearing.

19. Remove the main bearing(s) from the driveshaft using a wheel or gear puller.

20. Polish the driveshaft if needed with fine emery cloth.

#### 5.2.21.2 Installing New Main Bearing(s)

1. Remove collar from the new bearing and slide bearing on to the driveshaft with the collar flange facing the end of shaft. (If bearing does not slide freely on the driveshaft, preheat

inner race of bearing with a heat gun or use a tube and place it over the shaft and rest on the inner face of the bearing. Lightly tap tube to position the bearing.) Position the bearing on the driveshaft to the dimensions that were recorded when old bearing was removed.

2. Install bearing collar, aligning the two set-screws with the flat spots on the driveshaft used to position the bearing collar. Tighten the set-screws.

3. Reinstall the bearing pillow blocks in the same orientation as removed. Tighten the hex screws (60, Figure 5-1) to 40 N·m (30 lb·ft).

4. Reinstall the flywheel V-belts.

5. Reposition the flywheel assembly on the engine frame. Note the orientation of the overspeed trip pin (13, Figure 5-1) and the overspeed switch (58, Figure 5-1).

6. Secure the main shaft bearing pillow blocks to the engine frame with two (2) socket head cap screws (18, Figure 7-7) for each bearing block.

7. Reinstall the jackshaft assembly on the engine frame. Place the V-belts on sheave pulley.

8. Reassemble the jackshaft sheave and hub on shaft (see Figure 7-8).

   **Note:** Make sure jackshaft sheave is aligned with flywheel.

9. Tension flywheel V-belts per LC Specification A3545485, located in the appendix.

10. Heat crankpieces (23, Figure 5-1) in an oven to 260°C (500°F), for 2 hours.

11. Place woodruff keys (15, Figure 7-7) on the driveshaft.

12. Bring the flywheel assembly as close as practical to the oven heating area.

    **Note:** If too much time is lost going from the oven to the flywheel area, the crankpiece will cool and will not go on the driveshaft.

13. Install crankpieces on each end of driveshaft.

14. Reinstall flat head cap screw in each end of shaft.

    **Note**: Allow the crankpieces to cool to ambient temperature before continuing with reassembly.

15. Reinstall the inlet cam(s) (15, 38, Figure 5-1).

    **Note:** Make certain that correct cam is on each engine.

16. Reinstall the exhaust cam(s) (17, 37, Figure 5-1).

    **Note:** Make certain that correct cam is on each engine.

17. Line up the "0" mark on the inlet cam with the scribe marks on the exhaust cam. Tighten the four (4) socket head clamping screws.

18. Reinstall the spacer ring (61, Figure 5-1) on the crankpin journal.

    **Note:** Beveled larger diameter of spacer ring faces the crankpiece face.

19. Place inner retaining ring (62, Figure 5-1) over spacer ring.

20. Install the crankpin bearing (18, Figure 5-1) and secure with crankpin retaining cap (36, Figure 5-1).

21. Reinstall engine assembly on top cover plate of liquefier.

22. Reinstall valve assemblies per Section 5.2.7.

23. Reinstall piston assemblies per Section 5.2.11.

24. For final reassembly of the engines, see Section 5.2.12.

### 5.2.22 Replacing the Jackshaft Bearing (s)

#### 5.2.22.1 Removing the Jackshaft Bearing (s)

1. Disassemble the engine as specified in Section 5.2.1.

2. Loosen the four (4) jackshaft assembly hold-down bolts (5, 8, Figure 7-8).

3. Separate the jackshaft sheave pulley from its hub (14, Figure 7-8). Remove the two clamping screws located on the side of the V-belt pulley. Use one of the screws removed as a jacking screw by inserting it in the middle hole. Turn this screw clockwise; separating the pulley from its hub.

4. Loosen the set-screw on each bearing collar (6, Figure 7-8).

5. Using a spanner wrench, loosen the collar and remove from the bearing.

6. Slide the shaft through the bearings.

   **Note:** If the shaft is fretted, replace.

7. Remove bearings from bearing block by placing the shaft back into the bearing approximately 6 mm (1/4 inch) and tilting the shaft upwards. Bearing has to rotate 90° from original position to be removed from the pillow block.

#### 5.2.22.2 Installing the Jackshaft Bearing (s)

1. Install new bearings in the same manner as you removed them.

2. Slide shaft through the bearings, sheave pulley and its hub.

   **Note:** When sliding shaft through bore of the bearing inner ring, be sure the counterbore of eccentric collar "A" is toward eccentric boss "B" on the inner ring (see Figure 5-4).

3. Turn eccentric collar "A" in the direction in which shaft will rotate. Hand tight is often sufficient but a spanner wrench or drift pin may be inserted into the spanner wrench hole "C" and used to set the collar (see Figure 5-4).

   **Note:** Do not use a direct hammer blow to set the collar as such a blow may fracture the inner ring.

4. Tighten the set-screw in eccentric collar firmly against the shaft to 7.9 N·m (70 lb·in).

5. Reassemble the jackshaft sheave pulley to its hub.

   **Note**: Make sure jackshaft sheave is aligned with flywheel.

6. Tension flywheel V-belts per LC Specification A3545485, located in the appendix.

## 5.3 MAINTENANCE OF DELIVERY TUBE

Outgassing from the surfaces within the vacuum jacket will in time raise the pressure to a level sufficient to degrade the insulating effectiveness. The vacuum jacket must be re-evacuated in accordance with the following procedure:

1. Warm the delivery tube to room temperature. Tube may need to be removed from liquefier and dewar.

2. Remove the plastic dust cap from the pump-out fitting.

3. Install the pump-out valve operator (Appendix F, G, H).

4. Connect a mechanical vacuum pump to the valve operator pump-out port and evacuate the interconnecting line to a blank-off pressure of less than 20 mTorr.

5. Pump-out valve operator handle must be pushed into its body until it bottoms; then, screw clockwise 2 or 3 turns to engage the seal plug. When the handle is pulled back out, the port will be open.

6. Open the pump-out valve and evacuate the tube jacket to less than 20 mTorr.

7. Close the pump-out valve by pushing the handle in.

8. Open the vacuum pump line to atmosphere. This will keep the pump-out plug in its proper location.

9. Turn handle on the pump-out valve operator counter-clockwise 6 turns to disengage from the pump-out plug, then remove the pump-out valve operator.

10. Observe port to ensure the seal plug remains in the port. Use vacuum grease P/N 0579847 to fill the pump-out port before installing plastic dust cap.

## 5.4 LOCATING AND REPAIRING LEAKS

Leakage through a suspect component is revealed by either leakage of helium gas to atmosphere or leakage across a valve seal from high-pressure to low-pressure. The following section describes techniques for location and repair of minor component failure.

If a leak is suspect within a heat exchanger (high-pressure to low-pressure) or to vacuum, consult LC Customer Service for assistance in location and repair of the leak.

The most effective means for leak detection is a mass spectrometer. If such equipment is available, carefully scan all parts of the defective component. Bear in mind that the most likely points of leakage are mechanical joints, connecting fittings, O-rings, brazed joints, and welded joints. In many cases, evidence of mechanical damage will offer starting points for the testing procedure.

If a mass spectrometer is not available, the next most effective method is a bubble test with Leak-Tec®, P/N 0209942 or an equivalent substance.

**WARNING!** **Do not exceed the tabulated pressures shown in Table 5-4 when pressurizing the system components.**

**Note:** Solutions such as Leak-Tec® may be corrosive and must be rinsed from parts after using. Avoid solutions containing chloride.

### 5.4.1 Locating Leaks

The following two sections describe methods for location of leaks. Section 5.4.1.1 should be referred to for situations where helium gas is leaking from high-pressure to low-pressure. Section 5.4.1.2 should be referred to for situations where a leak to atmosphere is suspect.

#### 5.4.1.1 High Pressure to Low Pressure Leak

Verify the following preliminary steps are completed:

1. Disconnect all connections at the back of the liquefier.

2. Drain all pressure in the system. Gauges PI-33, PI-34, PI-35, and PI-60 show 0.0 bar (0 psig).

3. Install the locking bar through the engine flywheel.

4. Close all manual valves.

Pressurize the high-side to 13.8 bar (200 psig) at PI-33 and PI-34. Drain any remaining helium in the low-side through V339 to 0.0 bar (0.0 psig). With V339 and V640 closed, and a balloon on the gas bag vent connection "V", monitor the high-side pressure at PI-33 and PI-34 for loss of gas. Monitor the low-side pressure at PI-35. If the low-side pressure increases and high-side pressure decreases in this condition, there is a high-to-low leak. The possible leaks to the low-side could be in the engine valve seals, JT307 / V308 path through the RDT section, or the purifier to the low-side via V616 and V615. The amount of time necessary to verify that there is no leak from high to low can be as much as 1 hour, depending on the volume of piping, etc. Determining the exact location of the leak can be done by the following steps:

1. Perform an Engine Valve Seal Leak Check. Refer to Section 5.2.16.

2. Purifier V616 Test

   The first step is to drain all the pressure from the system. The compression fitting at collar penetration #10 must be capped with a 13.8 bar (200 psig) pressure gauge. V616 is a normally closed valve. The path to the low-side is through the normally open V615. Disconnect the 6.3 mm (1/4" OD) brass compression fitting to V615 and attach a helium cylinder regulated to 10.3 bar (150 psig) and pressurize. This will cut off the path to the low-side. Pressurize the high-side through V312 and observe the pressure gauge at collar penetration #10. If this gauge increases, then there is a leak through V616. If the gauge does not increase and PI-35 does increase, then the leak is elsewhere.

3. JT307 / V308 Test

   This leak must travel through the JT307 valve first and then through V308. This is an unlikely path for a high-to-low leak, but it must be checked.

Remove the RDT. Once capped, observe the pressure at PI-308. If the pressure stays at 0.0 bar (0.0 psig), this confirms tight, leak-free valves. If the pressure climbs only as high as the low-side pressure, then this confirms a V308 leak. If the pressure climbs to 0.7 bar (10 psig), then this confirms a JT307 leak.

### 5.4.1.2 Leak to Atmosphere

External piping leaks to atmosphere are generally found when the consumption of pure gas exceeds normal limits. Leaks are found by pressurizing all piping and using a soap solution such as Leak-Tec® or Snoop®. Apply an even coating of the solution using a soft, camel's hair or sable artist's brush. If the leak is small, apply the coating to several joints at one time and wait approximately 5-10 minutes. Carefully look for small areas of white foam. Extremely small leaks can be located by employing a magnifying glass and considerable patience. If the leak is large, apply the coating to one joint at a time; then watch for one or two large bubbles to form as the brush passes over the leak.

### 5.4.2 Repairing Leaks

If the cause of leakage is an O-ring, disassemble the particular component and clean the O-ring groove with a clean cloth moistened in solvent (refer to Table 5-3).

Inspect the groove carefully, looking for scratches or other damage. If such defects are found and cannot be repaired readily, contact the LC Customer Service Representative for assistance. When the groove has been put in satisfactory condition, lightly coat the replacement O-ring with grease and install it.

Repairing a thread seal always requires the disconnection of compression fittings and the removal of the leaking section. The leaking thread seal must be disassembled, cleaned, and reassembled with a proper thread sealant.

If the leak is at a mechanical joint or a self-sealing coupling, carefully tighten the joint using two wrenches. When the joint has been tightened, retest for leaks as before. If the coupling still leaks and if it is the gasket type (e.g. Aeroquip), remove the gasket and O-rings. Then clean and inspect the sealing surfaces carefully. If there is no evidence of damage, replace the O-rings and gasket and retest for leaks as before. If necessary replace the fitting.

**WARNING!** **Only qualified personnel must perform the repair of brazed or welded joints. Contact LC Customer Service Representative for advice if such repairs are necessary.**

Carefully clean the area in which the repairs were made making sure that no contaminants are left either on the inside or the outside of the component.

## 5.5 SYSTEM DECONTAMINATION

All the components in the Model 1410 system must be free of air and moisture and contain only pure helium at the time of use. Components of recovery systems need not be decontaminated to the same degree as the basic system components.

The following sections detail methods for removing contaminants from the system components.

### 5.5.1 Purging the Compressor

If the compressor pump has been opened for repair and the oil exposed to the atmosphere for more than 8 hours, the compressor module must be evacuated and purged to expel any traces of air and moisture. Short-term exposure of the pump internals to the atmosphere must be followed by evacuation; however, purging may be omitted. Refer to the compressor instruction manual for decontamination procedure.

### 5.5.2 Liquefier Cleanup Using a Cryogenic Adsorber

Linde Cryogenics recommends the use of a cryogenic adsorber. Refer to the cryogenic adsorber manual for instructions.

### 5.5.3 Liquefier Cleanup When Cryogenic Adsorber Is Not Available

This procedure is performed whenever the liquefier has been opened to atmosphere and a cryogenic adsorber is not available.

1. Plug the delivery tube sealing gland.

2. Using the Operator Interface Terminal, place valves JT307 and V308 in **MANUAL** and open them. With the $LN_2$ supply isolated, activate the $LN_2$ precooling so that solenoid valve V808 opens.

3. Close manual valves V341, V339, V312, V396 and V397.

4. Install the locking bar in the flywheel.

5. Connect the vacuum pump to valves V339 (connection "Y") and V397 and open the valves.

6. Evacuate to 50 mTorr as measured at the vacuum pump.

7. Backfill with pure helium gas to greater than 0.0 bar (0 psig) as indicated on PI-35, using valve V341; then, close valve V341. Repeat evacuation and backfill 4 to 5 times.

   **Note:** Prior to final backfill, open all 4 engine valves and pump the engine cylinders for a period of 15 minutes maximum. Remove the valve jacks after final backfill.

8. Using the OIT, close the J-T valve (JT307) and the return valve (V308).

9. Push a **COMPRESSOR START** switch on the OIT.

10. Push the **HX FILL** (V323) button on the OIT. This will energize valve V323 for 5 seconds and fill the precooler, boiler, main heat exchanger, engines and charcoal filter with pure helium gas.

11. Blow down manual valve V312 to 0.7 bar (10 psig) as indicated on PI-34. Check for signs of moisture.

12. Repeat steps (10) and (11) at least three times.

13. Press the **PURIFIER PURGE** button on the OIT; this will initiate the automatic purifier blowdown routine. This routine alternately backfills the impure side of the purifier via valves V323 and V620 and blows down through valves V632 and V609 (2 times each).

14. System is now ready for operation.

### 5.5.4 Liquefier HX Blowdown After Temporary Shutdown

This procedure is performed if the system is at room temperature and has not been opened to atmosphere but left in a shutdown mode over night or over a weekend.

Repeat steps in Section 5.5.3 except steps (1) and (5) through (8).

### 5.5.5 Evacuating the Interconnecting Piping

The interconnecting piping between the compressor(s) and liquefier must be evacuated in the following manner to remove air and moisture, if the piping was open to atmosphere.

1. Disconnect the self-sealing couplings on the supply and return lines at the compressor and liquefier connections. Install dust caps and plugs.

2. Close valve V201 on the RS Compressor or, if using Model 1400 Compressors, disconnect the self-sealing coupling at the compressor suction and install dust caps and plugs.

3. Open the manual bypass valve on the interconnecting piping.

4. Connect a vacuum pump to the evacuation valve on the interconnecting piping. Use a 3.5 $m^3$/hour (2 cfm) minimum displacement vacuum pump with a blank off pressure of 25 mTorr or better.

5. Evacuate the piping to 100 mTorr or better.

6. Backfill the interconnecting piping with helium gas to a positive pressure.

7. Repeat steps (5) and (6) three times.

8. Close evacuation valve and shut off the vacuum pump.

9. Close the manual bypass valve on the interconnecting piping.

10. Reconnect the piping and open valves as required.

### 5.5.6 APPLYING THREAD SEALANTS

A recommended procedure for the application of all thread sealants is described below. This procedure is to be used in conjunction with any recommendations of the sealant manufacturer. It is applicable to all semi-permanent threaded joints, (i.e., epoxy, or Neolube®).

1. Inspect both male and female threaded sections for dirt or damaged threads.
2. Thread mating parts together hand tight to ensure both male and female threads fit properly.
3. Apply sealant to the male thread whenever possible, taking care not to get sealant on first one half of thread.
4. Make up the threaded assembly hand tight; then remove and apply additional sealant as in step (3).
5. Make up the threaded assembly hand tight; then, fully seat the components with appropriate wrenches.
6. Tighten the fitting into proper orientation. Do not "back-off" the fittings to obtain proper alignment.
7. Clean excess sealant from the external threads to give a neat appearance.
8. Allow time for curing or setting of the sealant before pressurizing the component.

### 5.5.7 REMOVING EPOXY-SEALED THREADED CONNECTIONS

Epoxy resin is used, as a sealant, on some components of the liquefier for threaded connections that are not likely to be disengaged. It provides a reliable seal that does not age or loosen. Disengaging such joints should be avoided whenever possible because there is considerable risk of damage to the parts. However, if a joint must be replaced, heat the epoxy joint to over 93°C (200°F); then using two wrenches, disassembly the fitting.

If the parts are to be reused, thoroughly wire brush the threads to remove any old epoxy before reassembling with new sealant.

# SECTION 6

# TROUBLESHOOTING

This section covers some of the difficulties that may occur in day-to-day operation of the system. It is assumed that the Operator has read the preceding sections and is thoroughly familiar with the mechanical and electrical details of the equipment. The procedures given here will enable the operator to identify and correct operating difficulties.

The key factors in troubleshooting are the Operator's experience with the system and the log sheets that were kept while the system was operating properly. If he has become accustomed to the normal sound levels and operating characteristics, he will more readily recognize deviations from the normal. Furthermore, if the operator has regularly performed the inspections and capacity tests, he will be more likely to discover minor degradation of performance before serious difficulty arises.

## 6.1 LIQUEFIER MECHANICAL TROUBLESHOOTING

1. The Engine “Knocks”
   - a. Frozen Contaminants in Cylinder
     - i. Shut down immediately. Warm up and decontaminate in accordance with Section 5.5.
     - ii. Remove and clean pistons, valves and cylinders during the decontamination process. Follow the procedure outlined in Sections 5.2.1-5.2.5.
   - b. Worn Main Bearing

     Shut down and check bearing play per Section 5.2.20.
2. Crosshead Guide Hot (Temperature in excess of 54$^{o}$C [130$^{o}$F])
   - a. Lack of Lubrication in Crosshead Guide
     - i. Lubricate in accordance with Section 5.2.15.
     - ii. If the temperature does not drop, warm unit and remove pistons in accordance with Section 5.2.2. Clean piston, cylinder, crosshead and re-lubricate (Section 5.2.4, 5.2.11, 5.2.15, and Table 5-1).
3. Noisy Crankpin Bearing (Bearing Runs Hot)
   - a. Failed Bearing

     Replace bearing in accordance with Section 5.2.10.

4. “Clunking” Noise When Inlet Valves Open

    a. Excessive Play in Main Bearing

        Check in accordance with Section 5.2.20. If needed, replace main bearing in accordance with Section 5.2.21.

5. Excessive Black Dust on Cover Plate

    a. Flywheel V-Belts Too Loose

        Tighten V-belts in accordance with CPS Spec. A3545485 located in the appendix.

6. Engine Stops (Flywheel Does Not Turn Freely)

    a. Mechanical Interference is Causing Seizure of the Piston

        Warm unit, remove pistons, examine, and repair or replace in accordance with Section 5.2.2.

    b. Contamination

        Warm unit, clean in accordance with Section 5.5.

7. Liquefier Loses Gas

    a. High-Pressure to Low-Pressure Leak

        Check in accordance with Section 5.4.1.1.

    b. Leak to Vacuum Jacket

        Contact LC Field Service Representative for assistance.

    c. Leak to Atmosphere

        Check in accordance with Section 5.4.1.2.

## 6.2 LIQUEFIER OPERATIONAL TROUBLESHOOTING

1. Engine Will Not Start

    a. Valve V323 In Manual Mode

        The PLC can not open valve V323 to fill the heat exchanger if valve V323 is in the manual mode. Place valve V323 in the auto mode and restart.

    b. Overspeed Switch (OS-1) Tripped

        Reset OS-1 in accordance with Section 5.2.18, reset alarm on the Operator Interface Terminal (OIT) and restart.

    c. Emergency Stop Button Activated

        If the E-stop button is depressed, the unit will not start. Pull the E-stop button out, reset alarm on the OIT and restart.

d. High-Side Pressure Too Low

Valve V323 will open but, if the high-side pressure is below 9.6 bar (140 psig) after 30 seconds, the engines will not start. Be sure that the compressor is running and that valve V345 is set properly.

e. Pure Helium Supply Low (PI-32)

Increase the pure helium supply pressure. Reset alarm on the OIT and restart.

f. Locking Bar is Still In Flywheel

Remove locking bar. Reset alarm on the OIT and restart.

g. Compressor is Off

The engine will not start if a compressor is not running. Start at least one compressor.

h. Alarm Still Active

If a previous alarm that has shut down the engine has not been acknowledged, the engine will not start. Reset all alarms and restart.

2. Engine Slows Down and Stops (Flywheel Turns Freely)

a. Pure Helium Supply Low (PI-32)

Automatic shut down (Normal). Pure gas supply was low. Increase pure storage, reset alarm on the OIT and restart.

b. Electrical Failure

Emergency shutdown (Normal). If electrical power is lost, the flywheel will coast to a stop. Restart when power is restored.

c. Overspeed Shutdown

Emergency shutdown (Normal). If the rotation of the flywheel exceeds 270 rpm, the system will shut down automatically. If the flywheel exceeds 300 rpm, OS-1 will trip and shut the system down automatically. Overspeed could be caused by belt slippage or power glitches. Adjust V-belt tension in accordance with LC Spec. A3545485 located in the appendix. Reset alarm and restart.

d. Low Speed Shutdown

Emergency shutdown (Normal). If the rotation of the flywheel falls below 10 rpm, the system will shut down automatically. This can be caused by contamination in the Heat Exchanger. Warm up the system and clean in accordance with Section 5.5. Reset alarm and restart.

e. Valve V323 Manually Closed

During operation, if valve V323 is placed in manual and closed, the flywheel will coast to a stop because of lack of gas entering the system. Place valve V323 in auto mode. Reset alarm on the OIT and restart.

f. Dewar Pressure Too High (PI-308)

If the dewar pressure is too high, check to see if the RDT is contaminated. Remove RDT and decontaminate.

g. Compressor Tripped

If the compressor stops because of a safety switch on the compressor, the system will go into an automatic shut down. Investigate the problem with the compressor. Once fixed, reset the alarm and restart.

h. Emergency Stop Button Depressed

Reset button.

3. High-Side Pressure Below Normal

a. Regulator Valve V345 Setpoint Too Low

The system should run at 15.8 bar (230 psig) or higher at initial startup when the heat exchanger is warm. Increase valve V345 setpoint.

4. Large Pressure Drop in HX

a. Contamination

Shut down and warm up the system. Clean in accordance with Section 5.5.

5. Engine Speed Erratic

a. Loose Flywheel V-Belts

Tighten V-belts in accordance with LC Spec. A3545485 located in the appendix.

6. Liquid Production Low

a. Incorrect Engine Valve Clearance

Adjust the valve clamp clearances in accordance with Section 5.2.13.

b. RDT Vacuum is Soft

If the RDT has frost spots or is totally frosting up, then the liquid being delivered to the dewar could be vaporizing before it gets there. A frost spot will indicate a thermal short and the RDT will need to be repaired. An overall frosted

RDT will need to be removed, warmed, and evacuated. Follow the procedure outlined in Section 5.3.

c. Regulator Valve V345 Setting Too Low

The pressure at PT-1 controls the speed. If the pressure drops below 15.8 bar (230 psig), the engines will slow down to maintain 15.8 bar (230 psig). Turn the valve V345 setpoint clockwise 1/4 turn. Watch to see if PT-1 pressure rises. If so, the speed will increase. If not, return the valve V345 to its original setpoint.

d. Valve V806 Closed

Precooling is on. Turning on the precooler opens V808 solenoid valve. If the manual valve V806 is closed there will be no flow through the precooler. Open and adjust valve V806 in accordance with Section 2.1.9.

e. Engine Valve Leak

Check engine valve leakage in accordance with Section 5.2.16. Replace engine valve seal in accordance with Section 5.2.5.

f. Contamination

A large pressure drop in the HX is a good indication of contamination. Shut down and warm up the system. Clean in accordance with Section 5.5.

g. RDT Not Seated or Leaking at Seat

If some of the liquid is leaking by the cold seat of the RDT, the production will go down. A good indication is when TE-B gets colder then 5.2°K during normal operation. Be sure that there is still a gap between the RDT gland nut and the brass stop ring sleeve on the RDT. Tighten the RDT to the gland nut. This will pull the RDT down onto the seat. If this does not solve the problem remove the RDT and inspect the Teflon® O-ring.

h. Inadequate $LN_2$ Supply

Check to see if the $LN_2$ supply has is least 1.4 bar (20 psig) pressure and that $LN_2$ is being supplied to the unit.

i. Purifier Valve V616 Leaking

Shut down and determine if the system is leaking gas from high-to-low. Refer to Section 5.4.1.1.

j. Leak to Vacuum Jacket

An increase in vacuum jacket pressure is noticed while running. Contact LC Customer Service for assistance.

k. Precooler is Plugged

Precooling is on and nitrogen exhaust does not change in temperature regardless of valve V806 setting. System is contaminated. Shut down and warm up the system. Clean in accordance with Section 5.5.

l. Regulator Valve V345 Leaking High-to-Low

Shut down and determine if valve V345 is leaking across. Set valve V345 to maintain at least 16.2 bar (235 psig) on PI-33. This should be done when the flywheel is not spinning.

7. Engine Speed Slow

a. TE-A Very Cold

If TE-A is below 10°K, the engines may not be able to run slow enough to maintain 15.8 bar (230 psig) pressure. There is not enough compressor flow to maintain pressure setpoint with the minimum RPM of the flywheel. Wait to see if the temperature returns to normal. If TE-B is rising and the J-T is open, the system is contaminated. Shut down and warm up the system. Clean in accordance with Section 5.5.

b. RS Compressor Not Loaded

If the system is being run by a screw compressor, the compressor may not be loaded. Load compressor.

c. Regulator Valve V345 Setpoint Low

The pressure at PT-1 controls the speed. If the pressure drops below 15.8 bar (230 psig), the engines will slow down to maintain 15.8 bar (230 psig). Turn the valve V345 setpoint in 1/4 turn. Watch to see if PT-1 pressure rises. If so, the speed will increase. If not, return the valve V345 to its original setpoint.

8. J-T Does Not Open Automatically

a. Instrument Air Low

The J-T is a pneumatically controlled valve. The OIT may indicate that the valve is open but it isn't. Without 4.1 bar (60 psig) of supply air the valve will not function properly. Check to see if valve V306 is set for 4.1 bar (60 psig).

b. Dewar Pressure Too High (PI-308)

If the dewar pressure is too high, the J-T valve is programmed to close until the dewar pressure comes down.

c. J-T Valve in Manual Control Mode

If the J-T valve is in manual mode, it is no longer controlled by TE-A. It must be in the auto mode to be controlled automatically.

d. TE-A is Above Setpoint

TE-A controls the setpoint of the J-T valve. When the temperature goes below the TE-A setpoint the J-T valve will open.

9. Vacuum Pump Will Not Start

a. Cold Box Temperature Too Cold

The pump starts but valve V348 will not open. There is a safety built into the program so that solenoid valve V348 will close automatically when TE-B reaches 250°K. This is to prevent vacuum pump oil from cryopumping to the vacuum jacket. Therefore, the vacuum pump will not start until the TE-B raises above 250°K.

b. Fuse Blown

Replace fuse.

10. Engine Overspeeds

a. Loose Flywheel V-Belts

Tighten V-belts in accordance with CPS Spec. A3545485 located in the appendix.

11. Dewar Overpressurizes

a. RDT Return is Plugged

Remove RDT, warm up, and decontaminate in accordance with Section 5.5.

b. Valve V308 Manually Closed

Dewar over-pressurization can be caused by having valve V308 in the manual mode and closed. Return the valve to the auto mode.

c. If Running in Manual Mode, J-T Valve Open Too Much

If the J-T valve is in manual mode, it may be opened too much. Release to auto mode or reduce J-T position manually.

12. J-T Valve Open Fully, TE-B Continues to Rise

    a. Contamination

       Shut down and warm up the system. Clean in accordance with Section 5.5.

13. Low-Side Pressure Above 0.41 bar (6.0 psig) While the Engines Are Running

    a. Valve V379 Closed

       If valve V379 is closed, the excess gas in the system can not be dumped to storage. Open valve V379.

    b. Storage Pressure Equal to High-Side Pressure

       If the storage pressure equals the high-side pressure then the system can no longer send gas to the recovery storage. Wait until the system starts to call for gas and the system will automatically lower the storage pressure. The low-side will rise to 0.34 bar (5 psig) and the gas will be recovered in the gas bag.

14. Vacuum in Chamber Does Not Drop Below 100 mTorr

    a. Vacuum Pump Oil Dirty

       Review Section 5.2.19. The vacuum pump should be able to blank off below 25 mTorr. If this is not the case then the vacuum pump oil is probably dirty. Ballast the vacuum pump to clean oil or change the oil.

    b. Chamber Contains High Quantities of Moisture

       If the vacuum jacket contains moisture then pump and purge the vacuum jacket with dry Nitrogen.

    c. Leak to Vacuum Jacket

       Contact LC Customer Service for assistance.

## 6.3 PURIFIER OPERATIONAL TROUBLESHOOTING

1. Purifier Production Low

    a. Impurity of Gas Above 10 %

       With impurities greater than 10%, the system will regenerate very often. During regeneration cycles the system does not produce much liquid.

    b. Purifier Valve V615 Leaks

       Check in accordance to Section 5.4.1.1.

    c. Review Section 6.2

2. Purifier Will Not Turn On

   a. Impure Helium Pressure Too Low (PT-65)

      If the impure supply is below 31 bar (450 psig), the purifier will not turn on.

   b. Engine Temperatures are Not Satisfied

      For the purifier to turn on, TE-A has to be 23°K or lower and TE-B has to be 8°K or lower. Wait for temperatures to be achieved.

3. Purifier Continuously Regenerates on Temperature

   a. Valve V628 Not Open Enough

      If valve V628 is not open enough, then the purifier can not get enough gas to stabilize and the purifier will continue to cool down.

4. Purifier Regenerates Often

   a. High Impurity

## 6.4 ELECTRICAL TROUBLESHOOTING

1. There Isn’t Any Communication From the OIT to the PLC

   a. Cable Unplugged

2. Temperature Measurements Do Not Show Up on the OIT

   a. Cable Unplugged

   b. Check for a Loss of Power to Temperature Transmitter

**Note:** Silicon-diode temperature sensors are delicate, precision instruments and require special techniques for measuring continuity. Refer to the manufacturers' literature located in the appendix.

Do not check continuity of the system with an ohmmeter. In instances where the polarity of the diode is to be checked, forward voltage measurements should be made at a constant current of 10 μA. Do not apply a current of greater than one milliampere in the forward direction or a voltage of greater than two volts in the reverse direction. Either condition can result in permanent damage to the temperature sensor.

Use only a multimeter with a scale marked “Diode” to check the diode forward voltage. The good diode will read approximately 0.65 mV.

Refer to the manufacturer's literature located in appendix.

## 6.5 ALARMS / FAULTS

**Note**: Refer to Table 2 - 1

Alarms are generated to bring operator attention to abnormal conditions. Alarms generate an audible signal at the Operator Interface Terminal, and are displayed at the top of each page in the OIT. Alarm tone can be silenced by pressing the “**SILENCE ALARM**” control button. Alarms can be acknowledged by pressing the “**ACKNOWLEDGE ALARM**” button. New alarms that have not been acknowledged are highlighted at the top of the page.

Faults are provided and displayed on the corresponding page appropriate for the particular fault. Faults are shown in the main body of the page (below and separate from the alarm section at the top of the page). For example, a compressor shutdown fault is displayed adjacent to the compressor control button on the compressor control page. Faults, when active, are shown as highlighted displays. In general, faults require reset by touching the highlighted symbol.

# SECTION 7

# SPARE PARTS

## 7.1 ORDERING INSTRUCTIONS

This section contains the following information for the ordering of spare parts:

a. Engine / Cover Plate Assembly, Figures 7-1 through 7-10.

b. Extended Stem Valve (V308), Figure 7-11.

c. Normally Closed Actuator (V308), Figure 7-12.

d. Gas Operated Extended Stem Valves N.C., Figure 7-13.

e. Gas Operated Extended Stem Valve N.O., Figure 7-14.

f. Delivery Tube Assembly, Figure 7-15.

g. Delivery Tube Adapter, Figure 7-16.

h. Self-Sealing Couplings, Figure 7-17.

i. Model 1410 Equipment List, Table 7-1.

When ordering a part, always include the **part number**, the **description**, and **quantity** desired as well as the **serial number** and **model number** (if any) of the applicable liquefier module.

All orders should be forwarded to:

**LINDE CRYOGENICS (LC)**
**A Division of Linde Process Plants, Inc.**
6100 South Yale Avenue, Suite 1200
Tulsa, Oklahoma 74136 U.S.A.

| | |
|---|---|
| Telephone: | (918) 477-1444 or (918) 477-1200 |
| Fax: | (918) 477-1107 or (918) 477-1100 |
| E-mail: | Verna.Harrison@LPPUSA.com |

LC reserves the right to provide replacement parts that are interchangeable but not identical with the original equipment.