G3

Low Humidity Generator

User Guide

Table of Contents

1 Introduction

The RH Systems G3 Humidity Generator is a system capable of continuous, high-accuracy humidity generation over a wide range of humidity, temperature, and flow rates. The G3 design is an RHS hybrid two-pressure two-temperature system based on the fundamental two-pressure principle originally developed by NIST. The basis of this principle and its original development are discussed below.

1.1 Background of Humidity Generation

In 1948 at the U.S. National Bureau of Standards (now the National Institute of Standards and Technology), E.R. Weaver and R. Riley developed a "pressure method" for the generation and control of humidity. Their method, termed the *two-pressure principle*, was derived from measurements of temperature and pressure rather than requiring measurements of water vapor.

Using their technique, air or some other gas was saturated with water vapor at high pressure and then expanded to a lower pressure. When saturation and expansion were performed under constant-temperature conditions, the resulting relative humidity of the gas was simply the ratio of the lower pressure to the higher pressure (or at least very nearly).

Their equipment was designed for low rates of gas flow and was used under ambient temperature conditions. Their saturator was a small cylinder containing water and filled with fragments of pumice or stream-washed gravel through which the gas could be bubbled under pressure. This device was developed primarily for the calibration of electrically conductive hygroscopic films used in the measurement of water vapor in gases.

In 1951, also at the National Bureau of Standards, the two-pressure principle was the foundation on which A. Wexler and R.D. Daniels developed a new "pressure–humidity apparatus" with higher air-flow capability. Another significant improvement was the incorporation of temperature control. Developed primarily for hygrometer research and calibration, it was capable of producing atmospheres of known relative humidity from 10 %RH to 98 %RH over a fairly wide temperature range –40°C to +40 °C.

Wexler also designed and constructed a low-humidity generator based on a method termed the *two-temperature principle*. With the two-temperature principle, a stream of air or other gas is saturated with water vapor at a given temperature; then its temperature is raised to a specified higher value.

1.2 Two-temperature principle

In a two-temperature system, such as that shown in Figure 1, a stream of gas is saturated with respect to the liquid or solid phase of water at a low temperature and then warmed isobarically to a higher temperature for use. Measurements of the temperature and pressure of the cool, saturated gas stream, and in the warmer test chamber (or other point of use), are all that is required to determine the resulting humidity content of the gas stream.

Ideally, a two-temperature system exhibits no significant pressure difference between the saturator and chamber (or other point of use). Therefore, under ideal conditions, the dew point or frost point of the gas is effectively equal to the saturation temperature and may be expressed by

$T_d \approx T_s$ for $T_s \geq 0.01$ °C

$T_f \approx T_s$ for $T_s \leq 0.01$ °C

where T_d is the dew point temperature, T_f is the frost point temperature, and T_s is the saturation temperature.
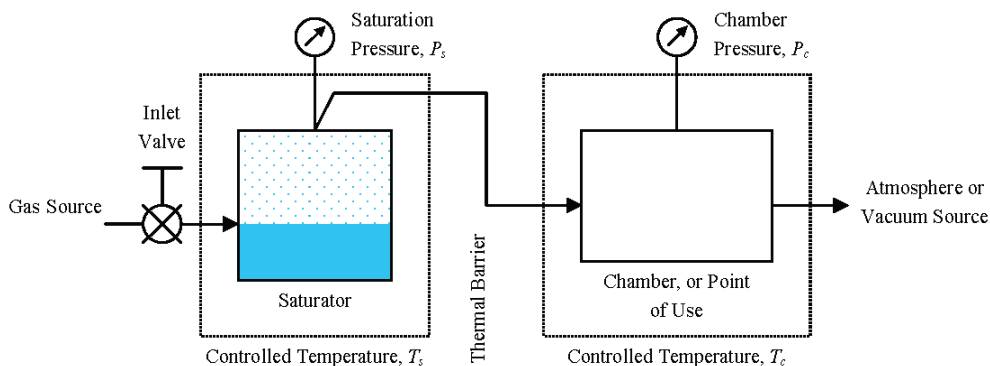
Figure 1—Simplified schematic diagram of the two-temperature principle where $P_s = P_c$.

Although dew point and frost point are easily approximated in a two-temperature system by the above equations, it is always best to measure the saturation and chamber pressures as well and then to treat the generator computationally as a combined two-pressure, two-temperature system. For this reason, all humidity equations presented in the later parts of this document are for combined two-pressure, two-temperature systems. A two-temperature system is a simplified implementation of the combined two-pressure, two-temperature principle.

1.3   The RHS hybrid two-pressure, two-temperature principle

Regardless of a generator's classification (two-pressure or two-temperature), temperature and pressure components should always be taken into account. Even though the temperatures or the pressures are *ideally* equal in a given generator design, temperature and pressure differences generally exist between the saturator and chamber.

Hybrid generators that combine the features of the two-pressure and two-temperature principles exploit the benefits of controlling temperature and pressure independently. In a hybrid generator, a stream of gas at an elevated pressure is saturated with respect to the liquid or solid phase of water at a given saturation temperature. Then the gas stream is expanded to a lower pressure and alternate temperature. Measurements of the pressure and temperature of the saturated gas stream, both at saturation and after expansion, are all that is required to determine the resulting humidity content of the gas stream.

In a hybrid generator, there are no ideal assumptions of pressure or temperature equality, as in the two-temperature principle. Thus, there is no direct simplification that can be made regarding the ideal humidity relationships between the dew or frost point temperature and saturation temperature, as with the two-temperature principle.

Since computing power is generally not a limiting factor, it is always best to use the mathematics of combined two-pressure, two-temperature principles in determining all generated parameters.
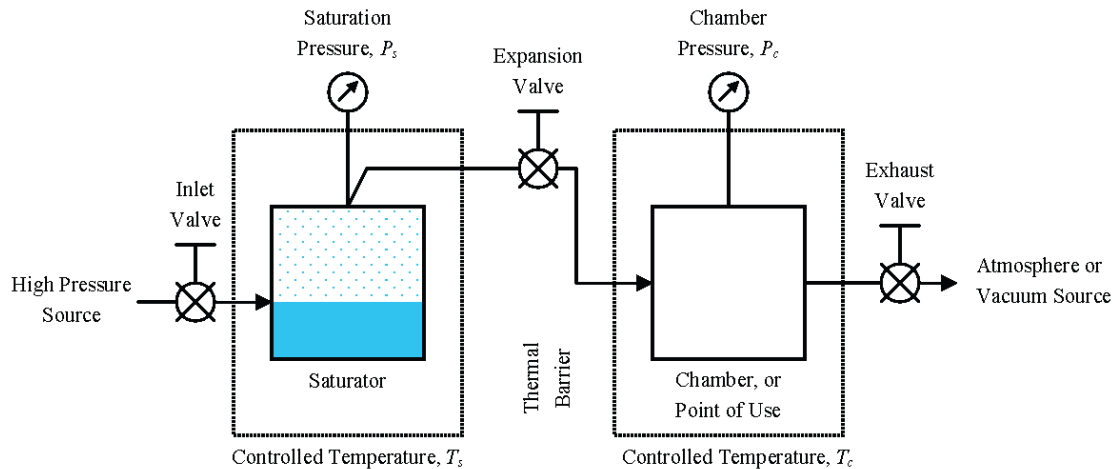
Figure 2—Simplified schematic diagram of the two-pressure, two-temperature principle where $T_s \neq T_c$ and $P_s \neq P_c$.

1.4 G3 Design

The G3, as depicted in figure 3, follows an overall design based on NIST two pressure and two temperature principles. Utilizing these principles, a stream of gas at an elevated pressure is saturated with respect to the liquid or solid phase of water at a given saturation temperature. Here, saturation temperature is the major determining factor for the quantity of water vapor admixed with the carrier gas. Pressure within the saturator is the major determining factor for the carrier gas quantity of the mixture. The humidified gas stream is then expanded to a lower pressure and warmed to an alternate temperature. Measurements of the pressure and temperature within the saturator, and the pressure and temperature following expansion (generally at the DUT), are all that is required to determine the resulting humidity content.

The G3 receives an input gas (or carrier gas) at its Gas Inlet connection on the rear panel. Gas is mechanically regulated to a manually set pressure which is displayed on the mechanical pressure gauge P_r and is also measured electronically on the air-in pressure sensor Pai. A mechanical over-pressure relief valve protects from accidental over pressure above 200 psig. Gas flows through the pressure controller which maintains, based on its setpoint, a downstream pressure within the saturator.

Depending on the mode, gas flows either through the Gen or Purge connection of the Gen/Purge valve, through the saturator, and finally to the flow controller. The flow rate of the gas leaving the Gas Outlet on the front panel is determined by the setpoint of the flow controller.

Saturator temperature is maintained by two Stirling coolers (not shown) on the top and bottom of the saturator. Heaters ae also attached there. The coolers and heaters work in tandem to provide temperature regulation of the saturator.

The saturator is a thermally controlled stacked plate unit that acts both as a heat exchanger to cool the incoming gas to saturator temperature, and as a means to allow the input gas to admix with water vapor at that same temperature.

Saturation temperature controls the partial pressure of water vapor within the saturator. The gas pressure controls the partial pressure of the background gas. The ratio of the two partial pressures (water vapor

pressure to background gas pressure) determines the mixing ratio and ultimately the humidity content of the exit gas.
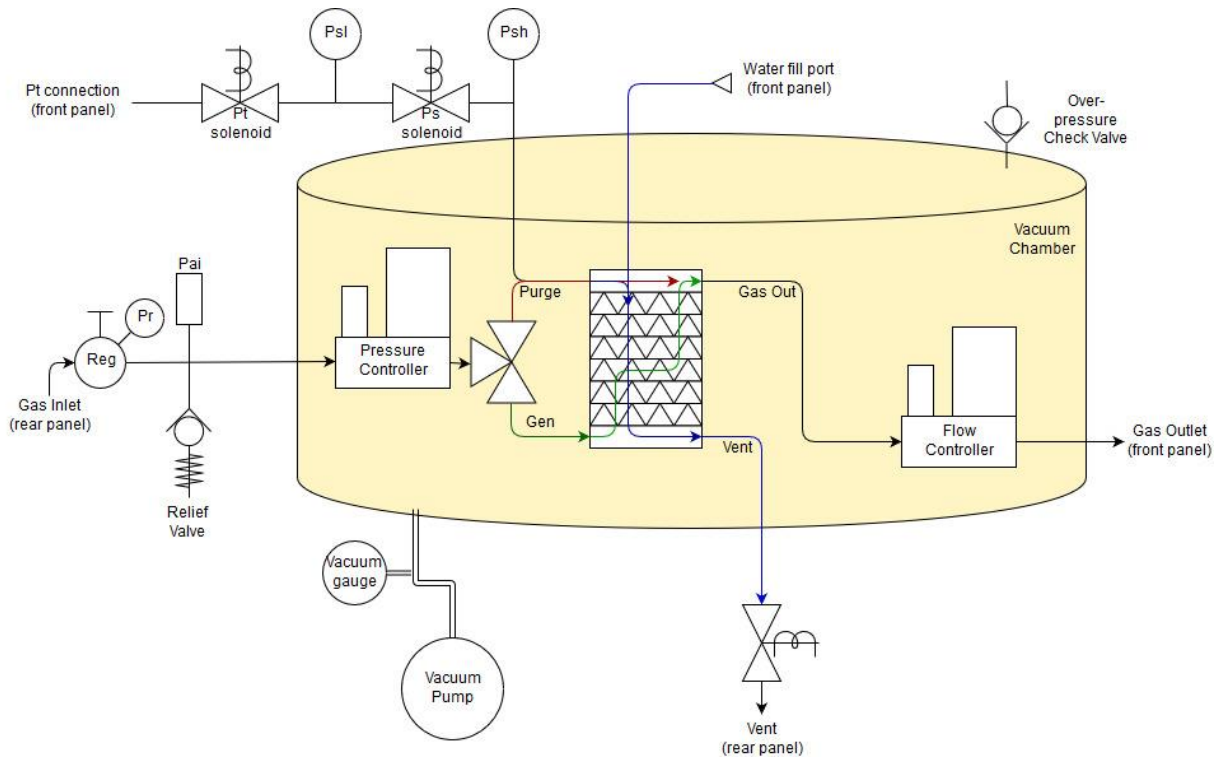

Figure 3—Pneumatic diagram of the G3 two-pressure, two-temperature system.

The electronic controls provide for automatic humidity generation based on desired humidity setpoints. The operator adjusts the desired exit flow rate setpoint and the desired dew point in the exit gas. The embedded computer control provides the computations needed to create the saturator temperature and saturator pressure PID control setpoints to achieve the desired gas dewpoint and flow rate. Utilizing appropriate mathematical algorithms within custom software programming, automated setpoint determination is employed to achieve and maintain any humidity value desired within the range of capability of the humidity generator. Although automatically determined by the computer, the operator may over-ride specific setpoints of temperature and pressure, allowing for customized testing functionality. The operator also has full control over the exit flow rate setpoint. While not controlled, both the temperature and pressure of the gas stream at the DUT are monitored, and appropriate adjustments are made to ensure the setpoints of saturator temperature and pressure are adjusted accordingly to maintain steady humidity control at the DUT.

The G3 has a unique design based on the compact FPSC Stirling cooler units utilized for saturator cooling. Typical outlet temperatures needed from the Stirling coolers are +10 °C to as low as -100 °C.

Uncertainty of the pressure measurements plays an important role in the accuracy of generated humidity. The humidity in the outlet stream is based on the absolute outlet pressure and on the ratio of saturator to outlet (DUT) pressure. In addition, when the saturator pressure is low and within the range of the lower pressure sensor, this low range sensor is utilized for both the saturator and test pressures on a time-shared basis. This time-sharing of a single pressure transducer eliminates problems normally associated with differences in zero-drift between separate transducers.

The saturator input pressure is maintained to the desired value by the pressure controller. As there may be a slight pressure drop as the gas passes through the saturator, the saturator pressure used within humidity computations is measured by a pressure sensor nearest the saturator exhaust. Differences between the controlled saturator inlet pressure and the resulting saturator outlet pressure are used to adjust the saturator inlet pressure setpoint to compensate for the pressure drop. This ensures the saturator pressure nearest the saturator outlet reaches desired saturator pressure setpoint.

Uncertainty of the saturator temperature measurement is very important to the humidity in the exit gas stream. All generated humidity parameters such as dew point and frost point temperature are dependent on saturator temperature, while other values such as %Relative Humidity are dependent also on temperature of the gas at the DUT. In the case where both the saturator and DUT temperatures are required, uncertainty of both temperatures must be considered.
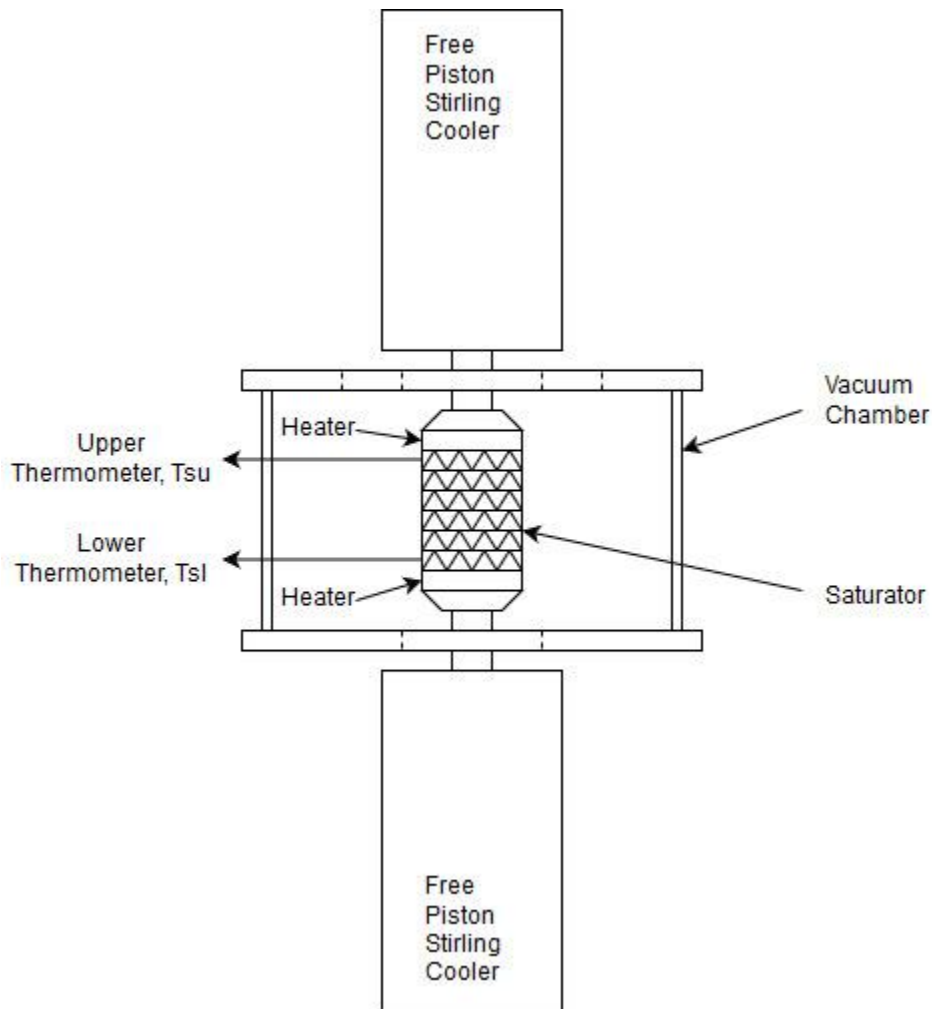
Figure 4—Thermal diagram of the G3 two-pressure, two-temperature system.

Saturator temperature is maintained by control of the Stirling coolers attached to the inlet and outlet plates of the saturator, and by heaters attached in the same locations as depicted in figure 4. The coolers and heaters work in tandem to produce stable temperatures at both the saturator inlet and outlet.

The vacuum chamber surrounding the saturator and other components serves both as a thermal isolator for the saturator, and as a barrier to prevent permeation of water vapor into the gas stream.

1.5 **Common Defining Equations**

The following equations of R. Hardy for saturation vapor pressure, enhancement factor, and temperature (from saturation vapor pressure) are common and fundamental to most of the humidity calculations presented here.

1.5.1 Saturation Vapor Pressure over Water

Saturation vapor pressure over *water* at a given ITS-90 temperature in the range –100 °C to +100 °C is defined by the formula

$$e = exp\left(\sum_{i=0}^{6} g_i\, T^{i-2} + g_7\, ln\, T\right) \tag{1}$$

where e is the saturation vapor pressure (in Pascals) over liquid water in the pure phase

        T is the temperature in Kelvin

and
- $g_0 = -2.8365744 \cdot 10^3$
- $g_1 = -6.028076559 \cdot 10^3$
- $G3 = 1.954263612 \cdot 10^1$
- $g_3 = -2.737830188 \cdot 10^{-2}$
- $g_4 = 1.6261698 \cdot 10^{-5}$
- $g_5 = 7.0229056 \cdot 10^{-10}$
- $g_6 = -1.8680009 \cdot 10^{-13}$
- $g_7 = 2.7150305$

1.5.2 Saturation Vapor Pressure over Ice

Saturation vapor pressure over *ice* at a given ITS-90 temperature in the range –100 °C to 0.01 °C is defined by the formula

$$e = exp\left(\sum_{i=0}^{4} k_i\, T^{i-1} + k_5\, ln\, T\right) \tag{2}$$

where e is the saturation vapor pressure (in Pascals) over ice in the pure phase

        T is the temperature in Kelvin

and
- $k_0 = -5.8666426 \cdot 10^3$
- $k_1 = 2.232870244 \cdot 10^1$
- $k_2 = 1.39387003 \cdot 10^{-2}$
- $k_3 = -3.4262402 \cdot 10^{-5}$
- $k_4 = 2.7040955 \cdot 10^{-8}$
- $k_5 = 6.7063522 \cdot 10^{-1}$

1.5.3 Enhancement Factor

The "effective" saturation vapor pressure over water or ice in the presence of other gases differs from the ideal saturation vapor pressures given in Equations 1 and 2. The effective saturation vapor pressure is related to the ideal by

$$\acute{e} = e \cdot f \qquad (3)$$

where $\acute{e}$ is the "effective" saturation vapor pressure

             e is the ideal saturation vapor pressure (as given in Equation 1 or 2)

and f is the enhancement factor

The enhancement factor, for an air and water-vapor mixture, is determined at a given temperature and pressure from the formula

$$f = exp\left[\alpha\left(1 - \frac{e}{P}\right) + \beta\left(\frac{P}{e} - 1\right)\right] \qquad (4)$$

with $\alpha = \sum_{i=0}^{3} a_i\, T^i \qquad (5)$

and $\beta = exp\left(\sum_{i=0}^{3} b_i\, T^i\right) \qquad (6)$

where P is the total pressure in the same units as e

           T is temperature in Kelvin

and a_i, b_i depend on temperature range and are given as

for water:

223.15 K to 273.15 K (–50 °C to 0 °C)	273.15 K to 373.15 K (0 °C to 100 °C)
$a_0 = -5.5898101 \cdot 10^{-2}$	$a_0 = -1.6302041 \cdot 10^{-1}$
$a_1 = 6.7140389 \cdot 10^{-4}$	$a_1 = 1.8071570 \cdot 10^{-3}$
$a_2 = -2.7492721 \cdot 10^{-6}$	$a_2 = -6.7703064 \cdot 10^{-6}$
$a_3 = 3.8268958 \cdot 10^{-9}$	$a_3 = 8.5813609 \cdot 10^{-9}$
$b_0 = -8.1985393 \cdot 10^{1}$	$b_0 = -5.9890467 \cdot 10^{1}$
$b_1 = 5.8230823 \cdot 10^{-1}$	$b_1 = 3.4378043 \cdot 10^{-1}$
$b_2 = -1.6340527 \cdot 10^{-3}$	$b_2 = -7.7326396 \cdot 10^{-4}$
$b_3 = 1.6725084 \cdot 10^{-6}$	$b_3 = 6.3405286 \cdot 10^{-7}$

for ice:

173.15 to 223.15 K (–100 °C to –50 °C)	223.15 to 273.15 K (–50 °C to 0°C)
$a_0 = -7.4712663 \cdot 10^{-2}$	$a_0 = -7.1044201 \cdot 10^{-2}$
$a_1 = 9.5972907 \cdot 10^{-4}$	$a_1 = 8.6786223 \cdot 10^{-4}$
$a_2 = -4.1935419 \cdot 10^{-6}$	$a_2 = -3.5912529 \cdot 10^{-6}$
$a_3 = 6.2038841 \cdot 10^{-9}$	$a_3 = 5.0194210 \cdot 10^{-9}$
$b_0 = -1.0385289 \cdot 10^{2}$	$b_0 = -8.2308868 \cdot 10^{1}$
$b_1 = 8.5753626 \cdot 10^{-1}$	$b_1 = 5.6519110 \cdot 10^{-1}$
$b_2 = -2.8578612 \cdot 10^{-3}$	$b_2 = -1.5304505 \cdot 10^{-3}$
$b_3 = 3.5499292 \cdot 10^{-6}$	$b_3 = 1.5395086 \cdot 10^{-6}$

1.5.4 Temperature from Saturation Vapor Pressure

Equations 1 and 2 are easily solved for saturation vapor pressure over water or ice for a given saturation temperature. However, if vapor pressure is known and temperature is the unknown desired quantity, the solution immediately becomes complicated and must be solved by iteration. For ease of computation, the following inverse equation is provided. This equation is generally used to find the dew point or frost point temperature when the vapor pressure of a gas has been determined. When vapor pressure is known, use the water coefficients to obtain the dew point and use the ice coefficients to obtain the frost point.

$$T = \frac{\sum_{i=0}^{3} c_i (\ln e)^i}{\sum_{i=0}^{3} d_i (\ln e)^i} \tag{7}$$

where T is the temperature in kelvin

and e is the saturation vapor pressure in pascals

with coefficients

for water:
$$c_0 = \quad 2.0798233 \cdot 10^2$$
$$c_1 = -2.0156028 \cdot 10^1$$
$$c_2 = \quad 4.6778925 \cdot 10^{-1}$$
$$c_3 = -9.2288067 \cdot 10^{-6}$$

$$d_0 = \quad 1$$
$$d_1 = -1.3319669 \cdot 10^{-1}$$
$$d_2 = \quad 5.6577518 \cdot 10^{-3}$$
$$d_3 = -7.5172865 \cdot 10^{-5}$$

for ice:
$$c_0 = \quad 2.1257969 \cdot 10^2$$
$$c_1 = -1.0264612 \cdot 10^1$$
$$c_2 = \quad 1.4354796 \cdot 10^{-1}$$
$$c_3 = \quad 0$$

$$d_0 = \quad 1$$
$$d_1 = -8.2871619 \cdot 10^{-2}$$
$$d_2 = \quad 2.3540411 \cdot 10^{-3}$$
$$d_3 = -2.4363951 \cdot 10^{-5}$$

1.6 Humidity Equations

The following equations are used in the G3 to calculate various humidity parameters. These equations are not approximations, but rather account for the temperature differences between the saturator and chamber, and the non-ideal behavior of water vapor when admixed with air or other gases.

1.6.1 Relative Humidity

Percent relative humidity is the ratio of the amount of water vapor in a gas to the maximum amount possible at the same temperature and pressure. For two-pressure, two-temperature systems, it is defined by the equation

$$RH = \frac{P_c}{P_s} \cdot \frac{e_s'}{e_c'} \cdot 100 \tag{8}$$

which then expands to

$$RH = \frac{P_c}{P_s} \cdot \frac{f_s}{f_c} \cdot \frac{e_s}{e_c} \cdot 100 \tag{9}$$

where P_c is the absolute chamber pressure

P_s is the absolute saturation pressure

f_c is the enhancement factor at chamber temperature and pressure

f_s is the enhancement factor at saturator temperature and pressure

e_c is the saturation vapor pressure at chamber temperature

and e_s is the saturation vapor pressure at saturator temperature.

1.6.2 Dew Point Temperature

Dew point temperature is the temperature to which a gas must be cooled to initiate condensing water vapor in the form of dew (note that dew point temperature can exist above or below 0°C). Dew point temperature is obtained with the following iterative steps.

a. Make an educated guess at the dew or frost point enhancement factor f_d. Setting $f_d = 1$ is a suitable first guess.

b. Next, compute the dew or frost point vapor pressure of the gas with the formula

$$e_d = e_s \cdot \frac{f_s}{f_d} \cdot \frac{P_c}{P_s} \qquad (10)$$

c. Use the dew or frost point vapor pressure e_d determined in the previous step, along with Equation 7 for water, to compute T. Call this value the dew point temperature T_d.

d. Use the dew point temperature T_d, chamber pressure P_c, and Equation 4 for water to compute the dew or frost point enhancement factor f_d.

e. Converge to the proper dew point temperature T_d by repeating steps b through d several times, as necessary.

1.6.3 Frost Point Temperature

Frost point temperature is the temperature to which a gas must be cooled to begin condensing water vapor in the form of frost or ice. Frost point exists only at temperatures below freezing. Frost point is obtained with the following iterative steps.

a. Make an educated guess at the dew or frost point enhancement factor f_d. Setting $f_d = 1$ is a suitable first guess.

b. Next, compute the dew or frost point vapor pressure of the gas with the formula

$$e_d = e_s \cdot \frac{f_s}{f_d} \cdot \frac{P_c}{P_s} \qquad (11)$$

c. Use the dew or frost point vapor pressure e_d determined in the previous step, along with Equation 7 for ice, to compute T. Call this value the frost point temperature T_f.

d. Use the frost point temperature T_f, chamber pressure P_c, and Equation 4 for ice to compute the dew or frost point enhancement factor f_d.

e. Converge to the proper frost point temperature T_f by repeating steps b through d several times, as necessary.

1.6.4 Vapor Concentration, PPMv

Vapor-concentration, traditionally referred to as parts per million by volume (ppm$_v$), is a ratio relating the number of moles of water vapor to the number of moles of the remaining constituents in the gas (the dry gas component). Once established by the following formula, the vapor concentration is insensitive to further changes in pressure or temperature, provided there is no subsequent condensation.

$$\text{vapor concentration } \frac{f_s \cdot e_s}{P_s - f_s \cdot e_s} \cdot 10^6 \text{ } \mu\text{mol/mol} \tag{12}$$

1.6.5 Vapor Concentration, PPBv

Vapor-concentration, traditionally referred to as parts per billion by volume (ppb$_v$), is a ratio relating the number of moles of water vapor to the number of moles of the remaining constituents in the gas (the dry gas component). Once established by the following formula, the vapor concentration is insensitive to further changes in pressure or temperature, provided there is no subsequent condensation.

$$\text{vapor concentration } = \frac{f_s \cdot e_s}{P_s - f_s \cdot e_s} \cdot 10^9 \text{ } \text{nmol/mol} \tag{13}$$

1.6.6 Humidity Ratio

Humidity ratio w is defined as the mass of water vapor to the mass of the dry gas; it is computed with the formula

$$w = \frac{M_w \cdot f_s \cdot e_s}{M_g (P_s - f_s \cdot e_s)} \text{ } \text{g/g} \tag{14}$$

where M_w is the molecular weight of water vapor, 18.02

M_g is the molecular weight of the carrier gas (28.9645 for air).

Humidity ratio may also be computed and expressed in grams per kilogram and micrograms per gram. When expressed in micrograms per gram, humidity ratio is traditionally referred to in parts per million by weight (ppm$_w$).

1.6.7 Absolute Humidity

Absolute humidity d_v is defined as the mass of water vapor to the unit volume of humidified gas and is computed with the formula

$$d_v = \frac{M_w}{R \cdot T_c} \cdot \frac{f_s \cdot e_s \cdot P_c}{P_s} \text{ } \text{g/m}^3 \tag{15}$$

where R is the molar gas constant 8.31472

1.6.8 Specific Humidity

Specific humidity q is defined as the mass of the water vapor to the total mass of the gas mixture and is computed with the formula

$$q = \frac{M_w \cdot f_s \cdot e_s}{M_g(P_s - f_s \cdot e_s) + M_w \cdot f_s \cdot e_s} \text{ g/g} \tag{16}$$

2 System Identification and Component Location

The RH Systems G3 Humidity Generator is comprised of multiple components that work in conjunction to generate accurate humidity in a carrier gas. The location and function of these major components are discussed below.

2.1 Front panel

Power switch, fill port, temp probe connections, ambient pressure measurement port, and gas outlet connections are all contained on the G3 front panel.
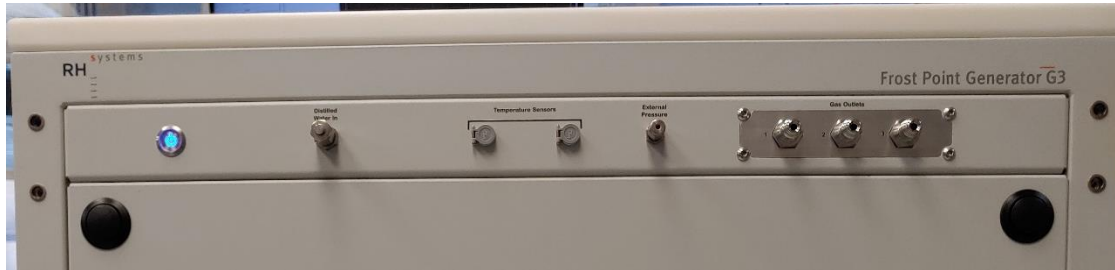
2.2 Computer, Monitor, Keyboard, and expansion ports for USB and RS-232 connections

The G3 System comes with a built-in VESA mount PC. The PC is internally mounted within the rear of the G3 (or on the back of the monitor). The PC runs RHS Control software which is used for G3 control and data collection.

The interface is optimized for a touch screen experience which is provided by the touchscreen monitor. The monitor is mounted to a swing arm which may be attached to any of the system's four corners.

In the standard configuration, all required electrical connections to the monitor (power, USB, and HDMI) are provided through a monitor connection panel at the upper left rear side of the G3.

Although not required for operation, some may prefer a physical keyboard and mouse which may be connected via USB. A wireless keyboard/mouse combination is included with the system and contains the mating USB wireless adapter.

An I/O panel is located near the front left of the G3 and provides multiple RS-232 and USB ports. These I/O ports connect to the PC and are useful for connection of accessories and/or measurement instruments. On some earlier generation systems, the O/I panel is made of externally mounted RS-232 and USB adapters.
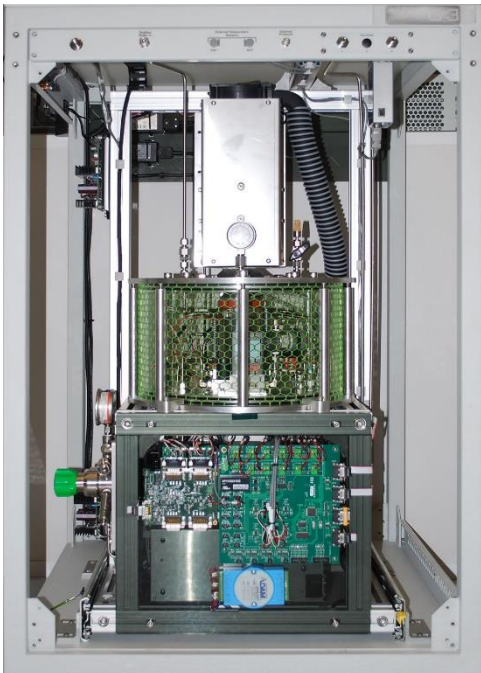

Left side panel

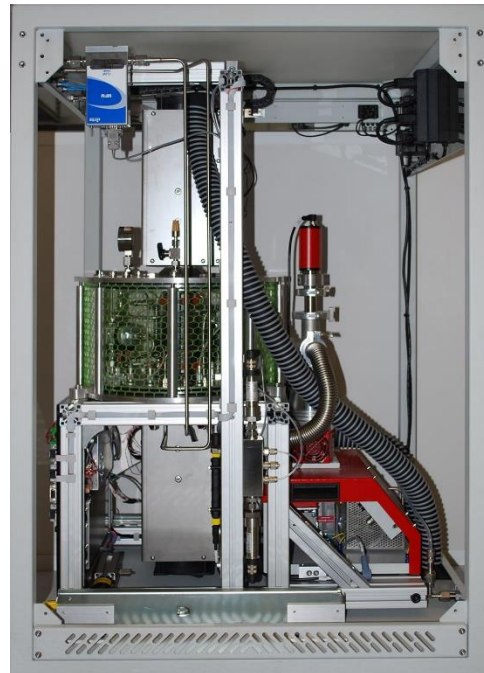Monitor connection panel   I/O panel

2.3 Inside view, cover panels removed

Rear view without panel
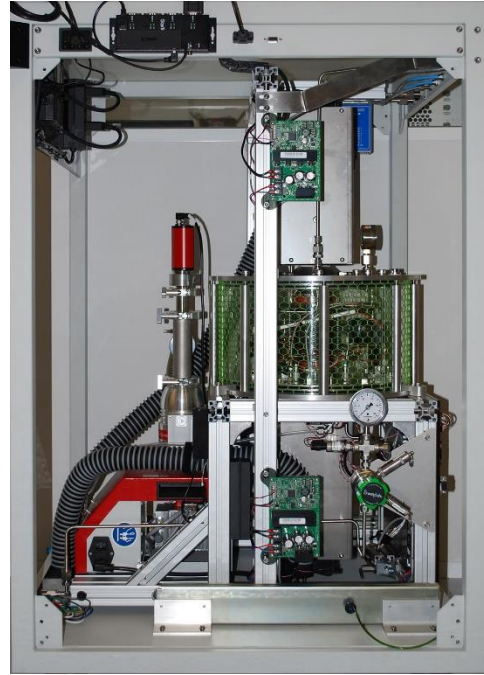
Left view without panel

Front view without panel

Right view without panel

2.4 **Major System Components**

1	Humidity Generator Support Frame
2a	Top Free Piston Stirling Cooler
2b	Bottom Free Piston Stirling Cooler
3	Vacuum Chamber
4	Saturator (Plate Stack Assembly)
5	Saturator Pressure Controller Valve
6	Saturator Exit Gas Flow Controller Valve
7	Vacuum pump
8	Vacuum chamber wall
9	Top Vacuum Flange Part A
10	Top Vacuum Flange Part B
11	Bottom Vacuum Flange
12	Generate & Purge - 3 Way Valve
13	Gas Inlet Pressure Regulator Assembly
14	Pressure Sensor Manifold Assembly

3 Installation

3.1 **Facility Requirements**

Prior to the arrival of your G3 instrument, preparations should be made to ensure you have the proper facilities available at the desired instrument location. The G3 will require the following for initial connection and continuous service.

3.1.1 Power

100-240 VAC, single phase, 15A, 50/60 Hz. The system uses a standard local power plug.

3.1.2 Compressed Gas Supply

Supply gas should meet the following specifications:

Supply pressure: approximately 35 to 250 psi (250 kPa to 1.7 MPa), regulated prior to the G3
Flow rate: up to 10 l/min (depending on model) while maintaining regulated pressure
Pressure dew point: -95°C or lower when measured at the inlet pressure
Oil-free: No mist or oil vapors
Connection: ¼" VCR fitting (adapters to Swagelok tube fittings available)

Recommend gas supply may be achieved via gas outlet from an N_2 gas cylinder or the 'Gas Use' outlet from a liquid N_2 Dewar.

3.1.3 Distilled Water

Initial supply: ~1 liter of distilled water
Connection: ¼" Swagelok fitting or ¼" VCR fitting (adapters available)

Use distilled water only. Use of deionized water is not recommended as it tends to be chemically aggressive to stainless steel and other metals and may cause pitting of the saturator. The G3 requires enough distilled water (<100 mL) for its initial fill of the pre-saturator, then a small on-going supply for continuous humidity generation.

3.1.4 Floor Space

The G3 requires a floor space of approximately 1.5 m x 2 m. This allows adequate space to the sides and rear of the unit for operation, service, and utility connections. The G3 is supplied on rolling casters for ease of positioning. The casters have integral leveling feet. Once rolled to position, the feet may be lowered to fix the position and level the instrument if needed.
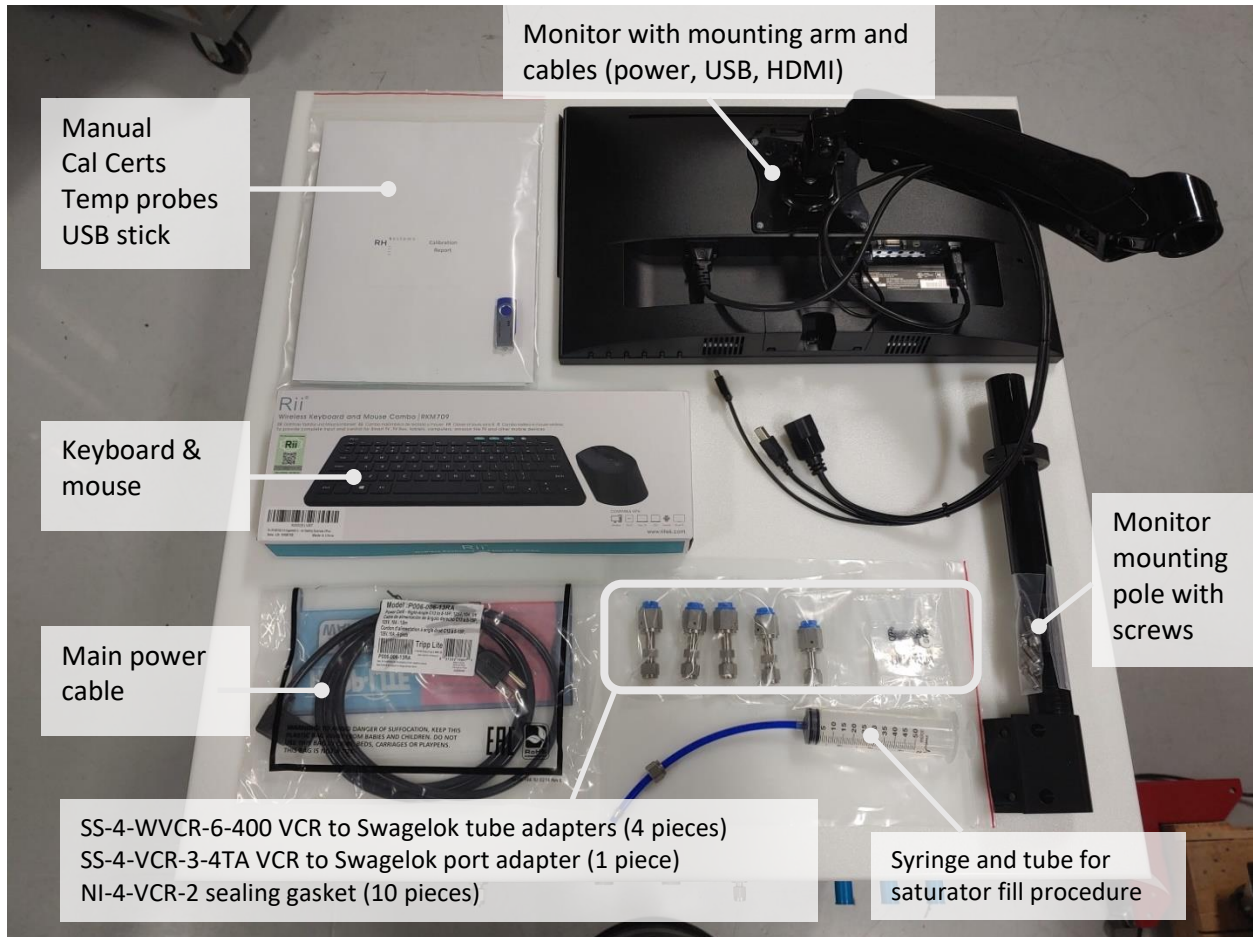
3.2 Uncrating

The G3 is shipped in a padded wooden shipping container. The front door doubles as a ramp to remove the G3 more easily from the crate. The G3 casters allow it to be rolled out of the crate, down the ramp, and onto the floor. **Use at least 2 people while uncrating the G3.**

1. Position the crate in an open area using a pallet jack or forklift.

2. Leave room at the front (about 3 meters minimum for the front door to lower downward and the G3 to be removed from the crate).

3. Cut the banding straps from around the crate.

4. Unhook the metal latches near the top of the door.

5. Lower the door. It becomes a ramp.

6. Remove the foam pieces attached to the ramp.

7. Remove the square foam piece between the G3 top and the crate's shelf.

8. Pulling first from the G3 bottom, slide the G3 out from the crate.

9. Roll it carefully down and off the ramp. Use caution at the bottom of the ramp so the G3 does not drop quickly to the ground.

10. Roll the system to the desired location.

11. Remove all packages and components stored in the upper compartment of the crate. These packages are accessory components needed for initial installation such as the computer, monitor, power supplies, and power cords.

3.3 Install Monitor (and keyboard/mouse if desired)

After uncrating the instrument and positioning it roughly where it will operate, install the monitor and associated parts.

Monitor with mounting arm and cables (power, USB, HDMI)

Manual
Cal Certs
Temp probes
USB stick

Keyboard & mouse

Monitor mounting pole with screws

Main power cable

SS-4-WVCR-6-400 VCR to Swagelok tube adapters (4 pieces)
SS-4-VCR-3-4TA VCR to Swagelok port adapter (1 piece)
NI-4-VCR-2 sealing gasket (10 pieces)

Syringe and tube for saturator fill procedure

1. Start by installing monitor mounting pole on the left rear corner of the instrument using the four supplied screws. Mounting holes are provided on each corner for flexibility, but the suggested mounting location is the left rear corner.

2. Slide the mounting end of the monitor arm over the top of the mounting pole and slide the arm down over the pole.

3. Plug the Power, USB, and HDMI monitor cables into their mating connectors on the G3 Monitor Panel.

4. Remove the wireless keyboard and mouse dongle from the inside of the mouse and plug it into one of the available USB ports on the G3 Monitor Panel.

Left
Rear
Corner

5. Turn the mouse and the keyboard on (their switches are generally found underneath them).

3.4 Remove front, back, and side panels

The system has removable panels allowing access to internal components.

1. Press the black button. A spring-loaded knob pops out.

2. Twist the knob then pull to remove the panels.

Note: Some earlier models use thumbscrews rather than spring loaded knobs. Remove the 4 thumb screws to remove the panel.

3.5 Unlocking Vacuum Pump

The vacuum pump has been locked down for transportation. Prior to operation, the locking nuts must be undone.

1. Using a 5/16" or 8mm wrench, completely loosen the nut shown and lock it in the upward position against the top of the screw. However, do not remove the screw. This allows the bar to ride freely on top of the spring.

2. There is an identical nut on the opposite side of the pump. Loosen and lock that nut in the exact same manner.

3.6   **Removing Shipping Bracket**

1. There is a bracket installed above the vacuum chamber with a label:
   "**SHIPPING SUPPORT BRACKET – REMOVE BEFORE OPERATION**"

2. Remove the 2 screws and any associated spacers between the bracket to the upper Stirling cooler using a 1/8" or 3mm hex key.
   a. The screw on the right side of the Stirling cooler is hidden by a large black/gray striped hose connected to the Stirling fan. Unplug this hose from the fan outlet fitting to access the screw. Remember to reinstall the hose after removing the screw from the support bracket.

3. Using a 6 mm hex key, remove the 4 screws at the back of the shipping bracket. Remove the bracket from the G3.
4. Save the bracket, screws, and washers for future shipping of the G3.
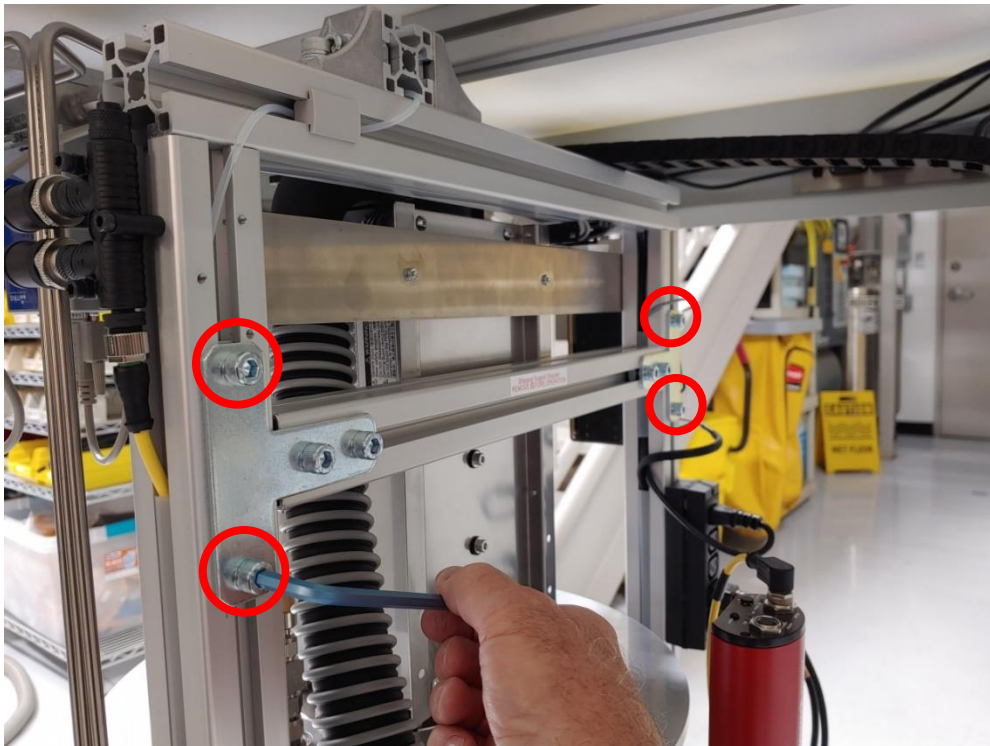
3.7 Back Panel Gas Connections

1. Connect a short tube or hose to the **Vent** connector. Place a small tray under the tube to catch occasional water droplets. Alternatively, you may run a tube to a floor drain. VCR gaskets and a VCR to ¼" Swagelok adapter have been provided for connecting to any ¼" tube.

Back panel   NI-VCR-4   SS-WVCR-6-400
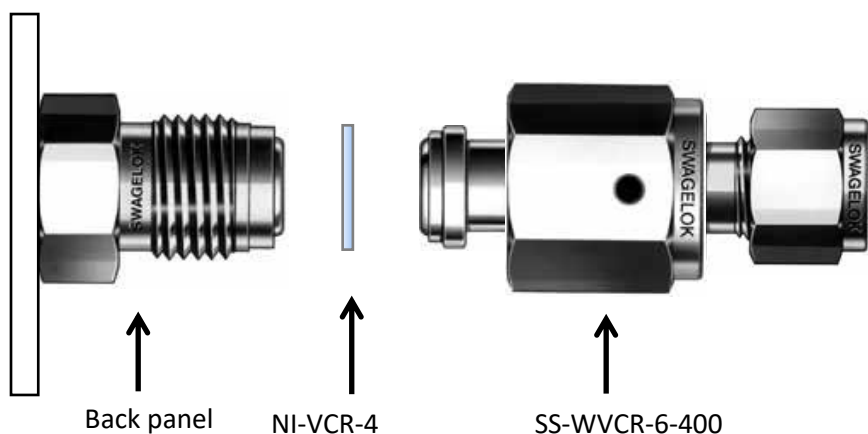
To properly make VCR connections:

➢ Install VCR gasket, NI-VCR-4
➢ Finger tighten the VCR nut onto the threaded gland at the back panel
➢ Using a ¾" or 19mm wrench, tighten the VCR nut **1/8 turn**

3.8 Adjusting Pressure Regulator

Turn on your gas supply and set the regulator for an indicated value between about 30 and 100 psi. When setting the regulator, it is best to set it to a value lower than your incoming pressure. For example, if you have only 50 psi input pressure, try setting the regulator no higher than about 45 psi. This ensures the G3 has enough headroom to properly regulate the incoming gas.

3.9   Leveling Vacuum Chamber

A reference bubble level is applied to the top of the vacuum chamber. Each caster wheel on the bottom of the G3 has a rotating knob that lowers an adjustable pad onto the ground for leveling purposes. If more than ½ of the bubble lies outside the center ring, adjust the leveling pads on the casters to bring it back into level so the bubble is close to center.

3.10 **Checking Vacuum Chamber Supports**

Prior to initial operation, the vacuum chamber support bars should be checked for proper adjustment. Inspect the 8 adjustable support bars around the outside of the vacuum chamber. Ensure they have not vibrated loose during shipping. If they are loose, or have fallen out, ensure they are properly in place and LOOSELY adjust them with FINGERS ONLY by rotating them until they JUST TOUCH both top and bottom of the vacuum chamber. They will become tight once the vacuum chamber is evacuated.

The system generally arrives with at least 5 inHg vacuum. If the system arrived with insufficient vacuum, please contact RH Systems for further instructions before proceeding.

Full Vacuum

No Vacuum
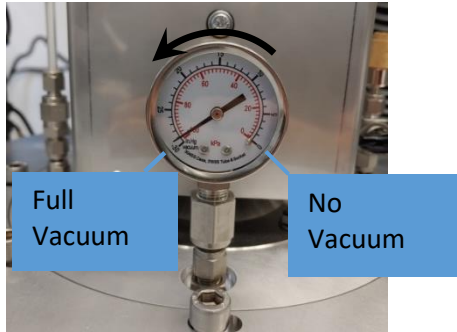
3.11 **Connecting A/C Power**

1. Using the supplied C13 power cable (or one you've sourced locally), plug the power cord into the back panel **Power** receptacle. Plug the other end into your AC power source. AC power requirements are identified in 3.1.1.

2. The switch in the power receptacle is an over-current circuit breaker for safety. Prior to operation, this circuit breaker must be turned ON. To do so, toggle it to the **I** position. This makes the AC circuit inside the system live, but the G3 will not fully energize until the main power switch on the front panel is also enabled.

Proper grounding is important for safe operation of the G3. Please ensure that the earth connection of your AC power source is sound.

4 Quick Start

Before proceeding, ensure that the system has already been connected and prepared as outlined in section 3.

4.1 Power On

1. Ensure the main circuit breaker switch at the back panel is turned on.

2. Press the ⏻ switch on the front panel. The switch will illuminate, and the system will energize.

The PC and monitor will start up, load Windows, and auto-launch the G3's **RHS Control** program.

4.2 Introduction to RHS Control

RHS Control is a PC program (available on Windows and Linux) which allows for operation of the G3 system. Operation may be manual, through direct entry of desired setpoints, or automatically, through a series of preprogrammed, user selectable setpoints and times. The short sequence that follows will guide you quickly through a successful frost point generating session.

4.2.1 Connection Window

The connection window automatically appears when RHS Control is launched. If the RHS Control program did not auto-load, initiate **RHS Control** by double-clicking its icon. The program loads and presents you with a Devices connection window.


It scans initially for any connected devices and shows them in a list. Find the G3 in the list and double click it to connect. If the G3 was the only device in the list, the window will automatically close.

The supplied G3 monitor is a touch screen. You may use a mouse to point and click, or you may touch the screen location with your finger. Either method is valid. If the Connection window is still open after connecting to the G3, close the window using the Close button.
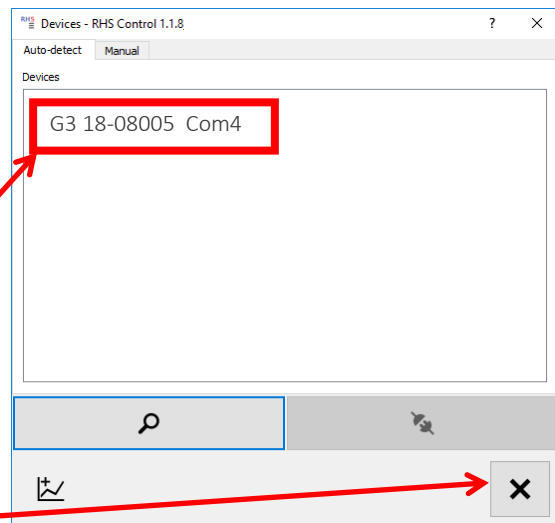
4.2.2 Control Window

Once the G3 is connected, its control window appears. From this window, it is possible to enter various setpoints of humidity, pressure, temperature, and flow as well as enable/disable vacuum and cooling functions. It also allows for operation modes of **Generate**, **Purge**, **Fill**, and **Vent**. This is the main window used to interact with the G3.
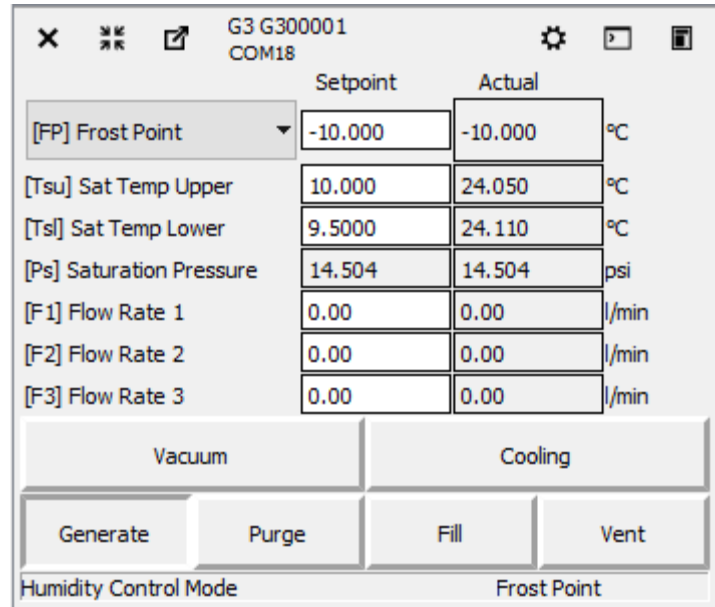
4.3   Initialize Vacuum

Prior to cooling the saturator, it is important that its surrounding chamber be evacuated. Evacuation removes water vapor from around the saturator and provides for a high degree of thermal isolation. Both are highly desirable benefits/requirements for proper humidity generation.

To initiate the vacuum sequence, press the **Vacuum** button. The vacuum pump will start (you'll likely hear a quiet pumping/whirring sound). The Vacuum button will also depress as shown within a few seconds to indicate that the action was taken.
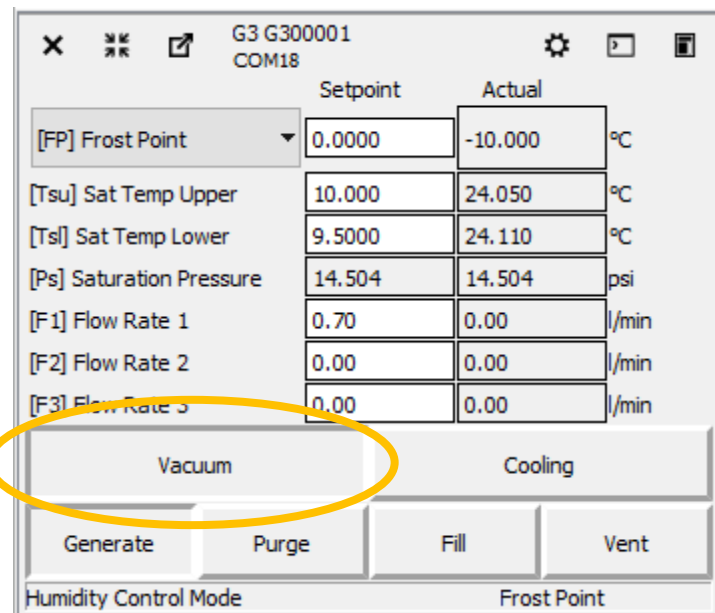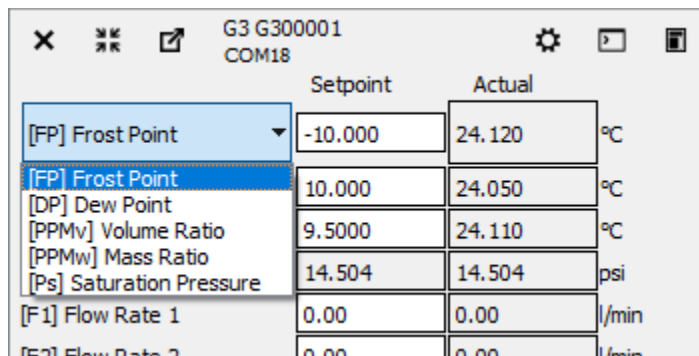

The mechanical vacuum gauge, located on the top front of the vacuum chamber, should begin to indicate the presence of vacuum (the needle will begin moving counterclockwise toward the 30 inHg dial position).

4.4 Purge

If you are following this Quick Start procedure, the system has likely been off for at least a short period of hours, days, or more. In this case, the internal gas path is possibly wet and requires a drying out period before suitable results may be generated. To assist in this dry out, the system may be operated in a Purge mode. Purge mode allows dry input gas to bypass the saturator and dry the components and tubing following the saturator. It will also purge any instruments that are connected to any of the three output ports. Purging the tubing, connections, and instruments following the saturator removes unwanted water, water vapor, and condensation that could adversely affect the generated or measured humidity. Before initial humidity generation, or before cooling the saturator, purge the G3.
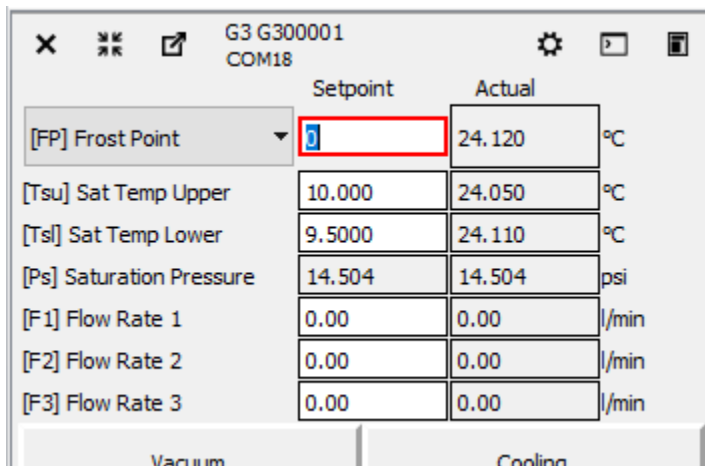
a) Using the drop-down selector as shown, select **[FP] Frost Point** as the humidity control mode.

b) Enter a Frost Point setpoint value of 0 °C. The field is bordered in red during entry. Pressing ENTER causes the field to border in yellow momentarily while the data is validated and sent to the G3. The new setpoint will update within a few seconds once read back from the control system.


c) Remove covers from the Gas Outlet fittings located at the upper right corner of the G3. Connect test devices to these ports if desired. Note the picture has devices connected to ports 1 and 3 which correspond to **Flow Rate 1** and **Flow Rate 3** of the Control Window. Since purge flow also passes through these ports and through any connected devices, it might be best to wait until the system has been purging for a while before connecting other instrumentation.

d) On the Control Window, set flow rates for each of the gas outlets. While purging, flow rates between 0.2 and 1.0 l/min are generally considered reasonable.

e) Ensure the system is in Purge mode (the Purge button is pressed in). If it is Generate mode, press the **Purge** button to switch it to Purge mode.
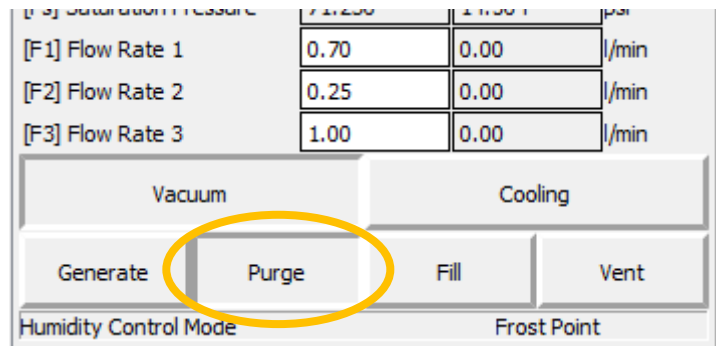
f) Press the **Cooling** button to enable saturator temperature control. Cooling function requires adequate vacuum (to a level below 1E-4 psi) before the Stirling coolers will begin to operate. The minimum level of vacuum required is generally achieved in less than 30 minutes.
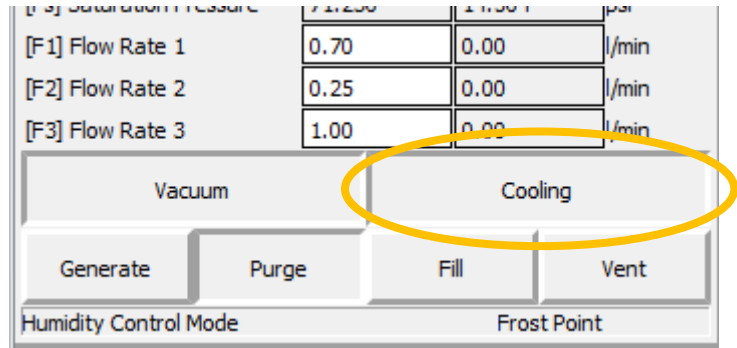
g) After running for a few hours, change the Frost Point setpoint to a lower value, such as -50 °C to allow the saturator to cool and cause the water to freeze. Notice that the Upper and Lower Sat Temperature setpoints compute automatically.

4.5   Generate

After allowing adequate purge time of approximately 1 hour or more, the system should be nearly ready to generate. If devices connected to the gas outlet ports are showing humidity reading above the current setpoint value while the G3 is in PURGE mode, additional purge time is likely required. While in purge mode, connected devices will generally indicate values lower than the G3 setpoint, indicating the purge is working. Ensure adequate purge before proceeding to generate mode.

a)   Enter the Generate mode by pressing the **Generate** button. Gas flow is then directed through the saturator rather than bypassing it. The humidity value a the outputs will quickly move upward toward the setpoint value.

b)   To change the humidity setpoint, simply enter a new setpoint value. You may also select a different humidity control parameter (such as **Dew Point**, **Frost Point**, **PPMv**, **PPMw**, or **Saturation Pressure**) from the drop down menu. If you select a different parameter for control, you may view it's approximate setpoint, but this parameter will not become the new humidity control parameter until you enter a new value (or the same value) in the Setpoint field. The current Humidity Control Mode is displayed on the bottom line of the Control Window.
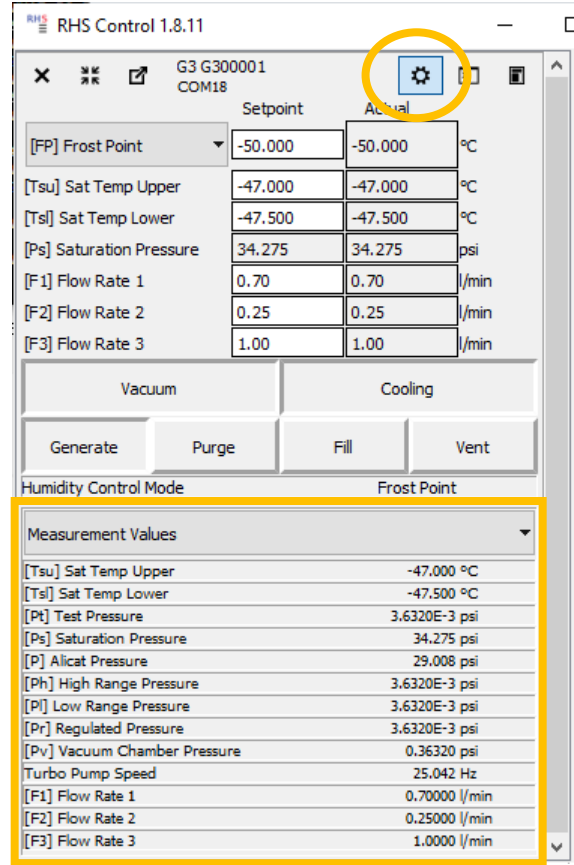
4.6 Viewing additional data

While generated data is visible in the Actual columns, additional numeric data is available.

1. Clicking the GEAR icon causes another window to appear below the Control Window with data and a selection bar at its top.

2. Click the drop-down at the top of this new window area to see a list of other data groups that may be displayed.
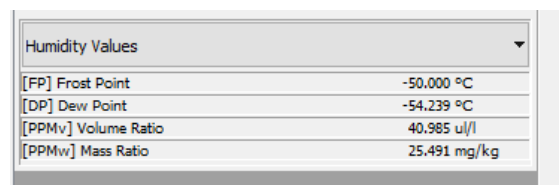
3. In this example, the **Humidity Values** data group was selected. You may view any data group at any time without affecting the operation of the system.

4.7 **Plotting data**

In addition to the numerical data views, data may also be plotted in graphical form.

To plot data:

a) Select the Graph icon   at the bottom of the screen. A data selection window appears.

b) Select an instrument (the G3) on the left side and any number of data items on the right side.
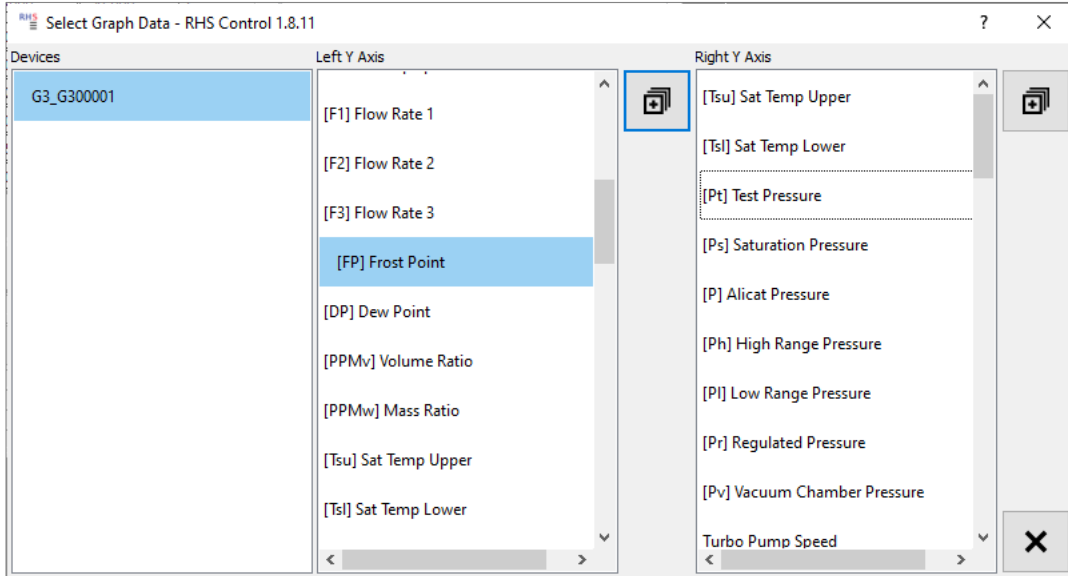
c) Close the window. A graph appears.
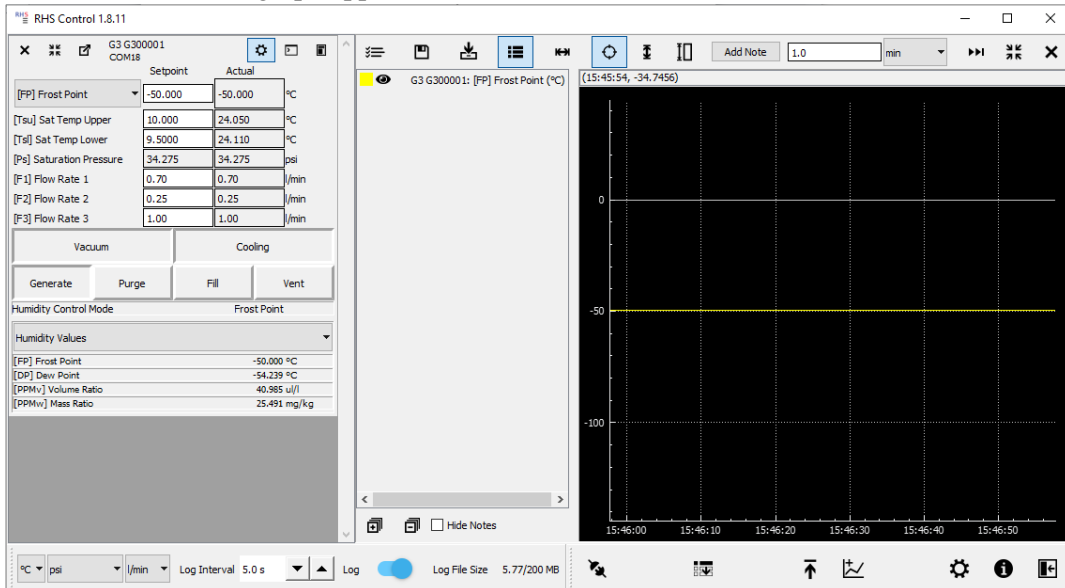
d) The graph starts in a strip-chart mode where the newest data always appears on the right side of the screen and the graph scrolls or scales to accommodate. Use the touch screen to swipe / pinch / zoom to scale or move the graph line(s) as desired.

4.8 **Idle mode**

The G3 performs best if it is allowed to remain operating at a set temperature with a small flow rate even when its generated output is no longer required. This allows the gas path tubing and connections to remain dry (or conditioned at a desired humidity) so that it is immediately ready to generate when next needed. Whether Purge or Generate mode is chosen for this idle operation depends mainly on the starting humidity value of the next anticipated need. If the next anticipated run will start at a low humidity (say below about -50 °C FP (below ~50 PPMv), Generate mode is best. If the next run is anticipated to start above -50 °C (above ~50 PPMv), Purge mode is generally best as it will keep gas path tubing drier during this idle time. The Vacuum should also remain enabled to keep the chamber evacuated and dry.

To create an idle mode:

1. Set all flow rate setpoints to low values such as 0.1 or 0.2 l/m.
2. Set the humidity setpoint to any future anticipated starting value. Or set to the lowest value anticipated during the next run and consider starting next time at this lowest value first.
3. Press the Purge button to place the system in purge mode (or if the setpoint from step 2 is lower than about -50 °C FP, Generate mode is likely a better choice.)
4. Ensure the Vacuum button remains enabled to ensure the chamber remains evacuated and dry.
5. For extended periods of expected inactivity (weeks or more), you may wish to disable the Stirling coolers. Do so by pressing the Cooling button to ensure it pops back out and is no longer depressed. Also, if Cooling control is disabled, Purge mode is the best choice to keep gas path tubing dry and preserve water in the saturator from being evaporated away during this idle time.

Note: For quicker restart in the future, it is best to leave the system operating in either purge or generate mode at a low humidity with coolers *enabled* rather than turning them off.

4.8.1 Example idle settings

Idle settings shown assume the next anticipated usage may likely begin at approximately -70 °C FP. With these settings, the saturator will remain cooling at -64 °C, flow will continue through all three gas outlets at a rate of approximately 0.1 liter/minute each, and the vacuum chamber will retain its vacuum. Since purge mode is used, the gas exiting the three gas outlets will be at a level drier than -70 °C FP to precondition tubing and connected instruments at a dry condition. Purge mode also ensures that gas is bypassing the saturator rather than flowing through it, thereby preserving water/ice level within the saturator.

4.9 Power off

For extended periods of non-usage (weeks or more), the system may be powered off completely.

1. Close the RHS Control program.
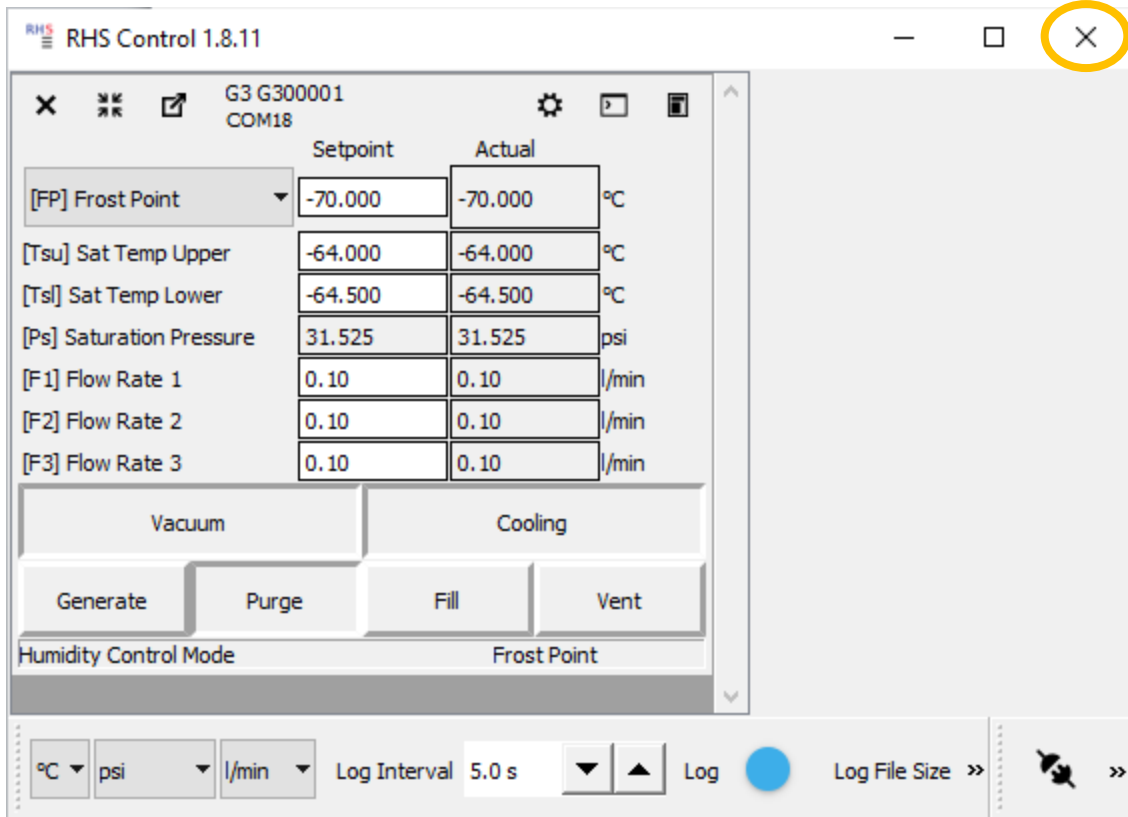
2. Press the front panel Power switch. The PC will go through an orderly shutdown sequence, followed by an automatic full system power down. When the power button light extinguishes, the system has completed its power down procedure.

3. To further remove power, turn off the circuit breaker switch at the lower rear panel and unplug the power cord if desired.
4. Turn off any pressurized gas source that is connected to the system gas inlet.

When restarting the system after a period of full power down, follow steps in section 4 to re-establish a dry, evacuated, operational system.

5 Operation

5.1 G3 Operation using RHS Control

RHS Control is a PC program (available on Windows and Linux) which allows the user to operate the G3 system. The system may be operated manually, through direct entry of desired setpoints, or automatically, through a series of preprogrammed, user selectable setpoints and times.

In addition to entering setpoints for control, the program offers visualization of resulting data in real-time both in numerical and graphical formats. It also allows for connection to other instruments (such as those connected as Units Under Test, or UUT's, provided they have a serial data port. For those instruments with a serial data port, a customized protocol description in the form of a *json* file is used to make the data connection. These json files are text files utilizing our RHS Descriptor Language to define the instrument protocol, commands, and data presentation method. These instrument specific files may be created and/or modified by end users, or they may be obtained from RH Systems for particular instruments. While these descriptor files are available for RH Systems brand products, they can also be created for a wide variety of instruments and are not limited by brand and model. The main requirement is that the instrument be connected via a serial interface that can respond to command requests in a consistent manner.

5.1.1 Launching RHS Control

To launch RHS Control, simply click its desktop icon [RHS]. The main program loads and automatically presents the Connection window.
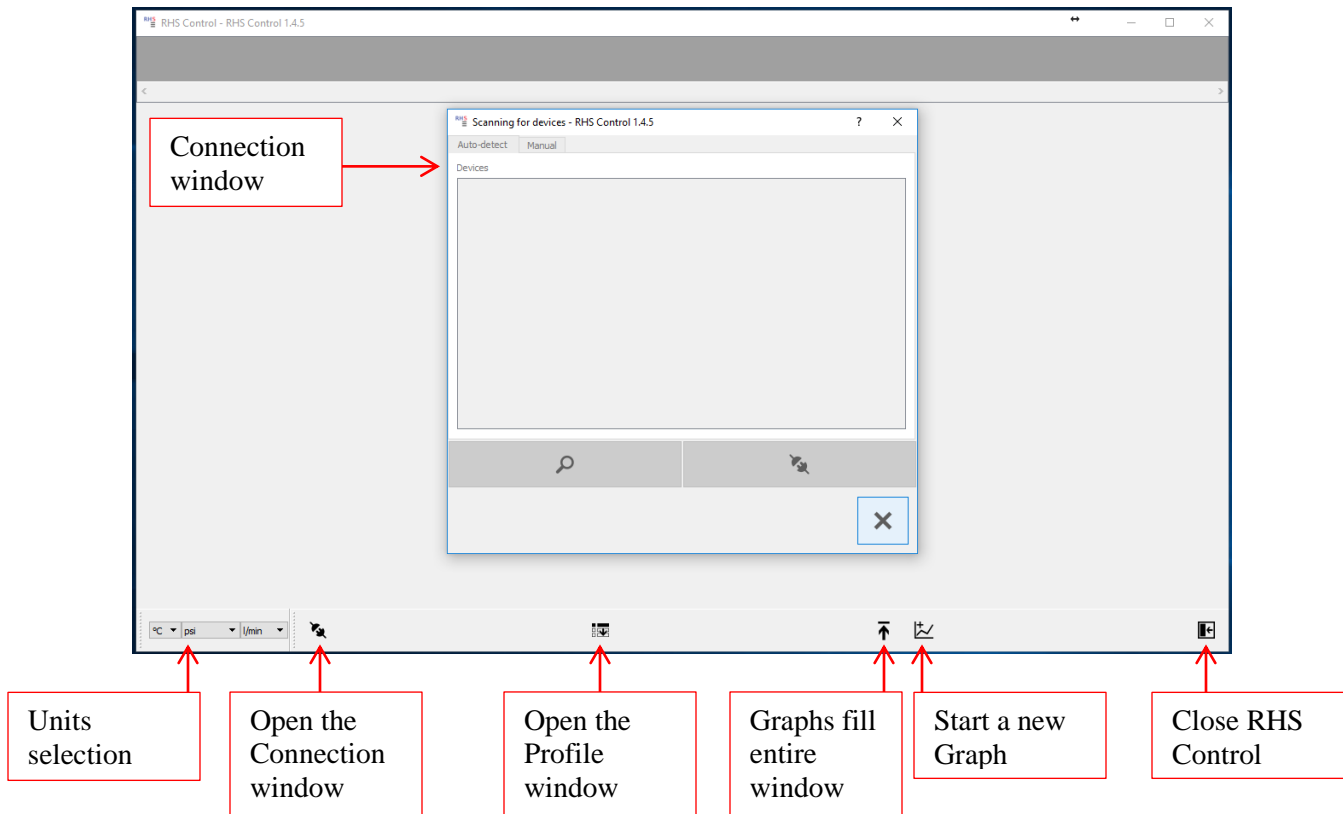
5.1.2 Connection Window

All instrument connections are initiated via the Connection window. When the program is first launched, this window appears automatically. However, it may be opened for use at any time simply by pressing the Connection button on the main RHS Control screen.

List of instruments found →

Search for instruments button →

Connect button ←

Close window button
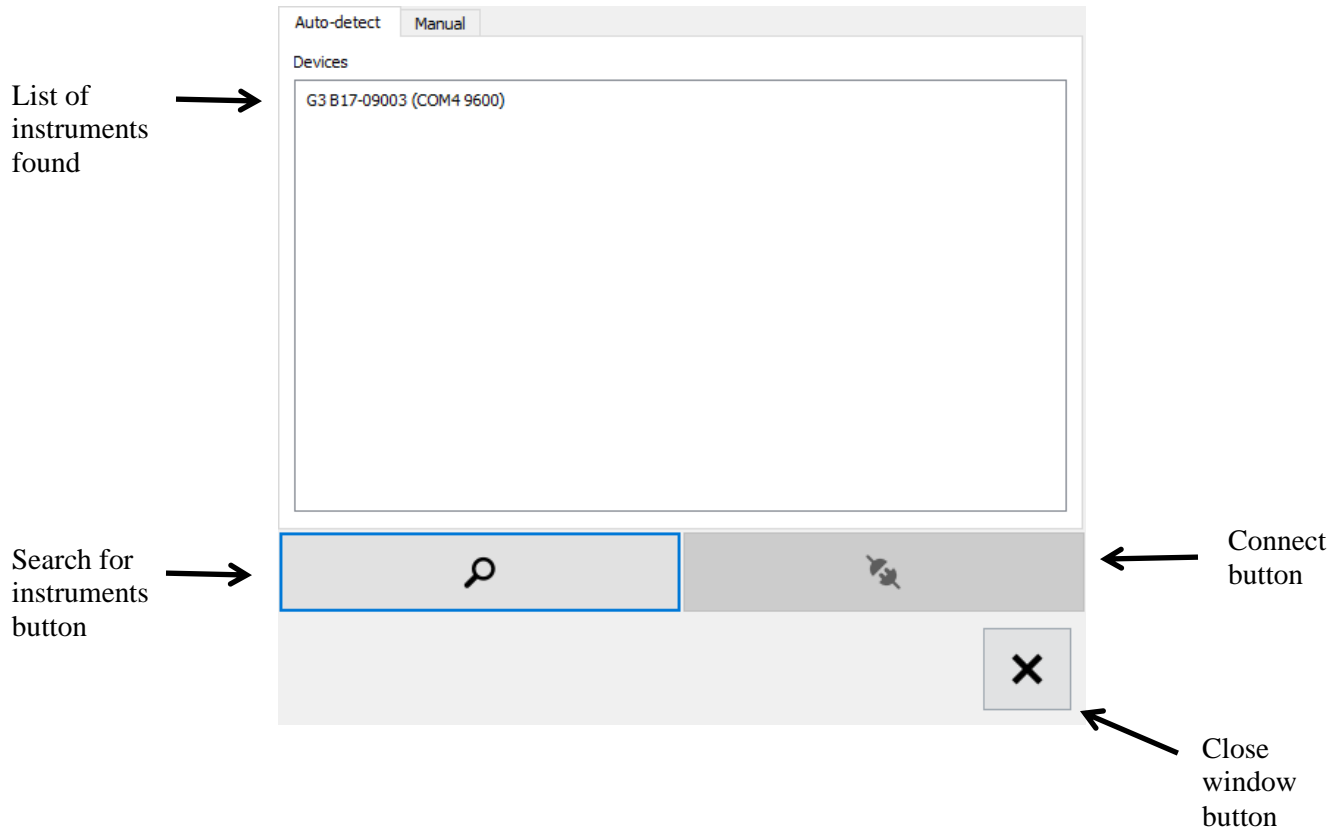
5.1.2.1 Connect the G3

When the Connection window opens, it initiates an automatic search for attached instruments. If it finds the G3, it will automatically connect.

To connect instruments:

1. If the instrument you want to connect with is not listed, ensure it is plugged into an RS-232 port. Then press the Search button.

2. Click on any instrument(s) listed. The selected line(s) will highlight.

3. Click the Connect Button. If there are no further instruments listed, the window closes automatically. If other instruments are still listed, the window remains open.

4. To close the window, press the Close button.

A unique window appears within the main screen for each connected instrument. The following window is typical of a running G3.

Minimize this window

Tear this window away from main screen

Show secondary data / coefficients windows

Show mini terminal window

Close instrument connection

Show serial comm data stream

G3 G300001
COM18

Setpoint Mode Selection

	Setpoint	Actual	
[FP] Frost Point	-70.000	-70.000	°C
[Tsu] Sat Temp Upper	-64.000	-64.000	°C
[Tsl] Sat Temp Lower	-64.500	-64.500	°C
[Ps] Saturation Pressure	31.525	31.525	psi
[F1] Flow Rate 1	1.00	1.00	l/min
[F2] Flow Rate 2	0.00	0.00	l/min
[F3] Flow Rate 3	0.00	0.00	l/min

Turns vacuum pump on/off

Vacuum

Cooling

Turns Saturator cooling on/off

Generate Purge Fill Vent

Toggles between Generate/Purge modes

Activates Water Fill mode

Vents pressure from saturator

All fields within the Setpoint column that are white in color are user editable.

The Setpoint Mode Selection is a drop-down menu that allows selection of the following control modes:

- [FP] Frost Point
- [DP] Dew Point
- [PPMv] Volume Ratio
- [PPMw] Mass Ratio
- [Ps] Saturation Pressure

The fields to the right of the Setpoint Mode Selection will change according to the control mode selected.

5.2 Apply Vacuum

The vacuum chamber is utilized both as a means of thermal insulation, and as a vapor barrier to prevent unwanted permeation of water vapor into the conditioned gas. Prior to generating a humidity value, vacuum is required.

1. Ensure the vacuum chamber is properly in place, its eight mounting screws secured, and the eight external supports installed and properly tensioned to very light finger tightness only.

2. Press the **Vacuum** button to toggle it ON. It takes a few seconds for the pump to start. Since the button always reflects the pump's status, it also takes a few seconds before the pump button reflects an ON (or pushed in) condition.

5.3   Fill, Purge, and Chill

The saturator provides a path for the gas to travel over a surface of water or ice. Prior to initial operation, and only occasionally after that, the saturator must be filled with liquid water. Each time after filling, it is recommended to purge for a period of time to remove any unwanted water/ice/vapor from the saturator outlet gas path, and chill (freeze the water).

The amount of time between filling operations is dependent on:

- Humidity levels generated (higher/warmer humidity levels use water faster)
- Flow rate of the gas (higher flow rates use water faster)
- Dryness of the incoming supply gas

The saturator holds approximately 75 ml of water. Approximate run times are listed below.

Dew/Frost Point °C	Approximate continuous run time at 1 L/min
+10	4 days
0	1 week
-10	3 weeks
-20	2 months
-30	6 months
-40	18 months
-50	5 years
-60	17 years
-70	75 years
-80	350 years
-90	1500 years

The table reflects the expected run time assuming a total flow rate of 1 L/min. For higher flow rates, divide the run time by the flow rate. As an example, if the total flow rate is 4 L/min, the expected run time at -20 °C would reduce to approximately 2 weeks (calculated as [2 months] / 4 = 0.5 month).

5.3.1 Fill the saturator

Filling the saturator is required initially, then once every few weeks, depending on the humidity and flow rates generated. Low humidity and low flow rates require less water. High humidity and high flow rates require more water and therefore more frequent filling. Filling may only be performed when the saturator temperature is well above freezing (at least 5 °C or higher).

1. If the saturator is at a temperature below 0°C, enter a Dew Point or Frost Point temperature of +10 °C. This will cause the saturator temperature to warm up to 12 °C or higher. This ensures that all ice in the saturator will melt to liquid water.

2. Ensure the **Cooling** button is enabled. Wait for the saturator to warm and stabilize at the setpoint temperature.

3. Press the **Fill** button. After a few seconds, the system will go to Fill mode and will also set the Purge mode and the Vent mode buttons automatically. Flow rate setpoints will also be zeroed, and saturation pressure setpoint is set slightly above ambient pressure.

4. Using a 9/16" wrench, remove the Swagelok cover nut from the Saturator Fill port.

5. Using the syringe and tube supplied in the accessories kit, draw in 1 full syringe of DISTILLED WATER from a distilled water bottle. Use **DISTILLED WATER ONLY**. Do not use de-mineralized, de-ionized, filtered, or drinking water.

6. Connect the hose to the Saturator Fill port.

7. <u>Slowly</u> inject the water into the saturator at a rate of no more than about 2-3 seconds per ml (about 2 minutes to inject the full 50 ml volume of the syringe).

8. Using the syringe, follow the water with air. Slowly inject about 2 syringes of air (about 100 ml total) at the same rate as the previous step.

9. Wait about 5 minutes to allow excess water to drain from the saturator. During this procedure, some water may drip/spray out the vent port in the back. This is normal and indicates a full saturator. A tube and catch pan may be used at the vent port to catch the excess water if desired.

10. Stop the Fill mode by pressing the **Fill** button again to toggle it off. This stops both the Fill and Vent modes. Purge mode remains on and saturation pressure setpoint remains slightly above ambient.

11. Reinstall the ¼" Swagelok cap.

5.3.2   *Purge the saturator*

After filling, it is a good idea to purge for an hour or more to ensure there is no excess liquid water in the gas path.

1. Select **Frost Point** as the humidity control mode, and enter a setpoint value of 0 °C.

2. Remove any covers from the gas outlet fittings and set a flow rate of 0.5 to 1 l/min for each of the three flow outputs.

3. If not already enabled, press the **Cooling** button to turn on saturator temperature control.

4. Ensure the G3 is still in purge mode (the Purge button is pressed in). However, if it is in generate mode, press the **Purge** button to switch to purge mode.

5. Wait an hour or more.

If a humidity monitoring instrument (such as RH Systems Model 373LX Chilled Mirror Hygrometer) is connected to one of the gas outlets, proper purging is indicated by low readings on the instrument. For example, at the conditions set above, the instruments should indicate at least -10 °C FP or lower while purging. If the readings are higher (warmer) than that, the gas path is likely wet and should be purged longer before proceeding.

5.3.3 Chill the saturator

Once the saturator has been filled and purged for a sufficient time, it is ready to begin chilling, causing the water to freeze. This is done while the system is still in Purge mode.

1. Ensure the G3 is still in purge mode (the Purge button is pressed in). However, if it is in generate mode, press the **Purge** button to switch to purge mode.

2. Select **Frost Point** as the humidity control mode and enter a value of -50 °C.

3. The saturation temperature setpoints will automatically adjust to appropriate values. Wait until the saturation temperatures have reached their setpoints.

4. Connect a hygrometer to one of the G3 gas outputs (a chilled mirror such as the RH Systems Model 373LX is recommended).

5. Monitor the hygrometer output. It should have a reading well below the indicated humidity value of the generator. Continue to run and monitor until the hygrometer reading remains relatively steady, and well below the G3 indicated humidity value.

The G3 should now be ready for use.

5.4 **Selecting Humidity Control Mode**

The G3 can control in one of several different humidity control modes which automatically picks suitable parameters for saturation temperature and saturation pressure. As an alternative, it may also be operated by entering setpoints for saturation temperature and saturation pressure directly.

5.4.1 Humidity Control Mode

While in a valid humidity control mode (FP, DP, PPMv, or PPMw), the G3 automatically determines suitable target values for saturation temperature and saturation pressure.

1. Using a mouse or finger, select the drop-down menu to reveal the various control mode options.
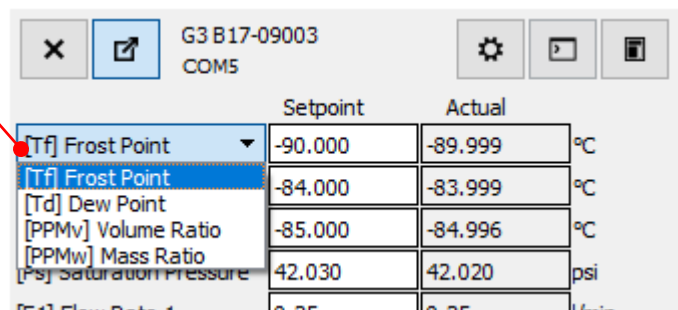
2. Select one of the listed control modes by clicking on it.

	Setpoint	Actual	
[Tf] Frost Point ▼	-90.000	-90.001	°C
[Tf] Frost Point	-84.000	-84.000	°C
[Td] Dew Point			
[PPMv] Volume Ratio	-85.000	-84.997	°C
[PPMw] Mass Ratio			
[Ps] Saturation Pressure	42.010	42.020	psi

3. Click the value in the Setpoint column, change it, and hit Enter.

	Setpoint	Actual	
[PPMv] Volume Ratio ▼	0.10077	0.10071	ul/l

4. The field border highlights. Edit the value and press Enter.

	Setpoint	Actual	
[PPMv] Volume Ratio ▼	0.1	0.10077	ul/l
[Tsu] Sat Temp Upper	-84.000	-83.999	°C

5. After pressing Enter, the highlight changes color to indicate the new setpoint is being sent.

	Setpoint	Actual	
[PPMv] Volume Ratio ▼	0.1	0.10075	ul/l
[Tsu] Sat Temp Upper	-84.000	-83.999	°C

6. Once the value is sent to the G3, the highlight disappears. A new value is then read from the G3 and will be displayed. Saturation Temperature and Saturation Pressure setpoints will be automatically recomputed as needed.

✕	⬈	G3 B17-09003 COM5		⚙	▢	▣
			Setpoint	Actual		
[PPMv] Volume Ratio ▼			0.10000	0.10080	ul/l	
[Tsu] Sat Temp Upper			-84.000	-83.998	°C	
[Tsl] Sat Temp Lower			-85.000	-84.997	°C	
[Ps] Saturation Pressure			42.020	42.010	psi	
[F1] Flow Rate 1			0.25	0.25	l/min	
[F2] Flow Rate 2			0.00	0.00	l/min	
[F3] Flow Rate 3			0.75	0.75	l/min	

Vacuum		Cooling	
Generate	Purge	Fill	Vent

Note that the new setpoint and control mode are changed at the same time, but not until you've entered a new value. What this means is that you can look at the associated humidity Setpoints without affecting the current control mode. In other words, you can perform steps 1 and 2 above without causing any change to the control mode. The mode changes only after you edit the setpoint and press Enter, as mentioned in step 3.

In all humidity control modes, the saturation temperature setpoint fixes at a reasonable value and does not change any further until you once again change the humidity setpoint.

Note that although the G3 automatically determines a suitable saturation temperature setpoint when entering a new humidity setpoint, you have the option to override it. If the new saturation temperature setpoint you enter is still within the range of suitable values for the current humidity setpoint, the new saturation temperature setpoint will be accepted. If, however, the saturation temperature setpoint you chose would not allow the G3 to reach your humidity setpoint, a new automatic setpoint will be chosen by the system, over-riding your saturation temperature setpoint. Changing the Saturation Temperature does not change the humidity mode.

Automatic calculation of saturation pressure is, however, an entirely different matter. Unlike temperature, which fixes to a single value, the saturation pressure setpoint constantly varies to bring about the desired humidity output based on current humidity setpoint and measured saturation temperature.

5.4.2 Sat Pressure Control Mode

There may be times that you prefer to maintain a fixed saturation pressure rather than a fixed humidity. When controlling a fixed saturation pressure, the saturation pressure setpoint will remain constant while the humidity may vary.

1. Click the Humidity Selection dropdown.

2. Select **[Ps] Saturation Pressure**

3. Enter a Saturation Pressure setpoint in the top field and press Enter.
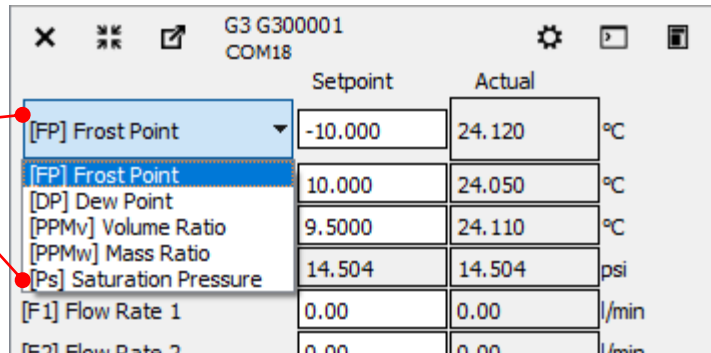
Saturation Pressure becomes the new setpoint, attempting to hold its value constant. Humidity setpoints and values may vary. Changing saturation temperature or flow rate setpoints has no influence on control mode, and saturation pressure control mode setpoint remains unchanged. To exit saturation pressure control mode simply re-enter a humidity control mode as described in 5.4.1.

5.5   Changing Set Points

Setpoints are used to inform the G3 of the desired humidity output, flow rate, and other factors. Setpoints are used as the target values for control.

1. With a mouse or finger, click on a setpoint field. The field highlights with a colored border.

2. With either a physical keyboard or the on-screen virtual keypad, enter the desired setpoint value.

3. Press Enter. The highlight color changes while the G3 is informed of the new value and is read back. The value read back is then displayed and the highlight removed.

4. Confirm that the number displayed is the number entered.
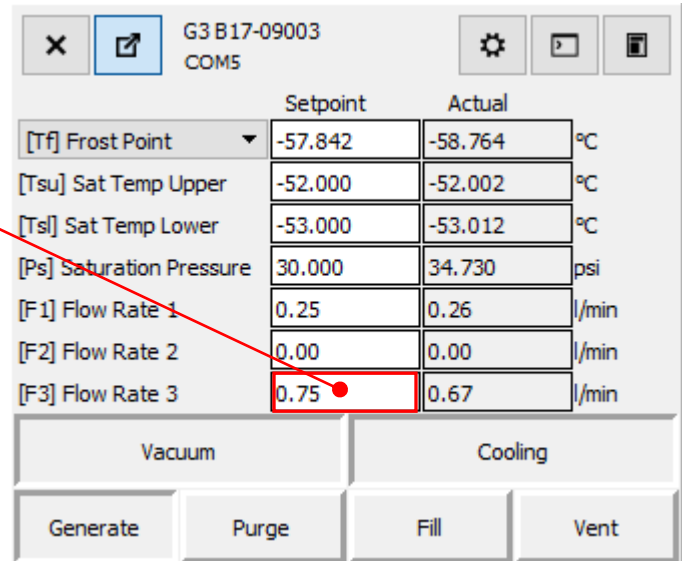
5.6 Purge mode

Purge mode is used to dry the saturator outlet tube and any connected instruments to prevent unintended humidity from altering the gas stream humidity once it exists the saturator. Enter purge mode by pressing the Purge button. The Purge and Generate modes are exclusive, meaning that Generate mode turns off when Purge mode is enabled.

While purging, you'll need at least 0.25 L/min or more of combined flow rate. All purge gas flows through the Gas Outlet ports at the front panel and may be monitored by connected measurement devices.

When in Purge mode, the supply gas entering the system at the back panel is used as the purge gas and should therefore have a frost point value much lower than the sat temperature during purge. As a general rule, the saturator should not be cooled lower than about -70 °C while in purge mode and using LN2 boil-off as the purge gas. Purge mode is generally only needed after filling with water. Once purged, and the saturator temperature is below freezing, the G3 may be switched to Generate mode.

The *pressure dew point* of the gas supplied to the G3 should be lower than the saturation temperature settings while in Purge mode. If the pressure dew point is higher (warmer, wetter) than the saturator temperature, then purging will have the opposite effect of wetting rather than drying the gas path. Choose a proper purge value that is warmer than the pressure dew point of the supply gas.

5.7 Generate mode

Generate mode is used to generate humidified gas. The humidified gas is directed to the Gas Outlet ports at the front panel. When generating, it is normal to use a humidity setpoint and at least one flow rate setpoint. Press the Generate button to enter Generate mode. Enabling Generate mode disables Purge mode.

Once the G3 has been sufficiently purged, and the saturator is frozen (i.e., the saturation temperature Actual value is below freezing), **Generate** mode may then be used to transition up and down in humidity values at will. Provided that the saturator remains frozen (remains below 0 °C), there is generally no need to switch back to purge mode while drying to lower humidity values or cooling the saturator further.

5.8 Viewing Data Graphically

Data may be viewed numerically, or as a graph. You may show several graphs at one time, each with independent variables, axes, and timing. All graphs can show fixed data, or running strip-chart-style data where it is always up to date with current information.

Graphs may show a combination of data from any connected instruments. Each parameter may be shown in a different color and may be quickly and easily shown or hidden during analysis.

Graphs respond to normal pinch-and-zoom, multi-touch gestures of the touch screen. They also work with a mouse to move/zoom/scale as desired.
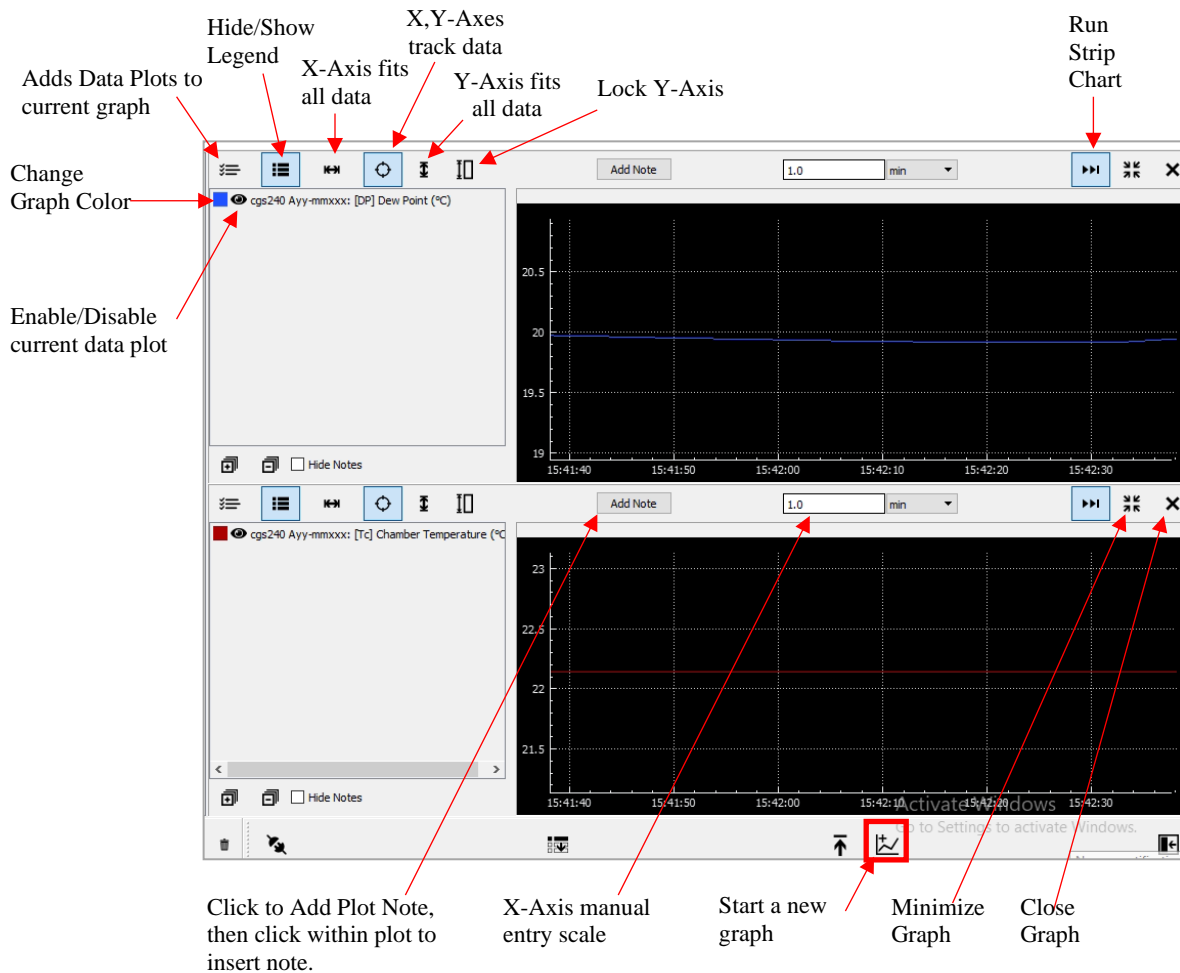
5.9 Auto Profiling

In addition to direct, real-time, user setpoint input, an auto-profile can be prepared on screen giving the system a set of future, time-based, setpoint instructions. With auto-profiling, an entire series of setpoints with associated run times is pre-programmed on screen for subsequent execution of the sequence. Or it may be stored to disk for later retrieval and execution. Auto-profiling allows the system to run full sequences of humidity/temperature/flow points completely unattended, storing system and instrument data the entire time. In addition, if other instruments are also connected to RHS Control (such as RHS/MBW Chilled Mirror Hygrometers), they too may be sent commands as part of the auto-profile sequence. In this way, any available connected instrument may be included to accept commands from auto-profiling.

Press the Auto Profile button at the bottom of the screen to open the Auto Profile window.

The Auto Profile window appears.
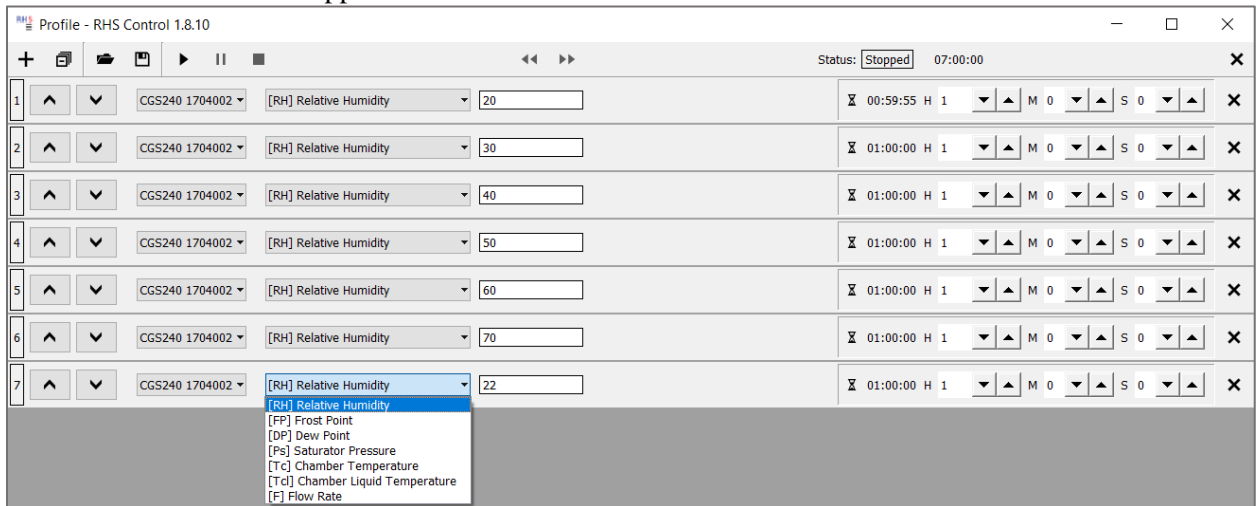
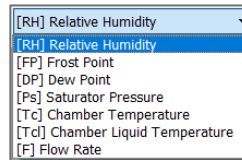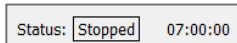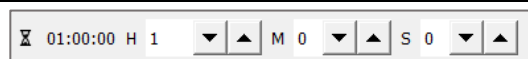|	
From left to right: • Add set-point • Clear set-point • Open profile • Save profile • Start profile • Pause profile • Stop profile	Connected instrument pull-down Control pull-down
 Profile Total Time	 Set point entry
 Move set-point line up/down	 Timer set-point controls for run time at each point
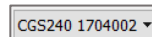
5.10 Change Units

Changing the units may be done at any time using the Units bar at the lower left corner of RHS Control. The units will change globally (numerically and graphically). This will affect the displayed units for all instruments connected to RHS Control. However, this does not affect the units logged during data collection. Data is always logged in units of pa, l/min, and degrees Celsius, regardless of the units being displayed.
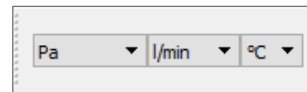
5.11 Connection of other instruments

A variety of other instruments may also be connected to RHS Control. If the instrument has an RS-232 serial port, and a properly written description file (.json file) is included in the G3, the Connection window should be able to find and connect to it. The system is already supplied with several json files for connection to most RHS and MBW brand instruments.

For a list of currently installed json files, look in the folder

> c:\RHS-Software\rhscontrol\configs\

The json files are stored as standard ASCII text files and may be viewed with any standard text editor such as NotePad, NotePad++, UltraEdit, and MS Word. Json files may also be written to communicate with other brands of instruments. Contact RH Systems, LLC for more information.

5.11.1 Serial connection

The G3 is supplied with several RS-232 serial comm ports located on the left side panel. There are several USB ports there also, each of which could support additional comm ports via USB-Serial converters. These G3 serial ports mimic the operation and pinout of standard PC serial ports and can independently operate at a variety of baud rates and communication protocols.

Generally, instrument connections are made using an RS-232 Extension Cable with male connection on one end, female connection on the other end, and wired straight through (pins 1-1, 2-2, 3-3, …, 9-9.) Note that all RH Systems brand instruments connect directly using only a straight through extension cable. If manufacturing your own cables, generally only pins 2, 3, and 5 are required for connection to most instruments.

RS232 Pin Out

Pin #	Signal
1	DCD
2	RX
3	TX
4	DTR
5	GND
6	DSR
7	RTS
8	CTS
9	RI

G3 Serial Connectors
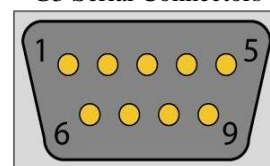
If a Null-Modem adapter would normally be required for the instrument to communicate with a standard PC, a Null-Modem adapter (which crosses pins 2 and 3) will then also be required when connecting to these ports of the G3.

To connect, plug the female end into any of the available serial ports on the left side of the G3.

Plug the male end into the instrument.

5.11.2 Software connection

After making the physical cable connection, connect to the RHS Control software by pressing the **Connect** button.

The Connection window appears and automatically searches for physically present instruments it finds that are not currently connected to RHS Control. (See section 5.1.2 Connection Window)

Double click to connect ➝

373LX 17-1203 (COM5 9600)

5.12 Data Logging

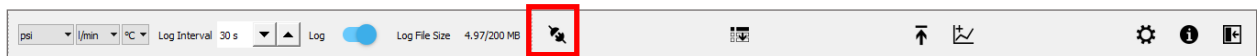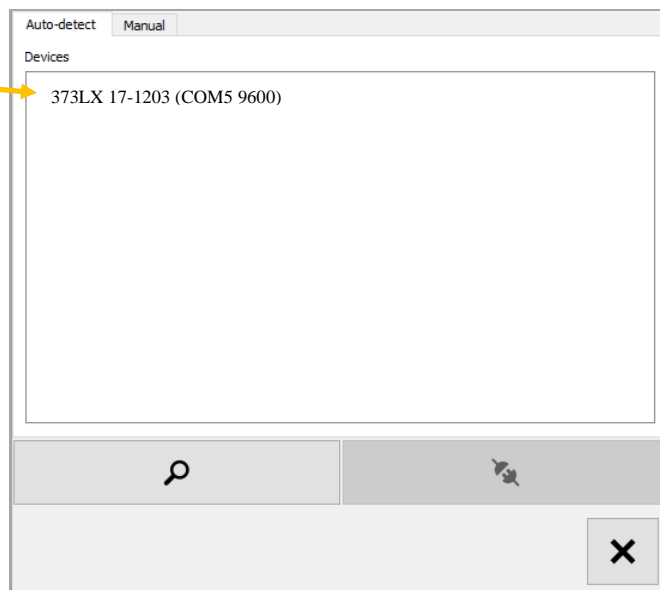All instrument data is stored in log files. Logging is defaulted to ON upon startup of RHS Control. Each connected instrument has a separate log file with common time stamps for easy post-run analysis using Excel or other programs of your preference. Data files are stored in CSV (comma separated value) format for easy import.

The data is logged at a time interval defined by the 'Log Interval' spin box located at the lower left corner of RHS Control.

Located to the immediate right of the **Log Interval** spin box is the **Log** toggle switch. The Toggle switch will be blue in color when logging is *enabled*, and red in color when logging is *disabled*. Yellow color indicates that the size is approaching its maximum. The act of toggling this OFF will close the file and stop data collection for all instrumentation connected to RHS Control. Toggling it back to ON will start a new log file.

Files names are identifiable by instrument name, serial number, and time stamp. Log files are stored in:
`RHS Control\logs\`

The current log file size is indicated. If the file reaches the maximum size limit, the file closes and a new file starts automatically. Maximum log file size is user selectable in the System Settings window.

5.13 System Settings

The **Settings** button provides access to the Settings Window.

System Info allows for selection/deselection of the on-screen keyboard. It also allows for a light and dark mode theme (light mode is shown throughout this manual).
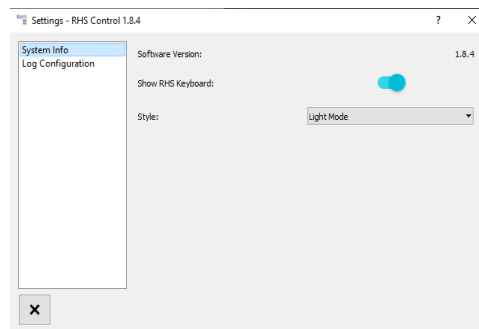
Log Configuration allows for changes to the log file data formatting options. It also allows setting the maximum log file size. Once the size is reached, the file will close and a new log file will automatically be generated.
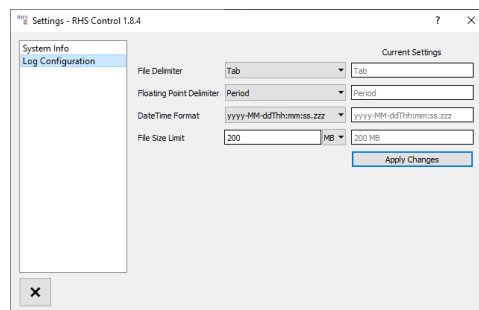
6 Model G3 Sub-Systems

This section provides details of the functional systems within the G3. These subsystems include the Electrical System, Pneumatic System, and Temperature Control System.

6.1 Electrical System

The G3 requires 100-240 VAC, 50/60 Hz, single phase power.

6.1.1 AC Power

AC power enters the system via the power connector located at the back panel, transferring AC into the system via a two-pole 15-amp circuit breaker. When the breaker is turned on, power is also applied to circuit breaker CB1 located behind the rear panel near the top. With CB1 ON, power is applied to CB2 and CB3. CB2, when on, applies power via Term 1 to the AC power strip which powers the 24 VDC power supply, 48 VDC power supply, and the vacuum pump.CB3, when ON, applies power via SSR1 to Term 2 & 3 to energize the 24 VDC PC power supply PSU1 and the Monitor AC power plug on the left rear G3 panel.
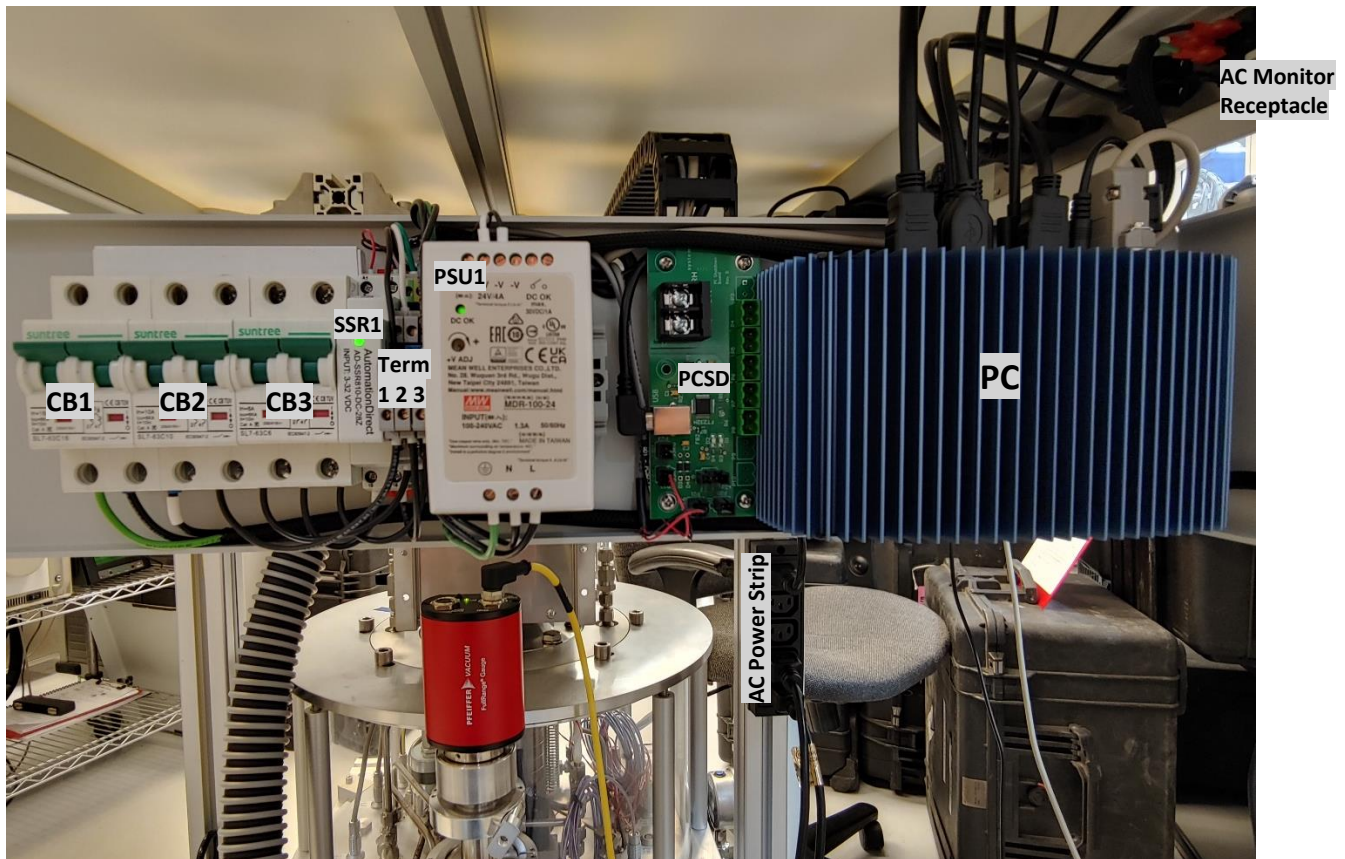
When the front panel power switch is depressed, another 24 VDC power supply PSU2 applies DC power to the MCB. The MCB in turn applies 5 VDC to the PC Shut Down board PCSD, activating SSR1. When SSR1 is activated, AC power is applied to the monitor AC power receptacle, and PSU1 to activate the PC. 5 VDC from the PCs USB port is also applied to PCSD to hold SSR1 active. SSR1 deactivates when the

front panel power switch is retracted, removing DC from the MCB, removing 5 VDC from the PCSD. This PCSD signal loss is sensed by the PC software, triggering an orderly PC shutdown. While the PC is shutting down, SSR1 remains active since the PCs USB power sustains SSR1 activation. Once the PC shuts down, USB power is lost and SSR1 deactivates to remove power from PSU1 (removing power from the PC) and from the monitor AC power receptacle (shutting off the monitor). Turning off the front panel power switch does not affect the vacuum pump operation. If it was running before the system was powered off, it will remain running to maintain the vacuum level of the chamber.

6.1.2 PC Power, 24 VDC PSU1

24 VDC power supply PSU1 is used to power the PC. It is activated via AC power supplied through SSR1. SSR1 is activated when power is received from the MCB through PCSD. This powers PSU1, powering the PC. SSR1 is then held active through DC power from the PCs USB port. When the MCB is shut down via the front panel power switch, SSR1 remains active until the PC finishes its orderly shutdown process. Once the PC completes shutdown, its USB power removes the holding activation of SSR1, thereby removing power to PSU1 and the PC. Reactivation occurs when the front panel power switch is depressed, activating the MCB's power supply, activating the MCB which activates SSR1, which activates PSU1 which powers the PC. Once again, holding activation of SSR1 is supplied by the operating PC through USB power.

6.1.3 DC Power, 24 VDC PSU2

24 VDC is used to power the Main Controller Board, relays, solenoids, heaters, and sensors. AC input power is always connected to the supply via the main power entry receptacle, through CB1, through CB2, through Term 1, through the AC power strip, then through its AC power cord. The 24 VDC power supply is equipped with a low-voltage remote control circuit that is wired through the front panel power switch. When the front panel power switch is turned on, 24 VDC power is enabled and applied, activating the MCB. The power supply is located on the back side of the MCB control panel.

6.1.4 DC Power, 48 VDC PSU3

48 VDC is used exclusively for powering the two Stirling cooler circuits. AC input power is always connected to the supply via the main power entry receptacle, through CB1, through CB2, through Term 1, through the AC power strip, then through its AC power cord. When AC power is applied, the fan within the 48 VDC power supply runs, but 48 VDC remains off. It is equipped with a low-voltage remote control circuit that is wired through the front panel power switch. When the front panel power switch is turned on, the 48 VDC power is enabled, therefore applying 48 VDC to the Stirling cooler circuit boards. The power supply is located on the back side of the MCB control panel.

PSU2
24 VDC

PSU3
48 VDC
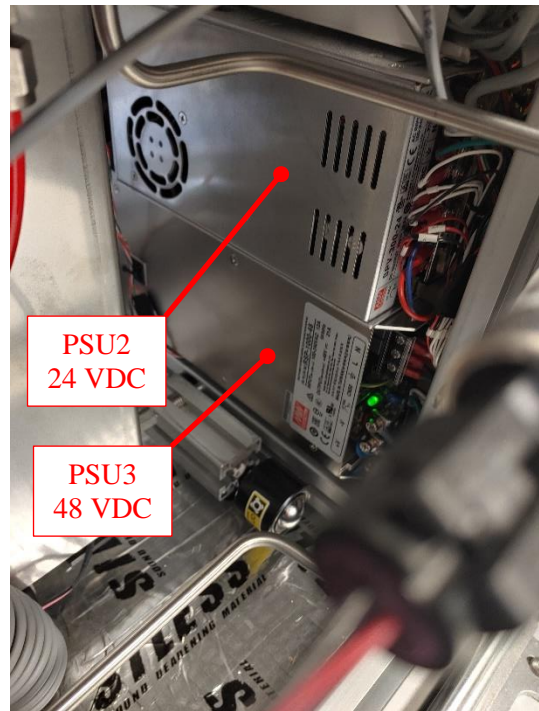
6.2   Embedded Control System

The control panel holds the Main Controller Board MCB, the Precision Temperature Measurement Board, and the Stepper Motor Controllers. The control system utilizes these boards, along with Stirling Cooler Controllers, Stepper Motor Controllers, Heaters, Valves, Pressure and Flow Controllers.

The embedded control system operates the Model G3 by performing all functions required for system control and humidity generation. Temperature, pressure and flow are continuously monitored and controlled by actuation of valves, relays, coolers, heaters, and other outputs. The embedded controller software consists of RHS custom developed code, coupled with a high-speed multi-tasking real-time operating system. Via this multi-tasking embedded software, the controller orchestrates the second-to-second operation of the G3 based on command input from any of

the RS-232 ports. Using a variety of communication methods (Terminal Emulator, a custom written PC program, or our RHS Control program), set points (frost point, dew point, saturation temperature, flow rate, etc.) are transmitted to the controller board. The job of the controller board is to accept these set points, continuously measure the various analog and digital sensors, and control the various electro-mechanical and thermal actuators to bring about and maintain the desired set point conditions.
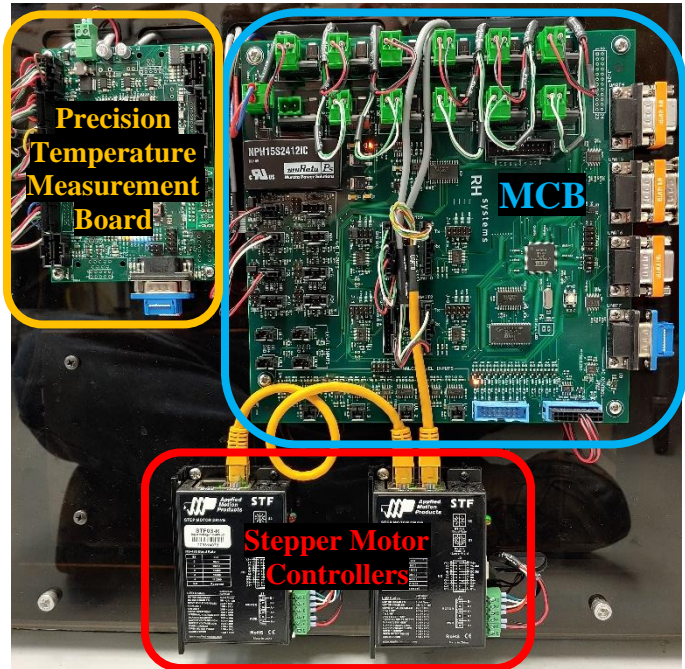
6.3   Main Controller Board

The Main Controller Board (MCB) has many different inputs and outputs used to operate the G3. Grouped by functional type, the following tables in this chapter list the various inputs and outputs of the MCB and reference the specific sections of this manual where each input or output is discussed.

The G3's embedded controller software resides within the MCB's Flash memory. Instrument specific configuration and calibration information, such as sensor coefficients resides within the MCB's Electrically Erasable Read Only Memory (EEPROM).

Voltage regulators on the MCB take the 24VDC input power and generate +12VDC, +5VDC, and +3.3VDC needed for various components on and off the board. DC power for sensors, solenoids, controllers, and others are supplied directly from the MCB.
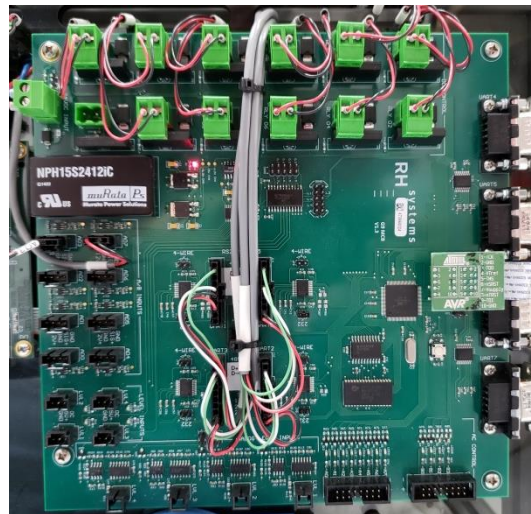
6.3.1 DC CONTROL

The MCB's DC CONTROL section (RLY1 through RLY12) powers valves, motors, heaters, fan, etc. These devices receive their 24 VDC power directly from the relay connector. These relay outputs power their connected devices directly, sourcing up to 2 amps each. The (+) pin of each relay connector is hard wired to 24 VDC. The (-) pin of each channel switches in ground via the relay. Each output channel has an adjacent LED. When an LED is on, it indicates that the connector's (-) pin is pulled to ground, allowing current to flow through a connected device.
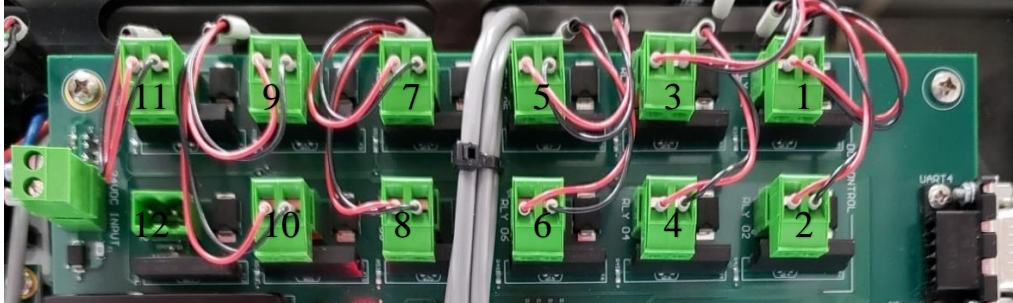
Positions of RLY1 through RLY12

Relay	Description	Reference
RLY 1	Upper Sat Heat	6.6.3
RLY 2	Lower Sat Heat	6.6.3
RLY 3	Tso Tube Heat (opt)	6.7.1
RLY 4	Sat Port Heat	6.4.1
RLY 5	Gen Mode Pulse	6.8.3
RLY 6	Purge Mode Pulse	6.2.3
RLY 7	Flow Heat A (opt)	6.7.2
RLY 8	Flow Heat B (opt)	6.7.2
RLY 9	Low Sat P Select	6.8.9
RLY 10	Ext P Select	6.8.9
RLY 11	Vent	6.8.3
RLY 12	Reserved	

6.3.2 D/A Outputs

The MCB's D/A Output section has two 0-5 VDC analog outputs used to independently control the power to the upper and lower stirling coolers.

Output B.V2 controls the upper Stirling cooler, while output B.V3 controls the lower stirling cooler. B.V2 and B.V3 each set an output level of 1-5 VDC representing a Stirling cooling power setpoint of 0-100%.
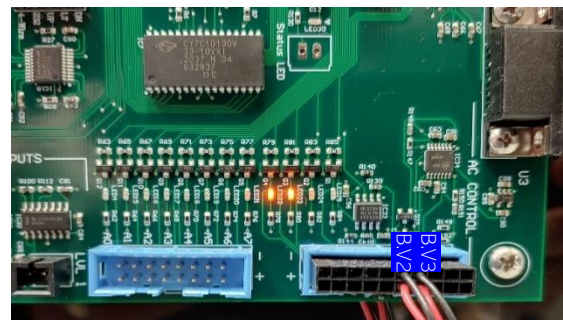
6.3.3 A/D Inputs

The MCB's A/D INPUTS section (AD0-AD7) has an 8 channel, 14-bit, 5 volt analog to digital converter system. Each connector also has 5, 12, or 24 VDC power available to directly power the connected devices or sensors. Note that connections to AD1 and AD3 are not used as measurement channels, but rather are utilized only for sources of power to drive the temperature measurement board, or to provide energizing signal to SSR1 to power up the PC.

Analog Input	Description	Reference
AD0		
AD1	5 VDC to PCSD board to enable SSR1	6.1.2
AD2	Regulator Pressure sensor	6.8.1
AD3	12 VDC power to Temp Board	6.4
AD4-7	Unused	
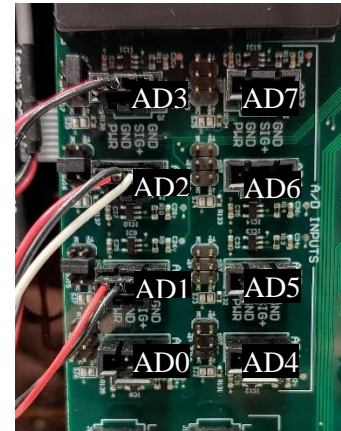
6.4   **Precision Resistance Measurement Board**

All temperature sensors in the G3 are 100Ω Platinum Resistance Thermometers (PRT's). The following table lists the probe channels and functions of the G3.

Channel	Probe name	Function
CH0/T1	Tsx	Auxilary Sat Temp
CH1/T2	Tsu	Upper Sat Temp
CH2/T3	Tsl	Lower Sat Temp
CH3/T4	Tso	Sat Outlet Temp (opt)
CH4/T5	Tx1	External Temp 1
CH5/T6	Tx2	External Temp 2
CH6-11/ T7-12	Spare	
CH 12/ T13	RefOhmsLow	Reference resistor
CH13/ T14	RefOhmsHi	Reference resistor
CH14-15/ T15-16	Unused	
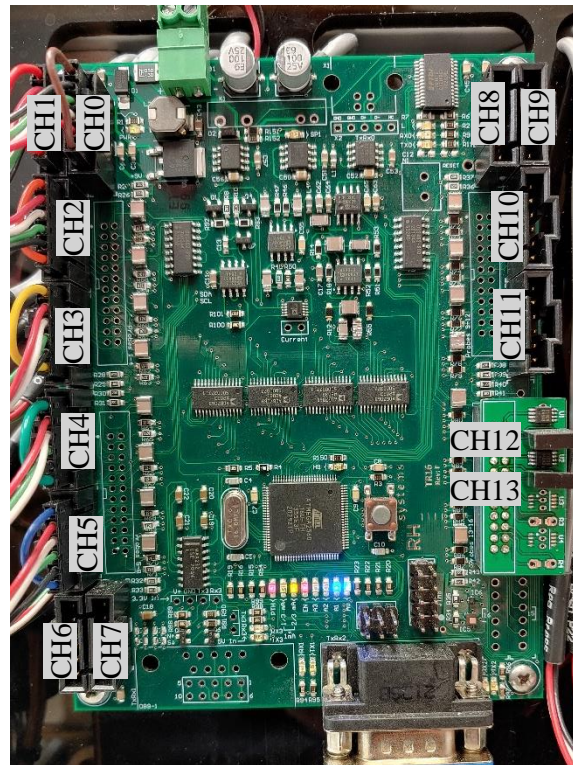
The board measures all thermometers using full current reversal DC pulse mode excitation and records these raw values. The raw values are then ratio-metrically compared to measurements of the precision reference resistors to determine their precise resistance values. The resistance values are then computed into individual temperatures using each probe's specific coefficients.

All probes are wired to the temperature board as 4-wire, 100-ohm PRTs. All probe connections are made via straight single row Molex plugs. The reference resistors are permanently soldered to an intermediary board and plugged into a 4-channel header. The reference resistors are known resistances, whose values are programmed into the MCB for use in determining resistances of the PRTs (typically approximately 60 and 140 ohms).

Communication occurs via RS-232 to the MCB UART 7 at 115200 baud, 8 bits, 1 stop bit, no parity.

12 VDC power is supplied from AD3 of the MCB.

6.5 Stepper Motor Controllers

Stepper motor controllers control the position of custom linear actuated needle valves used to vary and control flow rate.

The stepper controllers STF1 and STF3 control the G3's Flow1 and Flow3 setpoints (Flow 2 is controlled in a different manner and therefore has no stepper controller). The stepper controllers are individually addressable via an RS-485 communication protocol.

STF1 communicates at address 1, while STF3 communicates at address 3. They are linked together via an RJ45 style serial cable (not ethernet) and ultimately communicate with the MCB on UART0 at 9600 baud, 8 data bits, 1 stop bit, no parity.

Power for the stepper controllers is supplied directly from the 24 VDC power supply PSU2.
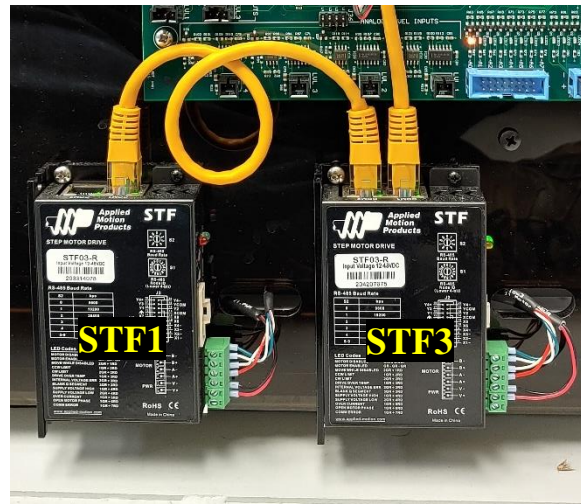
6.6 Saturator Temperature Control System

Saturator temperature is controlled by two Stirling coolers, one at the top and one at the bottom, which provide a direct contact surface to cool the top and bottom of the saturator assembly. The cooling is readily transferred by conduction from contact between plates in the saturator assembly. Contact heaters are also installed to heat the saturator. Saturator temperature is maintained by control of the Stirling coolers and heaters attached to the inlet and outlet plates of the saturator. The coolers and heaters work in tandem to produce stable temperatures at both the saturator inlet and outlet.

6.6.1 Stirling Controllers

The Stirling controller boards drive the Stirling coolers by producing an approximate 80 Hz variable amplitude drive signal which is frequency modulated on a high frequency carrier wave. This carrier wave is demodulated within the Stirling's electromagnetic coil which then provides the force to drive its piston.

The amplitude of the 80 Hz signal applied to the electromagnetic coil effectively determines the cooling power of the Stirling.

The controller boards provide power to the Stirling cooler fans at connector CN6. The Stirling hot side temperature is also monitored at connector CN2 to auto-stop the coolers under fault conditions.

6.6.2 *Upper and Lower Coolers*

The upper cooler is nearest the saturator outlet. Cooling power applied via the Stirling cooler is controlled by MCB output B.V2, a 1-5 VDC signal which represents 0 to 100% cooling power. The 1-5 VDC signal is injected at CN7 pins 1(+) and 8(-) of the upper Stirling controller board. An enable signal (0V) is applied to CN7 pin 4 via a jumper wire from CN10 pin 6. The 48 VDC power supply input to the Stirling controller board is connected at CN1 pins 1(+48 VDC) and 2(GND). The Stirling drive output is connected to CN8 pins 1 and 2.

The upper cooler is nearest the saturator outlet. Cooling power applied via the Stirling cooler is controlled by MCB output B.V3, a 1-5 VDC signal which represents 0 to 100% cooling power. The 1-5 VDC signal is injected at CN7 pins 1(+) and 8(-) of the upper Stirling controller board. An enable signal (0V) is applied to CN7 pin 4 via a jumper wire from CN10 pin 6. The 48 VDC power supply input to the Stirling controller board is connected at CN1 pins 1(+48 VDC) and 2(GND). The Stirling drive output is connected to CN8 pins 1 and 2.

Connector	Pin	Signal	Function
CN1	1	+48 VDC	Power In
CN1	2	Gnd	Power In
CN2	1	Warm side thermistor	Measurement
CN2	2	Warm side thermistor	Measurement
CN6	1	DC (+)	Fan
CN6	2	DC (-)	Fan
CN7	1	1-5 VDC(+)	Input SetPt
CN7	4	0 VDC	Enable
CN7	8	0 VDC	Input Gnd
CN8	1	Stirling Output	Drive Output
CN8	2	Stirling Output	Drive Output

6.6.3 Upper and Lower Heaters

The upper and lower saturator heaters are contact heaters on the circumference of each of the Stirling cooler's cold flanges. The heaters are used to counteract the effects of cooling and work in tandem with the coolers to control upper and lower saturator temperature. The heaters are operated from 24 VDC. The heaters are connected to fixed frequency pulse width modulated (PWM) output signals of the MCB. The upper heater is connected to RLY1. The lower heater is connected to RLY2.

6.6.4 Saturator temperature measurements

The upper saturator temperature, nearest the saturator's gas outlet, is measured by a 100 Ω platinum resistance thermometer (PRT) and connected through a bulkhead fitting to CH1/T2 of the precision temperature measurement board. This PRT is designated T_{sl}. This PRT is used as both the measurement and control thermometer for the upper saturator temperature.

The lower saturator temperature, nearest the saturator's gas inlet, is measured by a 100 Ω platinum resistance thermometer (PRT) and connected through a bulkhead fitting to CH2/T3 of the precision temperature measurement board. This PRT is designated T_{su}. This PRT is used as both the measurement and control thermometer for the lower saturator temperature.

An auxiliary thermometer is available for secondary measurement of either the upper or lower saturator temperature, measured by a 100 Ω platinum resistance thermometer (PRT), connected through a bulkhead fitting to CH0/T1 of the precision temperature measurement board. This PRT is designated T_{sx}. This PRT is a measurement only, and not used in saturator temperature control.

All three temperature probes (T_{su}, T_{sl}, and T_{sx}) are uniquely configured to work within a vacuum environment. While each probe is sealed, they are not fully hermetic. Therefore, if used as-is, the internal gas environment within the probe sheath surrounding the sensing element may eventually succumb to the effects of the vacuum environment. Vacuum around the sensing element would result in loss of adequate thermal contact due to a lack of molecules to transfer heat. The G3 overcomes this potential problem by allowing the probes internal sheath to remain at atmospheric pressure while physically residing within the vacuum chamber. The probe sheath is sealed to a pressure tube that is vented to the environment outside the vacuum chamber. This allows the chamber to retain vacuum while the probe's internals remain at atmospheric pressure.

6.7   Auxiliary Heaters

6.7.1 Outlet Tube Heating

Heaters on the saturator outlet tubing are used to assist in the purge process, driving condensed water vapor from undesired areas of the saturator outlet. In addition, they are used to warm the gas to a suitable exit temperature. Thermometers on the tube heaters measure the temperatures and are used to control fixed frequency PWM output signals. Both saturator outlet heaters operate from 24 VDC. The heater closest to the saturator outlet is connected to RLY 4 of the MCB. The other heater (optional), located further from the saturator but over a longer area of the tube, is connected to RLY 3.

6.7.2 Flow Controller Heating

Depending on the specific G3, heaters may also exist on the flow controller to assist in drying the flow controller's gas path. Flow controller temperature is an integral measurement of the flow controller itself and is queried along with its other parameters. Heating of the flow controller is accomplished through fixed frequency PWM of contact heaters (if installed) on the outside of the flow controller body. The flow controller heater is connected to the MCB's RLY 7. If a second flow controller option is installed inside the vacuum chamber, the heater (if it has one) is connected to RLY 8.

6.8   Pneumatic System

The pneumatic system is responsible for control of gas flow and pressures throughout the system. The pneumatic system consists of the following major components: pressure inlet regulator, regulated pressure measurement, sat pressure regulator, saturator, flow control valve, flow meter, and gas outlet.

Compressed air enters the system at the back panel fitting labeled *Gas In*. The Gas In fitting is connected via tubing to the pressure regulator.
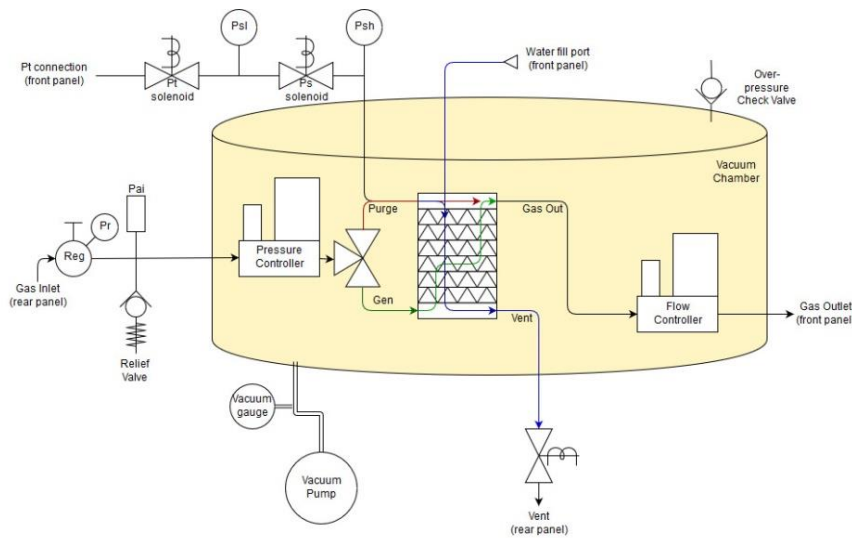

6.8.1 Regulator and Pressure Sensor

The pressure regulator is used to regulate the system pressure, isolating it from upstream pressure variations. Gas enters the regulator assembly. The inlet pressure safety relief valve protects the system from input pressure in excess of 300 psig. The regulated pressure safety relief valve protects the system from regulated output pressure in excess of 200 psig. Regulated pressure is adjusted by turning the knob to increase or decrease the regulated pressure output.

Pressure should be adjusted between 35 psi minimum and 120 psi maximum but should always be set for a value below your available supply pressure.

Regulated pressure output is indicated on the attached dial gauge and is also measured by the Regulator Pressure Sensor through AD3 of the MCB.

Gas is then connected inside the vacuum chamber to the pressure controller.
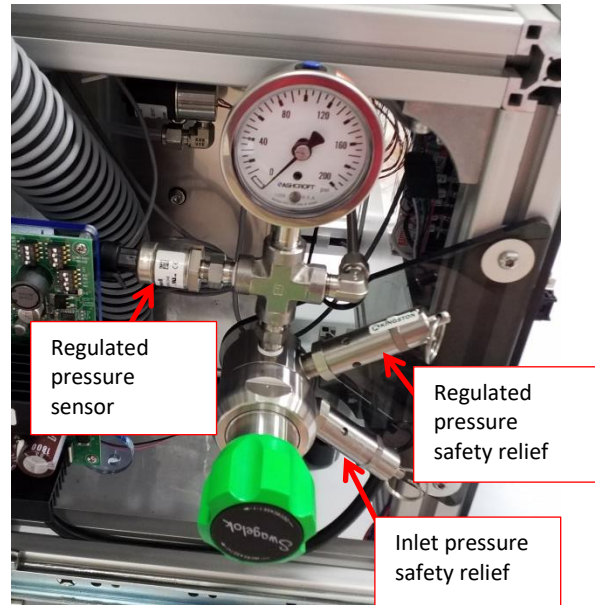

6.8.2 Pressure Controller

The pressure controller is used to maintain a selectable pressure within the saturator, independent of flow rate. It has an integral gauge pressure sensor with measurement relative to its ambient environment pressure. Since the controller is located within the vacuum chamber, its ambient environment pressure is vacuum, or 0. This causes the sensor to effectively measure absolute pressure rather than what we would traditionally refer to as gauge pressure.

Pressure regulation of the saturator is accomplished via an internal closed loop control using its pressure measurement and its proportional solenoid valve. Rather than relying on the integrated pressure measurement for system accuracy, a higher accuracy independent pressure is used to measure the saturator pressure. Any differences between the two sensors are automatically accounted for to ensure the saturator is controlled with the highest accuracy measurement.

Controller power (12 VDC) and communication is via UART 0, at address 'P' on a multi-drop RS-232 connection. This multi-drop RS-232 connection is shared with the flow controller. Queries go out from the MCB on UART 0_Z. Replies from the pressure controller are received on UART 0_A. Signal ground connection is at UART 0_GND. Typical communication occurs at 19200 baud, 8 data bits, 1 stop bit, no parity.
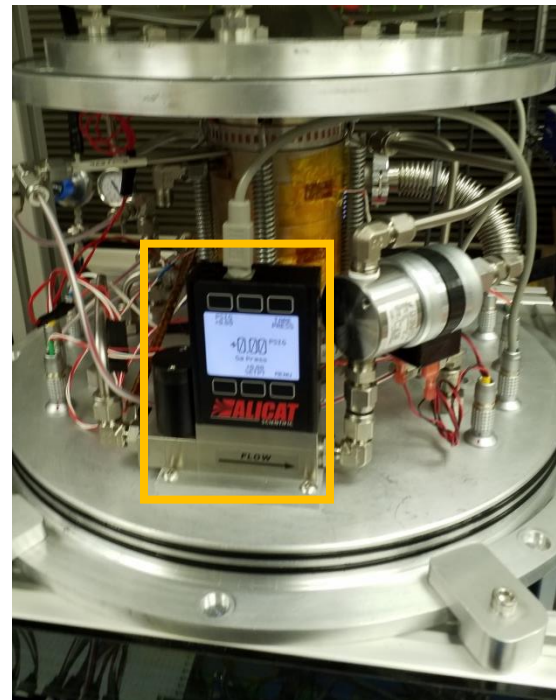
6.8.3 Generate/Purge Solenoid Valve

The Generate/Purge Solenoid Valve is a magnetically locking directional valve used to determine the entry point of gas flowing into the saturator. When generating, gas flows out the center stem of the valve and is directed into the bottom of the saturator. Gas then flows up and out the top of the saturator. This is the normal direction while generating.

When purging or filling with water, gas flows through the base of the Generate/Purge valve and is directed into the top of the saturator. If the vent solenoid is closed, gas may flow through the flow controller. This allows dry gas to be used to dry out the top gas exit tube of the saturator, resulting in a purge mode. If the vent solenoid is open, gas flows from top to bottom in the saturator allowing the saturator to be filled with water while also pushing out any excess.

Flow direction through the Generate/Purge valve is set via an actuating pulse from MCB RLY 5 (Generate) or RLY 6 (Purge). The valve magnetically locks in the last set position.

Saturator

Generate/Purge Solenoid Valve
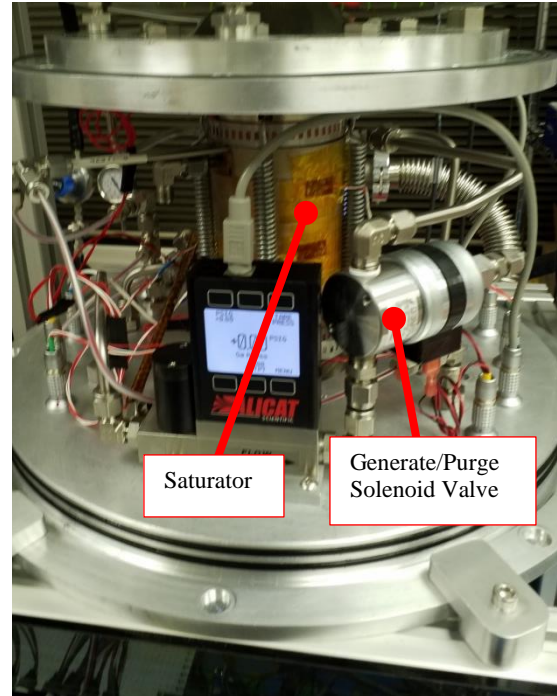
6.8.4 Saturator

The saturator is an efficient heat exchanger constructed from disks of solid copper. Channels for water and gas are machined into the solid disks which are then nickel plated, stacked, and vacuum brazed into a single, solid column structure. Normal flow is bottom to top. Purge flow is across the top plate only. Flow during water fill/clear is top to bottom.

6.8.5 Flow Controller – Alicat

Flow controller(s) measure and control the flow rate through the saturator and finally through device(s) under test. It is powered from 12 VDC and is read via RS-232 communication. It is connected directly to the MCB's UART 0. Power to the flowmeter (12 VDC) is provided by UART 0 12+ and UART 0. Measurements from the flow meter are queried at addresses 'F', 'G', and 'H' (for Flow 1, 2, and 3 respectively) and received via RS-232. Queries go out from the MCB on UART0_Z. Replies from the flow meter are received on UART0_A. Signal ground connection is at UART0_GND. Typical communication is at 19200 baud, 8 data bits, 1 stop bit, no parity. Newer G3 systems only use Alicat flow control on Flow 2. Flow 1 and 3 are handled via Stepper valve and flowmeter (see section 6.8.6 Flow Control - Stepper Valve and Flowmeter)

6.8.6 Flow Control - Stepper Valve and Flowmeter

The flow controller(s) mentioned in section 6.8.5 work well when generating frost point values warmer than about -70 °C. For lower values, a different flow control approach is utilized. This alternate approach relies on a custom designed linear positioning needle valve placed within the vacuum chamber.

For control feedback, flow measurement is made via a separate flowmeter. Although the flowmeter physically resides outside the vacuum chamber, it is hermetically sealed (all welded construction and connections, no elastomers). The flowmeter(s) receive 24 VDC power and are read via RS-485 communication on device address 1, 2, or 3 (for Flow 1, 2, or 3), or globally on address 254 (depending on system configuration). Typical communication parameters are 9600 baud, 8 bits, 1 stop bit, no parity. Flow meters share communications with other devices on UART2 of the MCB.
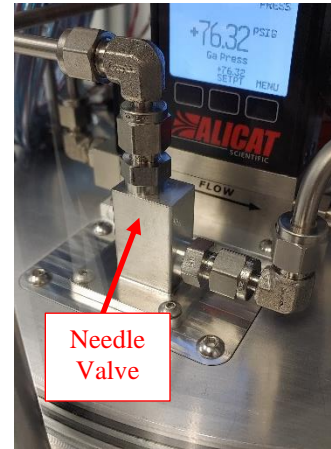
The needle valves, physically located within the vacuum chamber, are actuated via stepper motor driven linear actuators. Each stepper motor is physically located outside, underneath the vacuum chamber. The stepper motors are each operated by a stepper motor controller connected to the MCB via either RS-232 or RS-485, address as device 1, 2, or 3 (for Flow 1, 2, 3), and connected via UART 0. The stepper motor controllers are powered by 24 VDC.

6.8.7 Vent Solenoid

For venting the saturator of pressure, and for draining of excess water during filling operations, the G3 is equipped with a vent solenoid. The vent valve is a normally closed solenoid valve.

To vent, the solenoid is energized via RLY 11. When de-energized, the vent valve is blocked.

It is physically located underneath the left side of the vacuum chamber. It's outlet tube connects to the vent fitting at the G3's bottom rear panel.
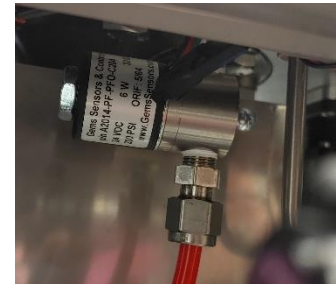
6.8.8 High Range Pressure Sensor, Ph

The high range pressure sensor, Ph, continually measures the saturation pressure. It is powered from 12 or 24 VDC (depending on make and model) and is read via RS-485 communication on device address 01. It is connected directly to the MCB's UART 2. DC power to the pressure sensor is provided by UART 2. Measurements from the pressure sensor are queried and received via addressable RS-485, 2-wire, half-duplex mode RS-485 connection between the MCB and pressure sensor occur on UART 2 _Z and _Y. Communication parameters are typically set at 9600 baud, 8 data bits, 1

stop bit, no parity. The UART 2 communication channel is also shared with the other pressure sensor Pl, the vacuum gauge, and the vacuum pump.

If Keller brand pressure sensors are utilized, communication with pressure sensors is made via a separate connection on UART 3 rather than a shared connection on UART2.

6.8.9 Low Range Pressure Sensor, Pl

The low range pressure sensor, Pl, measures the saturation pressure during those times when sat pressure is low enough to be within its measuring range. When this occurs, the sensor shares its time between measurements of the saturator, and measurements of the external (front panel) pressure. Use of the low range sensor for measurement of the saturator is activated by energizing RLY 9 and de-energizing RLY 10 of the MCB.

When the saturation pressure rises above the measuring range of this sensor, the low range sensor disconnects from the saturator. The saturator is once again monitored only by the high range sensor, freeing the low range sensor to exclusively monitor the external (front panel) pressure. Use of the low range sensor for measurement of the external (front panel) pressure is activated by de-energizing RLY 9 and energizing RLY 10 of the MCB.

The sensor is powered from 24 VDC and is read via RS-485 communication on device address 02. It is connected directly to the MCB's UART 2. DC power to the pressure sensor is provided by UART2. Measurements from the pressure sensor are queried and received via addressable RS-485, 2-wire, half-duplex mode RS-485 connection between the MCB and pressure sensor occur on UART 2 _Z and _Y. Communication parameters are typically set at 9600 baud, 8 data bits, 1 stop bit, no parity. The UART 2 communication channel is also shared with the other pressure sensor Ph, the vacuum gauge, and the vacuum pump.

If Keller brand pressure sensors are utilized, communication with pressure sensors is made via a separate connection on UART 3 rather than a shared connection on UART2.
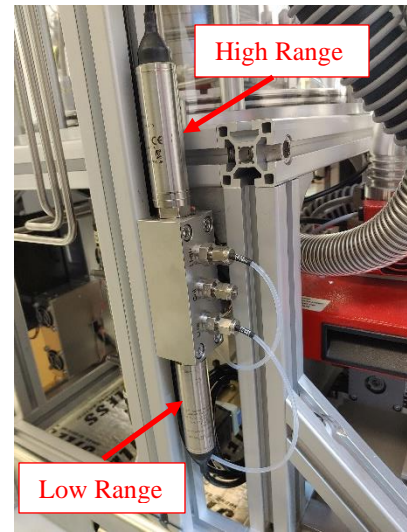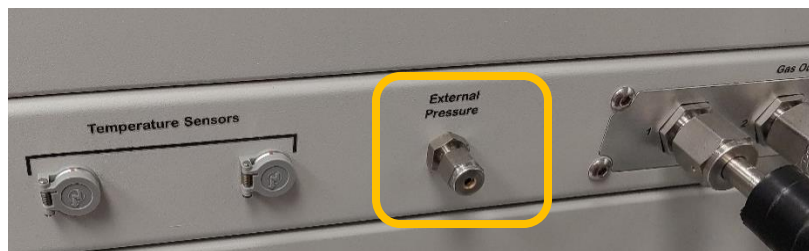
6.8.10 External Pressure Sensor

There is no dedicated external pressure sensor in the G3. Rather, the low range sensor, P_l, is used to monitor external (front panel) pressure, time-sharing when needed between the external (front panel) pressure and the saturation pressure. See 6.8.9 for further details.
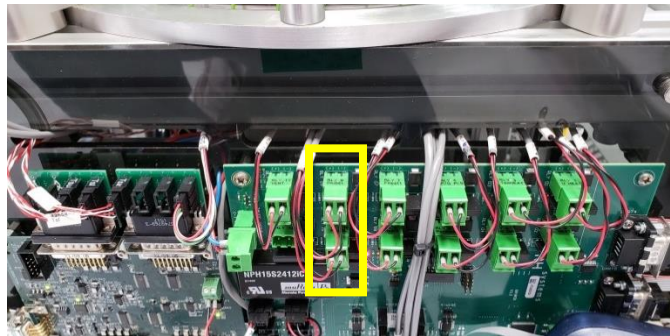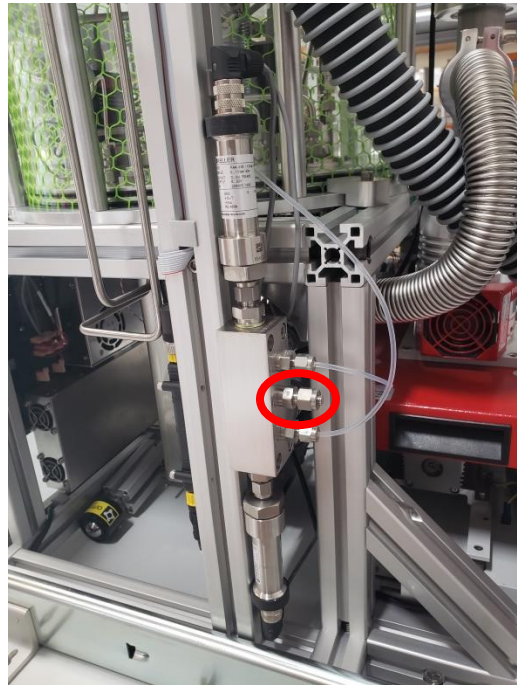
7 Calibration

7.1 Pressure Calibration

Proper calibration of the transducers used for measurement of saturation and test instrument pressure is needed to ensure adequate system performance. There are two separate sensors, each with a different operating range. Calibration of these two sensors should be performed individually, one at a time.

7.1.1 Calibration of Low Range Transducer

1. Set the Saturator Pressure setpoint to 0 (it will show its minimum but that's ok).

2. Set all Flow Rate setpoints to 0.

3. Unplug the green connectors at RLY 9 and RLY 10 of the MCB (see section 6.8.9). This pneumatically isolates the pressure transducer.

4. Remove the ¼" Swagelok cap on the CAL port of the pressure transducer manifold.

5. Connect a pressure calibrator (a source of regulated pressure and a pressure reference) to the CAL port.

6. For easy visualization of steady conditions, show **Psl** on a graph.

7. In the secondary data window, show **Low Range Pressure Coefficients**. In addition to the transducer's coefficients, you'll also see both the **Pressure** and **Raw Reading** of the transducer.

8. Apply a minimum of 4 different calibration pressures over the range of the transducer. Since the low range transducer is a barometer, its measurement range is approximately 800 to 1200 mb (11 to 17 psia).

9. For each applied pressure, record your Reference Pressure along with the Raw Reading and Pressure of the transducer. This information can be used as your As-Found calibration data.

10. Using the **Reference Pressure** and **Raw Reading** data, compute new calibration coefficients A0, A1, A2, and A3 to the formula

$$P = A0 + A1*Raw + A2*Raw^2 + A3*Raw^3$$

where P is **Reference Pressure**

Raw is **Raw Reading**

11. Enter the new coefficient into the appropriate field of the **Low Range Pressure Coefficients** window.

12. Re-run the pressure calibration points again to collect your As-Left calibration data.

13. Disconnect the pressure calibrator from the CAL port.

14. Re-install the ¼" Swagelok cap on the CAL port.

15. Re-install the green connectors of RLY 9 and RLY 10

Range of reasonable expected values for A0…A3

Coefficient	Default	Expected range of computed value
A0	0.0	Value of A0 should be between 0 and ±1
A1	1.0	Value of A1 should be between +0.9 and +1.1
A2	0.0	Value should be between 0 and ±1E-5
A3	0.0	Value should be between 0 and ±1E-9

7.1.2 Calibration of High Range Transducer

1. Set the Saturator Pressure setpoint to 0 (it will show 10 psia as a minimum but that's ok).

2. Set all Flow Rate setpoints to 0.

3. Unplug the green connectors at RLY 9 and RLY 10 of the MCB (see section 6.8.8). This pneumatically isolates the pressure transducer.
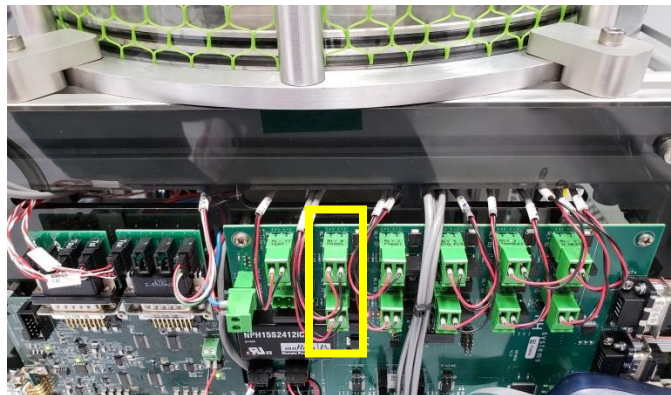
4. Remove the 1/8" tube from the HIGH port of the pressure transducer manifold.

5. Connect a pressure calibrator (a source of regulated pressure and a pressure reference) to the HIGH port.

6. For easy visualization of steady conditions, show *Psh* on a graph.

7. In the secondary data window, show **High Range Pressure Coefficients**. In addition to the transducer's coefficients, you'll also see both the **Pressure** and **Raw Reading** of the transducer.

8. Apply a minimum of 4 different calibration pressures over the range of the transducer. The measurement range of the high range transducer is approximately ambient to 10 bar (ambient to 145 psia) although the pressure never exceeds 8 bar in use.

9. For each applied pressure, record your Reference Pressure along with the Raw Reading and Pressure of the transducer. This information can be used as your As-Found calibration data.
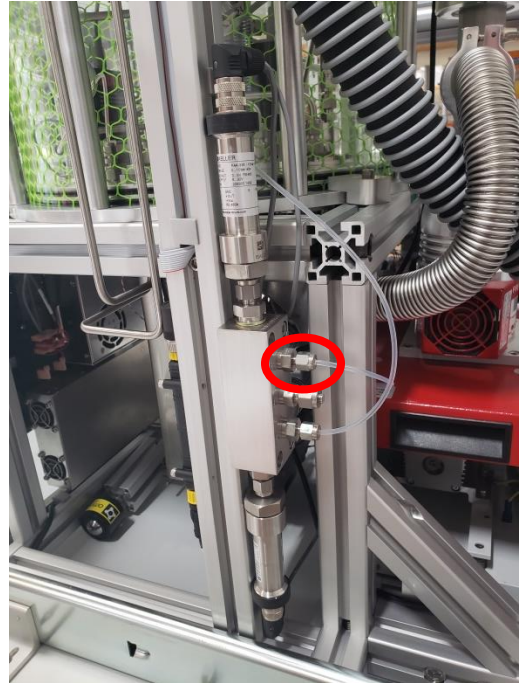
10. Using the **Reference Pressure** and **Raw Reading** data, compute new calibration coefficients A0, A1, A2, and A3 to the formula

$$P = A0 + A1*Raw + A2*Raw^2 + A3*Raw^3$$

where   *P* is **Reference Pressure**
          Raw is **Raw Reading**

11. Enter the new coefficient into the appropriate field of the **High Range Pressure Coefficients** window.

12. Re-run the pressure calibration points again to collect your As-Left calibration data.

13. Disconnect the pressure calibrator from the High port.

14. Re-install the 1/8" tube to the HIGH port.

15. Re-install the green connectors of RLY 9 and RLY 10

Range of reasonable expected values for A0…A3

Coefficient	Default	Expected range of computed value
A0	0.0	Value of A0 should be between 0 and ±1
A1	1.0	Value of A1 should be between +0.9 and +1.1
A2	0.0	Value should be between 0 and ±1E-5
A3	0.0	Value should be between 0 and ±1E-9

7.2　Temperature Calibration

Proper calibration of the sensors used for measurement of the saturator temperature assures adequate system performance. There are three sensors used for measurement of the saturator (Tsu, Tsl, Tsx). Optionally, there are two additional sensor channels available (Tx1, Tx2). The use of these additional channels is dependent on user requirements.

7.2.1　Calibration of Sat Temperature Probes (Tsu, Tsl, Tsx)

Calibration of the saturator temperature probes requires access into the vacuum chamber.

1. Refer to section 8.1 Extracting/Retracting Vacuum Chamber to pull the entire vacuum chamber forward for better access.

2. Refer to section 8.2 Opening Vacuum Chamber to open the vacuum chamber, gaining access to temperature probes inside.

3. Secure the vacuum chamber in the open position.

4. Note the location and identification of the three temp probes installed in the saturator.

5. Remove the temperature probes and wipe them with a cloth to remove thermal grease residue.

6. Unbundle the excess wire allowing the probes to be located away from the vacuum plate. Do the same for all three probes.

7. Install the probes in your temperature calibration bath along with your reference thermometer. You can calibrate them all together at the same time.

8. For easy visualization of steady conditions, show ***Tsu, Tsl,*** and ***Tsx*** on a graph.

9. In the secondary data window, show ***Temperatures***. This window shows temperatures and resistances of all probes.

10. Using the calibration bath, run at least 4 temperature points over the desired range. A range of at least -90 °C to +10 °C is preferable, however a larger range may also be used for purposes of calibration. For the lowest point, an LN2 calibration may be a suitable option.

11. Record the As-Found data for each calibration point which consists of Reference Temperature, Probe Temperature and Probe Resistance for each probe being calibrated.

12. Using the Reference Temperature and Probe Resistance, compute the R_0, a, b, and c coefficients to the Callendar-Van Dusen equation

    $$R = R_0[1 + a\text{t} + b\text{t}^2 + c(\text{t}-100)\text{t}^3]$$

    where　R is resistance of the probe in ohms, and
    　　　　t　is the Reference Temperature in °C

13. Select the secondary window for the specific probe, such as ***[Tsu] Sat Temp Upper Coefficients***, and enter the new Ro, a, b, and c coefficients.

14. Press the ***Save Coefficients*** button to store the new coefficients to the G3 permanent memory.

15. Repeat steps 12 through 14 for each of the remaining probes being calibrated.

16. Re-run the temperature calibration points to record your As-Left calibration data.

17. Using a syringe or other suitable instrument, insert a small amount (~0.5 ml) of low temperature thermally conductive vacuum grease into the hole where the temp probes will be re-installed. (Apiezon® N cryogenic vacuum grease is suitable.)

18. Recoil excess cable accordingly and reinsert each probe it the proper location to an insertion depth of 50 mm (2").

19. Refer to section 8.3 Closing Vacuum Chamber to close the vacuum chamber. Pay attention to the radial alignment mark when doing so.

7.2.2 Calibration of External Temperature Probes (Tx1, Tx2)

1. Plug the probe cables into the front panel connectors.

2. Install the probes in your temperature calibration bath along with your reference thermometer. You can calibrate them together at the same time.

3. For easy visualization of steady conditions, show *Tx1* and *Tx2* on a graph.

4. In the secondary data window, show *Temperatures*. This window shows temperatures and resistances of all probes.

5. Using the calibration bath, run at least 4 temperature points over the desired range.

6. Record the As-Found data for each calibration point which consists of Reference Temperature, Probe Temperature and Probe Resistance for each probe being calibrated.

7. Using the Reference Temperature and Probe Resistance, compute the R_0, a, b, and c coefficients to the Callendar-Van Dusen equation

$$R = R_0[1 + a\mathrm{t} + b\mathrm{t}^2 + c(\mathrm{t}\text{-}100)\mathrm{t}^3]$$

where R is resistance of the probe in ohms, and
t is the Reference Temperature in °C

8. Select the secondary window for the specific probe, such as *[Tx1] External Temp 1 Coefficients*, and enter the new *Ro*, *a*, *b*, and *c* coefficients.

9. Press the *Save Coefficients* button to store the new coefficients to the G3 permanent memory.

10. Repeat steps 7 through 9 for each of the remaining probes being calibrated.

11. Re-run the temperature calibration points to record your As-Left calibration data.

8 Vacuum Chamber

8.1 Extracting/Retracting Vacuum Chamber

1. Remove the front panel for access to the vacuum chamber. It may be best to remove the side panels as well.

2. As the top front panel moves with the vacuum chamber, you'll need to unsecure it from the G3 frame. To do so, reach up into the front top panel corners and loosen the 2 thumb screws from each side that are securing the top panel to the frame. Do not remove the screws completely. They only need to be loosened to allow the panel to move with the vacuum chamber.
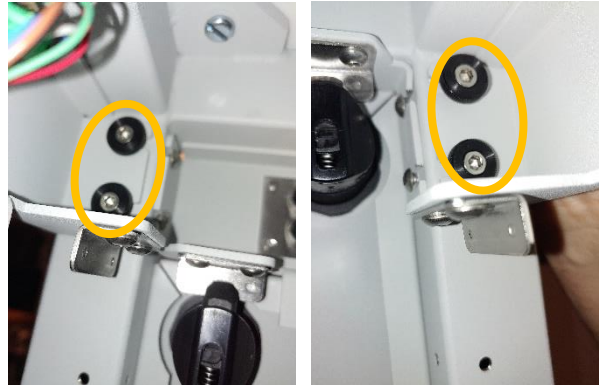
3. The center portion of the lower rear panel also moves with the vacuum chamber. Completely remove the 6 thumb screws from the center portion, allowing it to move freely with the vacuum chamber. Save them for later reinstallation.

4. The left slide rail is fitted with a retaining pin for transportation. Remove the pin by depressing the center button and pulling it straight out from the rail. Move it clear of the rail to prevent interference with slide rail movement.
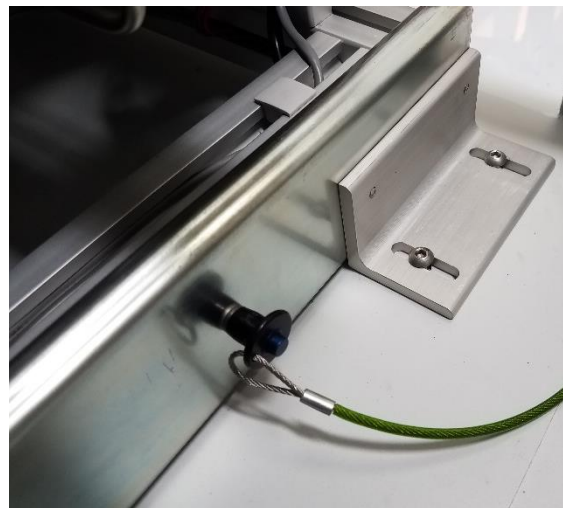
5. Unlock the slide rail by pressing down on the yellow tab with your hand or foot. Slide the chamber out about **6 to 8 inches only**. Use caution when sliding out chamber. If sliding out too far, the system may tip forward.

6. Position the roller kick stand for balance. Reach under chamber assembly and pull pin lever to release kick stand from its locked position. Rotate the kick stand 90 degrees downward. Ensure the pin locks in place with the foot in the downward position.


7. It is now safe to extend the chamber fully outward toward the front. The foot will prevent the G3 from tipping.

Retraction of the vacuum chamber is the reverse of extraction.

8. Push the chamber inward toward the frame, stopping short about 6 inches.

9. Pill the pin lever on kick stand and rotate the stand up 90° to the horizontal position. It should easily lock into position.

10. Push the chamber in fully until the slide locks into position.

11. Tighten the 4 top panel thumb screws which secure the top panel to the frame.

12. Re-install the 6 thumb screws in the lower rear panel.

13. Re-insertion of the slide locking pin is optional if the system is not intended for movement or transport.

8.2 Opening Vacuum Chamber

1. Warm the saturator to a temp of 20°C. Since the saturator exterior will be exposed to room ambient air during the calibration procedure, warming the saturator prevents unwanted condensation on its outer surface.

2. Set the Saturator Pressure setpoint to 0.

3. Set all Flow Rate setpoints to 0.

4. Stop *Cooling*.

5. Stop *Vacuum* and wait a few minutes for the vacuum pump's turbine to slow below 200 Hz.

6. Refer to section 8.1 Extracting/Retracting Vacuum Chamber to pull the entire vacuum chamber forward for better access.

7. Remove the gray striped hose on the right side from its upper Stirling fan shroud. Push it back and out of the way.

8. Slowly open the vacuum vent valve on the top right side of the chamber. This allows air to enter the chamber. The mechanical gauge on the top front of the chamber will begin to rotate clockwise toward 0. Wait until 0 pressure is achieved, then open the valve completely.

9. Remove all 8 vertical columns by rotating counter-clockwise as viewed from above. The hex bolt is pocketed on the underside of the top plate. The column may need to be lifted for the bolt to travel. This allows better clearance for removal.
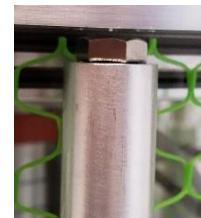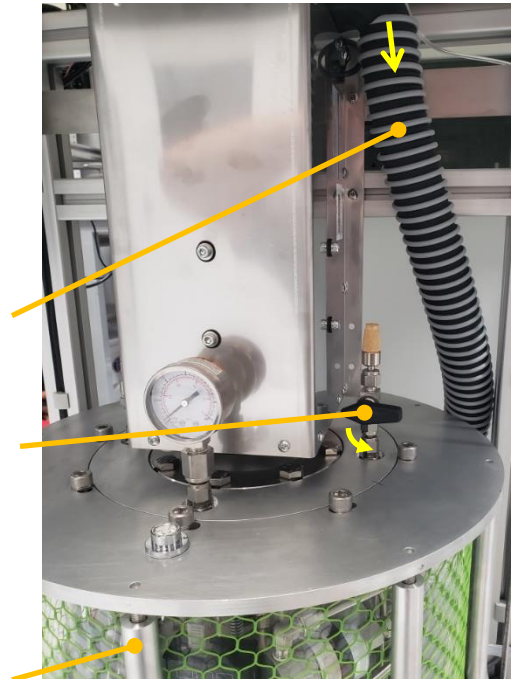
10. Using an 8 mm or 5/16" hex key, loosen the 8 screws holding the top chamber plate. This is done slowly and in sequence to avoid damage to plate and/or acrylic tube. Use a star pattern skipping 2 screws between each one that you turn, continuing in a circular pattern. Loosen first screw approximately ¼ turn then move to next screw in the sequence. Repeat this pattern until all eight screws are fully loosened and can be removed. For example, if the screws are numbered in a circle from 1 to 8, loosen in the following order: 1, 4, 7, 2, 5, 8, 3, 6.

11. Using a small flat blade screwdriver, loosen the screws holding the RS-232 connector to the leftmost MKS flowmeter. Remove the RS-232 cable from the flow meter to make room for chamber removal.

12. Once the top chamber plate is ready to be removed, hold the ring plate underneath with your fingers and apply pressure with thumbs on the sterling flange. Lift and rock the plate slightly in different areas until acrylic clears bottom plate O-rings.

13. Lift the plate upward to access the inner chamber.

8.3 Closing Vacuum Chamber

Chamber reassembly is basically the reverse of removal.

1. Inspect the O-rings and sealing surfaces for cleanliness. Remove any debris that may affect sealing.

2. Place chamber back in place. Pay close attention to the alignment mark on the top for proper radial alignment. Improper radial alignment will result in misalignment of outer upright support bars in step 5 below.
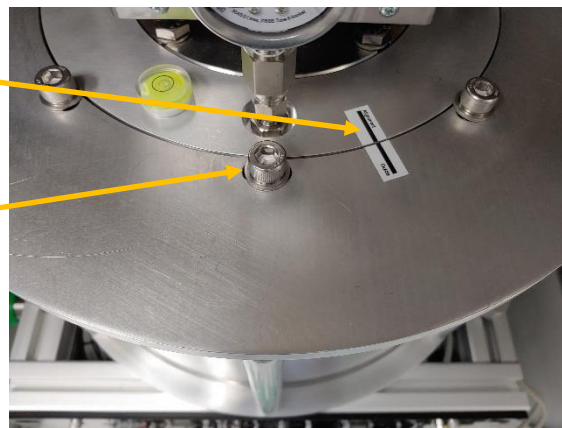
3. Reinstall the 8 socket screws and tighten them slowly and evenly using the star pattern mentioned previously. Continue to pay close attention to the alignment mark as you tighten.

4. Snug up all 8 bolts evenly. Do not overtighten.

5. Install the 8 outer support bars. The hex bolt fits up into the hex pocket on the underside of the top plate. As you spin clockwise, the support rod assembly lengthens and fits nicely into the round hole below it. LOOSELY FINGER TIGHTEN ONLY to the point where the support touches both the top and bottom plates. DO NOT OVERTIGHTEN. Once vacuum is applied to the system, the support bars will become tight.

6. Reattach the MKS flowmeter RS-232 connector and tighten in place with a small screwdriver.

7. Reattach the upper Stirling cooler's gray striped fan hose.

8. Close the vacuum chamber vent valve. When closed, the valve's lever will be horizontal and pointing inward.

9. Start the vacuum pump.

10. Observe the vacuum gauge for proper evacuation. The needle should begin moving counter-clockwise indicating that evacuation is occurring.

11. Press the yellow slide tab and slide the system back toward its normal position, stopping about 6 inches short.

12. Reach in to release center foot by pulling its pin and rotating upward. It should 'click' into place when horizontal.

13. Slide the system the rest of the way in until the yellow tab locks the slide in place. It is not necessary to install the locking pin (unless you plan to relocate or ship the system).

14. Replace 6 thumbscrews in the lower back panel.

15. Retighten 4 thumbscrews inside upper top panel edges.

16. Replace side panels.
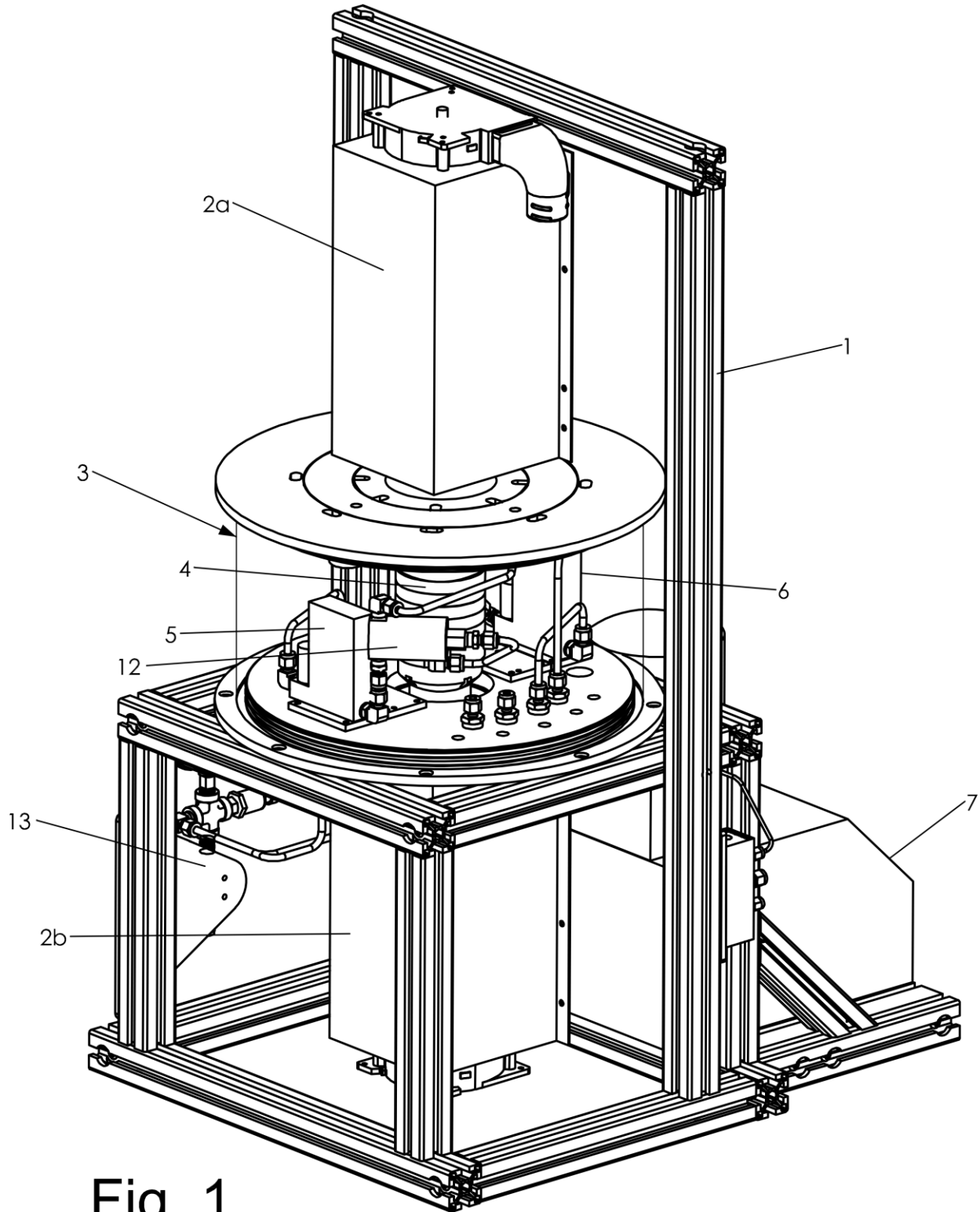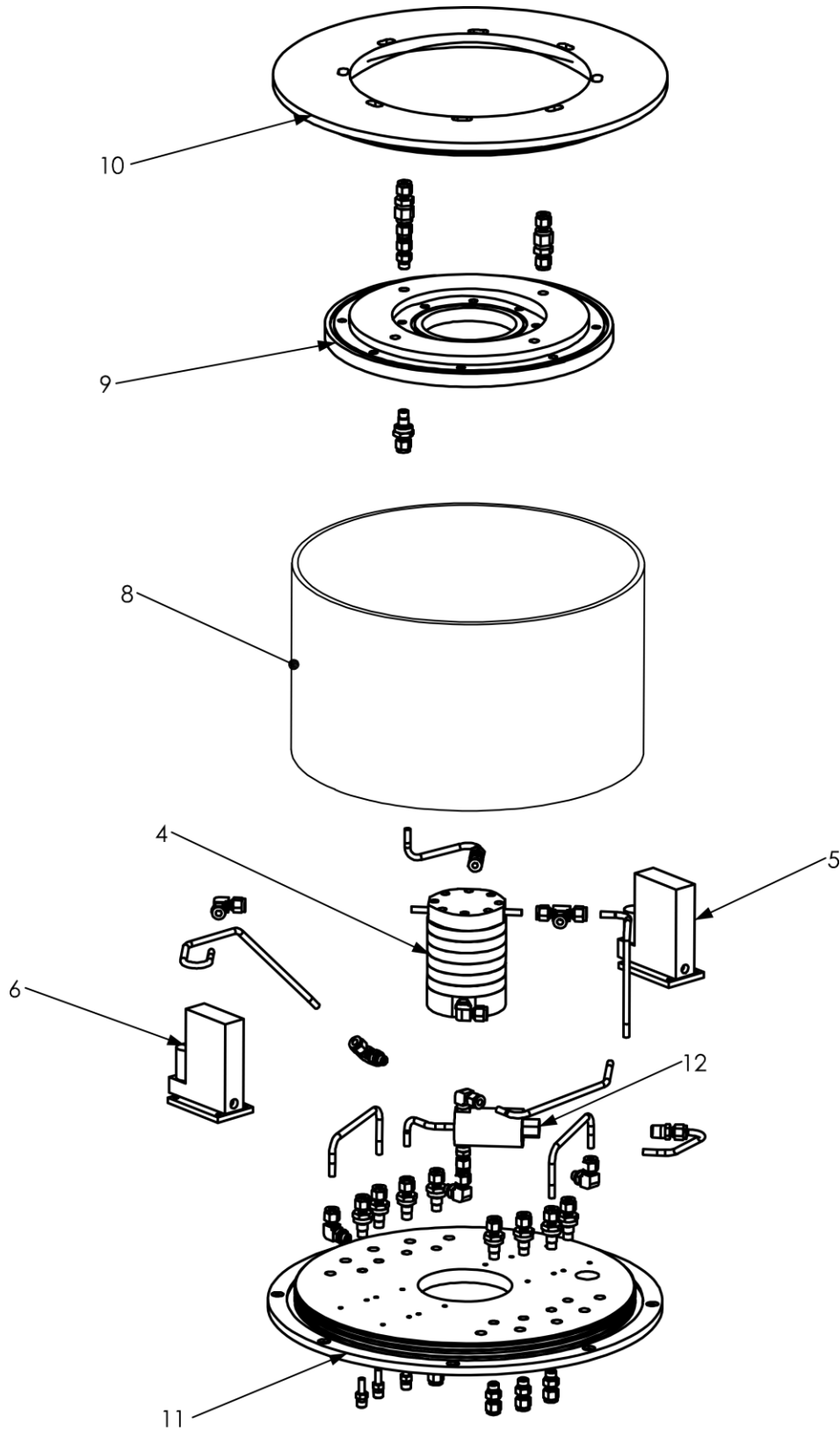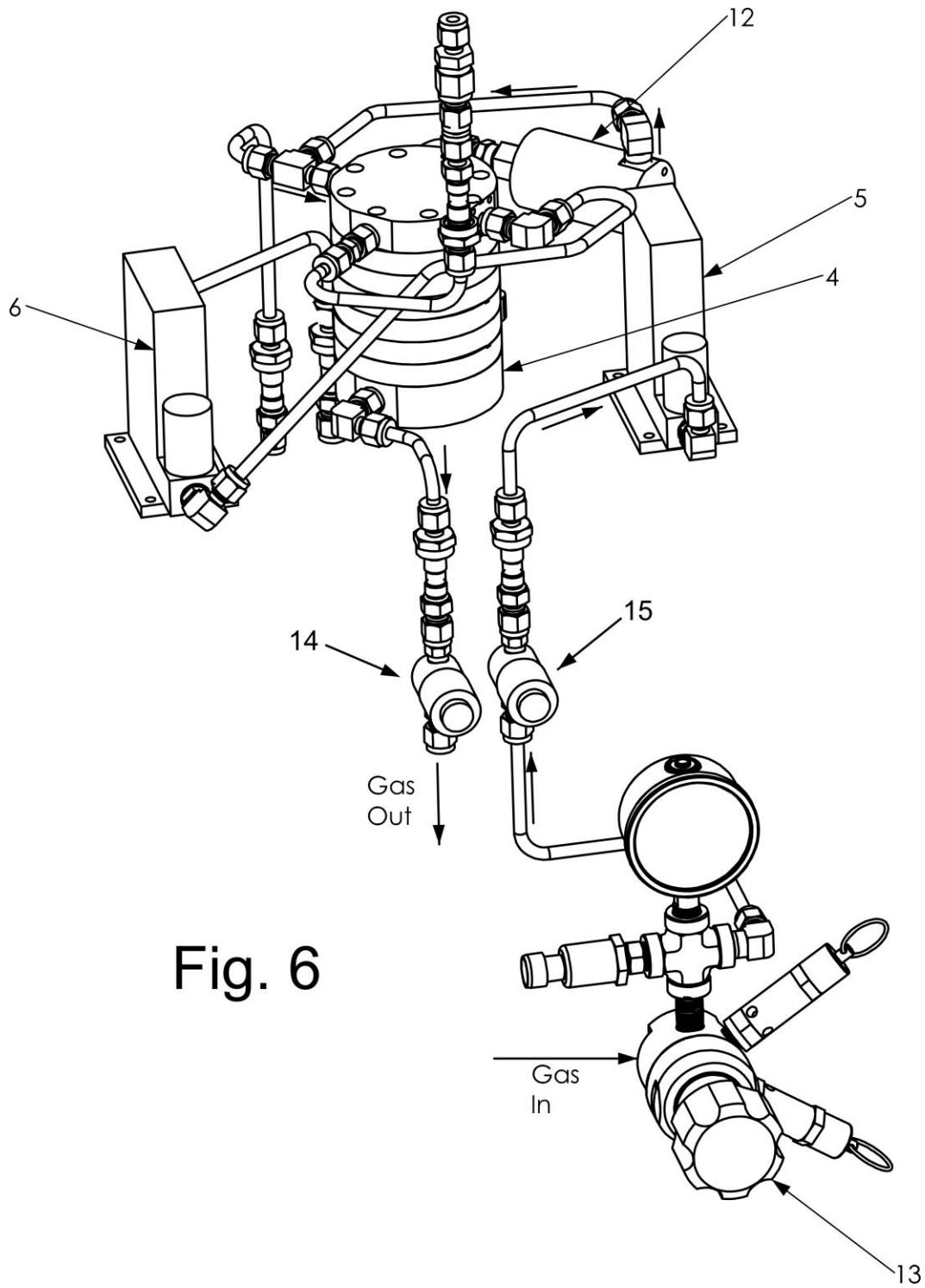
17. Run the system normally.

9 Parts List

Fig. 1

10

9

8

4

5

6

12

11

Fig. 4

12

5

4

6

15

14

Gas
Out

Fig. 6

Gas
In

13

Figures 1,4 and 6 show different views of the humidity generator assembly. The items shown in Figures 1, 4 and 6 are:

|	
1	Humidity Generator Support Frame
2a	Top Free Piston Stirling Cooler
2b	Bottom Free Piston Stirling Cooler
3	Vacuum Chamber
4	Saturator (Plate Stack Assembly)
5	Saturator Pressure Controller Valve
6	Saturator Exit Gas Flow Controller Valve
7	Vacuum pump
8	Vacuum chamber wall
9	Top Vacuum Flange Part A
10	Top Vacuum Flange Part B
11	Bottom Vacuum Flange
12	Flow-generator & Purge - 3 Way Valve
13	Nitrogen Inlet Pressure Regulator
14	Purge outlet valve
15	Entry On-off Valve

10 Drawings
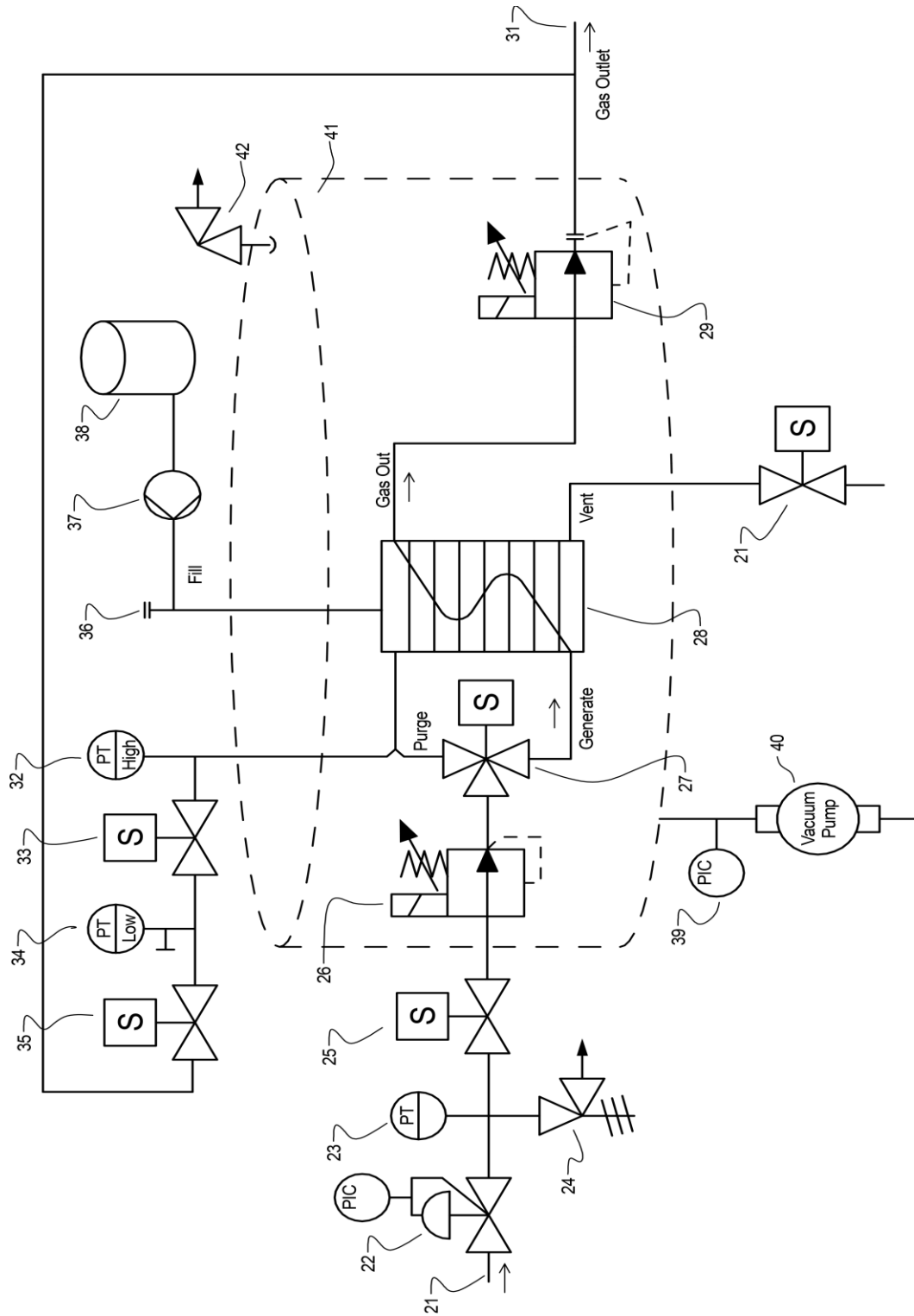
Fig. 7

Elements Illustrated in Figure 7:

| 21	Inlet gas
22	Inlet pressure regulator
23	Inlet pressure transmitter
24	Inlet relief valve
25	Saturator on/off valve
26	Saturator pressure control valve
27	Three way valve
28	Saturator
29	Exit flow control valve
31	Exit Pressure
32	Saturator pressure transmitter (high range)
33	Blocking valve (1)
34	Exit pressure transmitter (low range)
35	blocking valve (2)
36	Water fill point
37	Water fill pump
38	Water fill tank
39	Vacuum pressure gauge
40	Vacuum pump
41	Vacuum chamber
42	Vacuum chamber over pressure valve
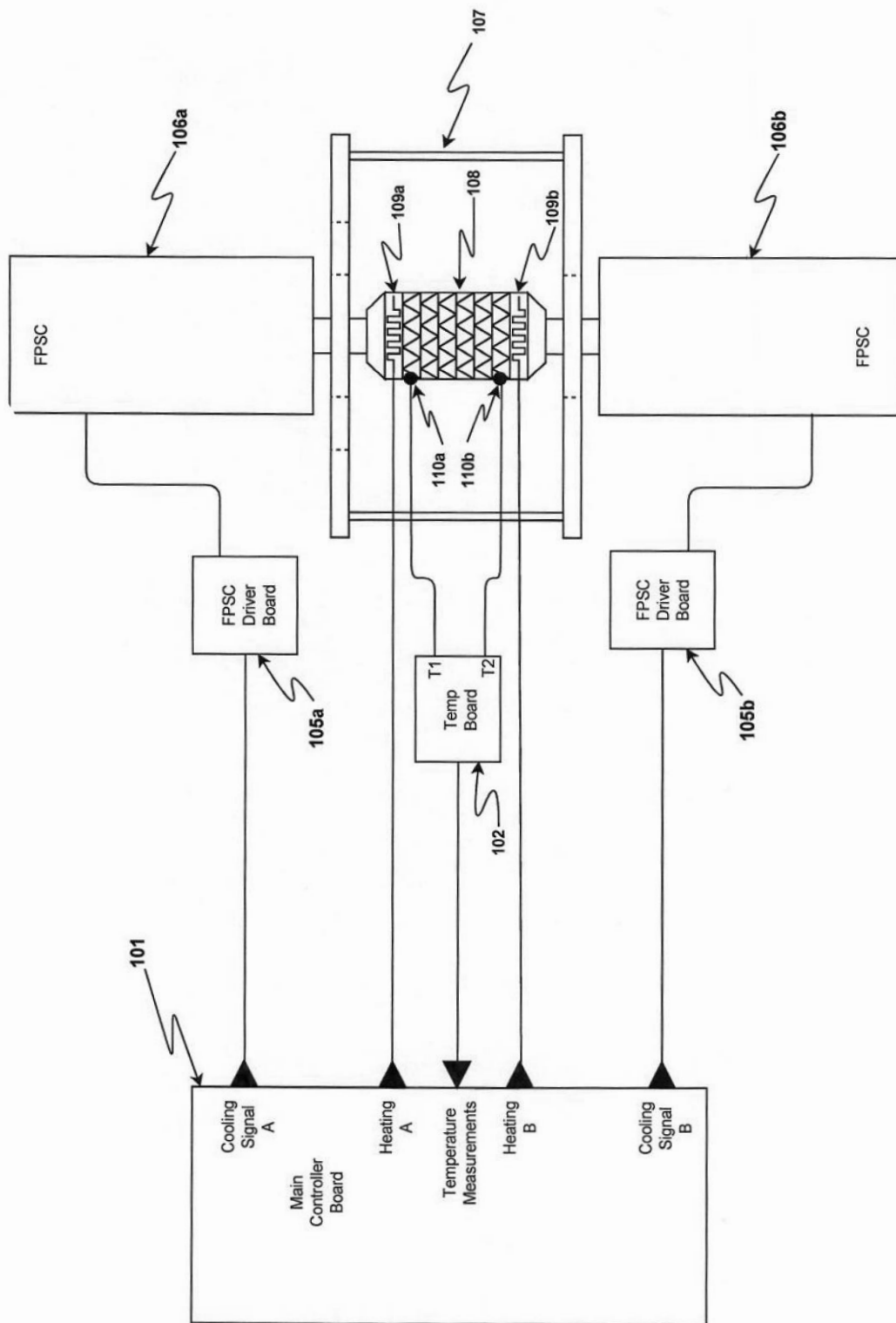
Fig. 8
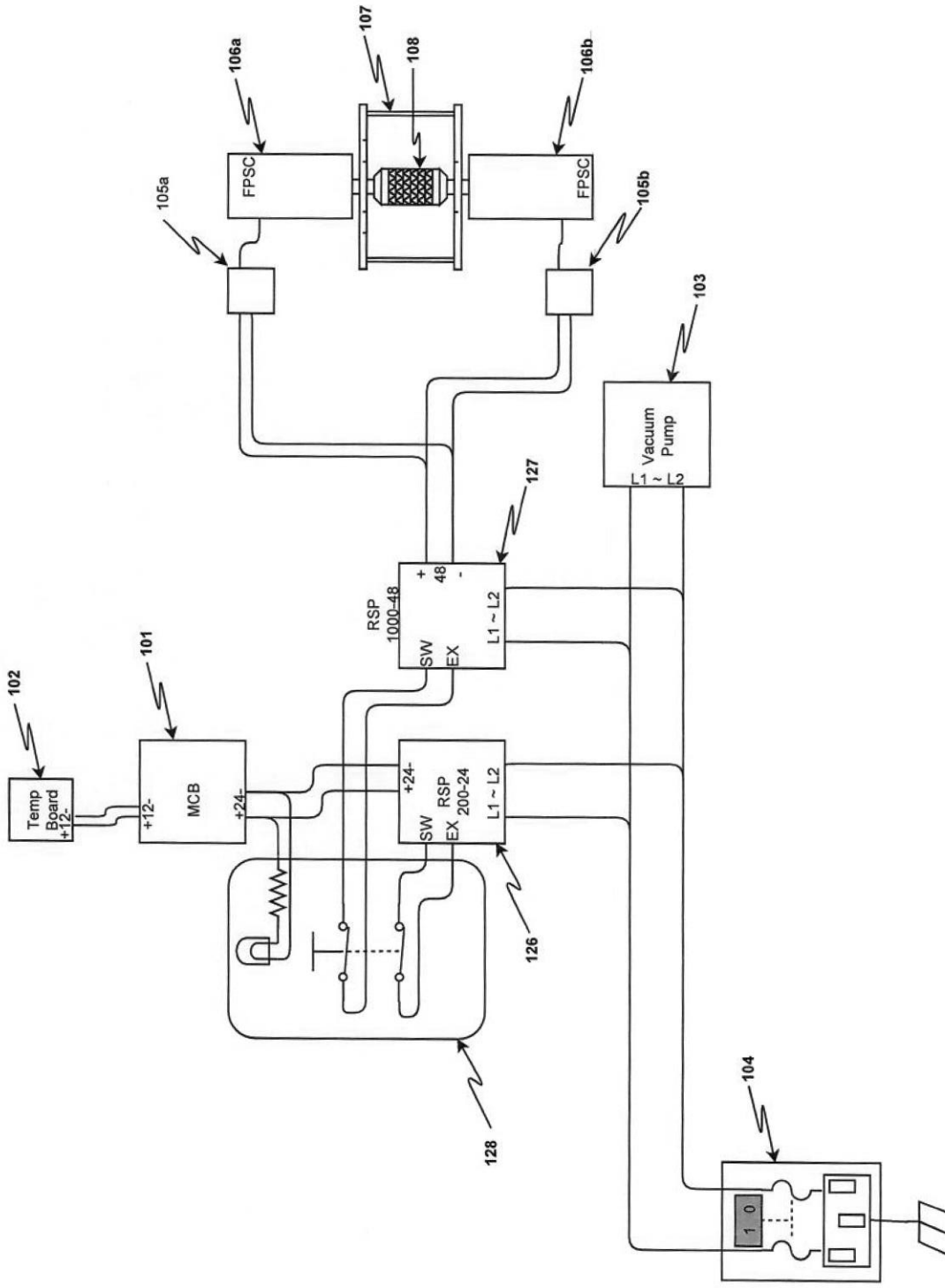
Fig. 9

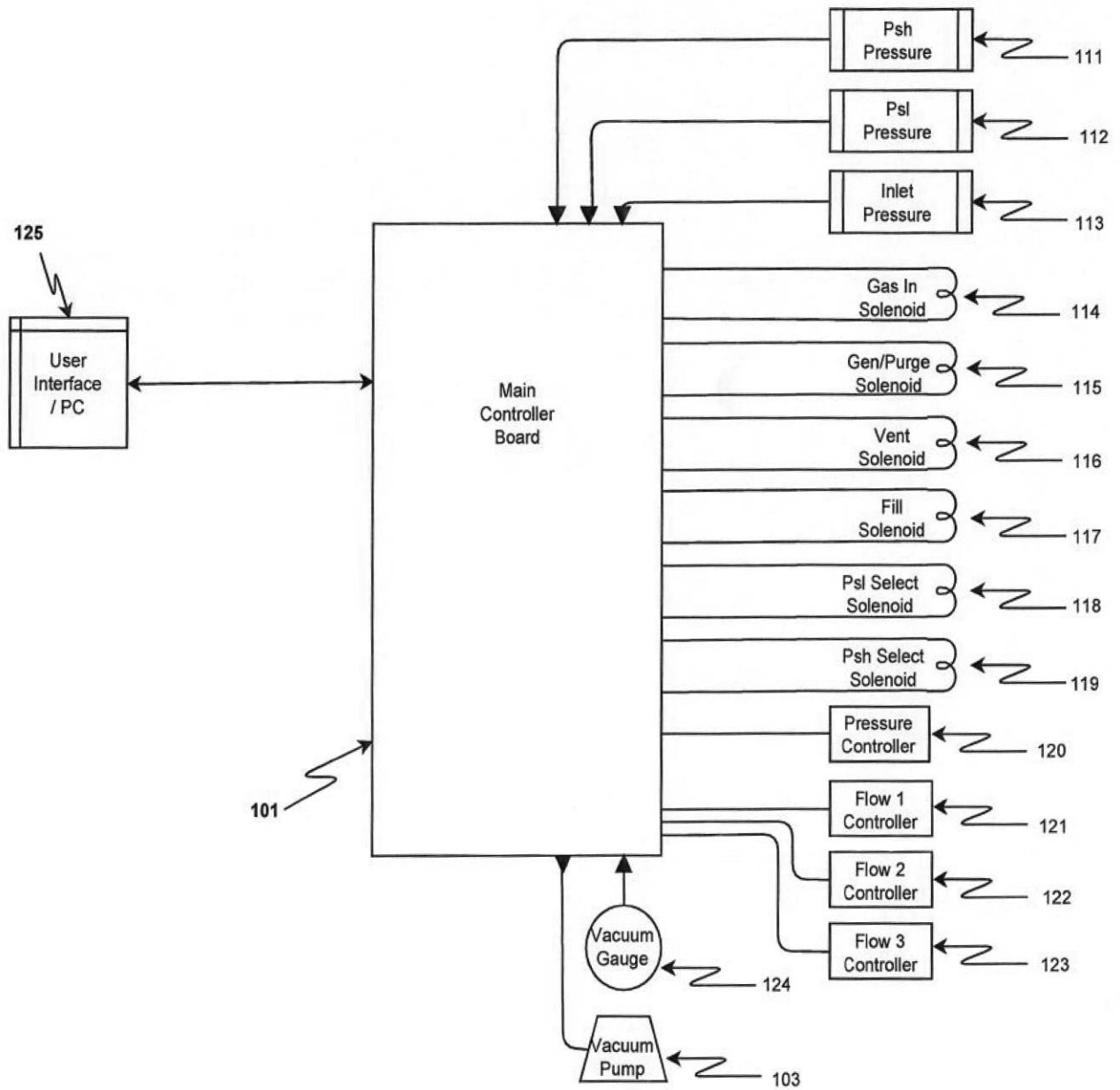Fig. 10

In Figures 8-10, the following items are illustrated:

101	Main controller board with analog and digital I/O, custom Firmware
102	Multi-channel high accuracy temperature measuring circuit
103	Vacuum Pump
104	AC input power receptacle
105a	Electronic control circuit to drive 106a
105b	Electronic control circuit to drive 106b
106a	Free Piston Stirling Cooler (FPSC)
106b	Free Piston Stirling Cooler (FPSC)
107	Vacuum chamber
108	Saturator
109a	Heater Top
109b	Heater Bottom
110a	Saturator Temperature Sensor a (upper)
110b	Saturator Temperature Sensor b (lower)
111	Saturator pressure sensor (transmitter)
112	Exit pressure sensor (transmitter)
113	gas inlet pressure sensor
114	Gas inlet valve
115	Directional valve to select gas flow path purge / generate
116	Vent valve solenoid

117	Water fill valve solenoid
118	Pressure selection valve low (Psl)
119	Pressure selection valve high (Psh)
120	Pressure controller
121	Flow 1 controller
122	Flow 2 controller – optional
123	Flow 3 controller – optional
124	Vacuum gauge sensor
125	User Interface with PC – custom programming
126	24 VDC power supply
127	48 VDC power supply
128	Power switch with integrated LED indicator

Document History

Revision History

Revision Number	Revision Date	Summary of Changes	Author
preliminary	25 Apr 2018	Initial	Bob
Rev 1	17 Jul 2022	Major revision overall	Bob
Rev 1.3	23 Jul 2023	Grammar/spelling corrections	Bob
Rev 1.3.1	26 Apr 2024	Review and minor changes	Bob