ORNL/TM-2019/1403

Certification and User Manual for A 5kW Heat Exchanger Test Loop at Low-Temperatures and High-Pressures

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Computer Science and Engineering Division

CERTIFICATION AND USER MANUAL FOR A 5KW HEAT EXCHANGER TEST LOOP AT LOW-TEMPERATURES AND HIGH-PRESSURES

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ABSTRACT

Yankee Scientific has designed and built a custom heat exchanger test stand (HXTS), for Oak Ridge National Laboratory, to support a program to develop advanced heat exchangers (HX) for geothermal Organic Rankine Cycle (ORC) power plants under Subcontract Number 40000141544 with ORNL. The test stand was designed to measure the performance of laboratory scale sub-sections of these advanced heat exchangers. Provisions have been made to facilitate testing the advanced heat exchanger as a primary refrigerant vaporizer and as a recuperator and as the system condenser. The test loop was operated with a controller and was instrumented with 11 thermocouples, 5 pressure gauges, 2 pressure transducers, 2 differential pressure transducers, and 3 flow meters.

1. INTENDED USE OF THE TEST STAND

This test stand flexibility can enable a variety of future test programs to be conducted with minimal modifications of the system. This test loop will enable the testing of a variety of materials and components in several industries, such as geothermal, waste heat removal, automotive, and building industries. Specifically, this test stand, or test loop as it often referred to in the industry, can be used to test the following components:

- Heat exchanger materials,
- Novel working fluids, such as mixtures of refrigerants, and
- Subscale components:
    - Recuperators,
    - Condensers,
    - Evaporators,
    - Turbines,
    - Pumps.

2. OPERATING TEMPERATURES, PRESSURES, AND FLOW RATES

Table 1 specifies the minimum and maximum for the flow rates of the fluids considered. All the technical design specifications are shown in Appendix A.

Table 1. Minimum and maximum operating conditions for the refrigerant and brine.

Loop: Fluid:	Refr. #1- Min R245fa	Refr. #1- Max R245fa	Refr. #2- Min R134a	Refr. #2- Max R134a	Brine-Min water	Brine-Max water
Flow, gpm	0.1	0.65	0.1	0.65	0.05	0.5
Flow, ft^3/hr	0.802	5.214	0.802	5.214	0.401	4.011
Flow, m^3/hr	0.023	0.148	0.023	0.148	0.011	0.114
T, °F	80	300	300	80	150	320
P, psia	100	300	100	725	200	200
Den, lb/ft^3	83.66	83.66	76.46	76.46	61.23	61.23
Den, kg/m^3	1340	1340	1224.73	1224.73	980.8	980.8
mdot, lb/hr	67.10	436.18	61.33	398.64	24.56	245.57
mdot, kg/s	0.00845	0.05496	0.00773	0.05023	0.00309	0.03094

3. HEAT EXCHANGER TEST STAND DESCRIPTION

Three fluid loops are included in the HXTS including a simulated hot brine loop (using ordinary water as a substitute for brine), a refrigerant loop that can be R134a or R245fa, and a cooling water loop to chill the refrigerant condenser and trim cooler. A simplified flow schematic for these fluid loops and the HXTS components is shown in **Error! Reference source not found.**. T he sake of clarity, two larger schematics of the test loop sections were included in Figures 2 and 3. A front view picture of the HXTS is shown in Figure 4. The major system components are also identified in Appendix A.

In the brine loop (blue line in the schematic), heat is supplied to the brine loop via a 208 VAC 3 phase 7.5 kW nominal capacity cartridge heater. The brine water heater is controlled by an SCR based control system developed by Wattco, Inc. The controls for the Wattco's heater are mounted in a control box located to the left of the HXTS. The heater controls include a controller used for inputting and displaying the setpoint and actual water temperatures and an over temperature controller that limits the heater temperature.
The brine loop transfers its heat to the refrigerant loop through the heat exchanger being tested, with a maximum brine temperature of 160 °C (320 °F). The brine loop is held at about 200 psig to prevent it from boiling. This elevated pressure is maintained by applying pressurized inert gas to the top of the brine sump tank.

The refrigerant loop, the refrigerant is pumped to the test heat exchanger at pressures from 100 to 720 psig, and at a temperature below 37 °C. The refrigerant absorbs heat in the test heat exchanger, which may vaporize and reach superheated or supercritical conditions. The high pressure refrigerant leaving the heat exchanger is passed through a back pressure regulator valve that allows the refrigerant pressure to drop to nearly the condenser saturation pressure. The back pressure regulator valve simulates the pressure differential that would occur in the turbine of an ORC power station.

A city water cooled condenser chills the refrigerant and delivers the condensed fluid to the receiver sump tank, which is the refrigerant source for the high pressure pump. The city water cooling loop includes a pump driven recirculation loop to maintain high water velocities within the condenser even on occasions that only require a small amount of city water flow. Heated city water is discharged to the system drain.

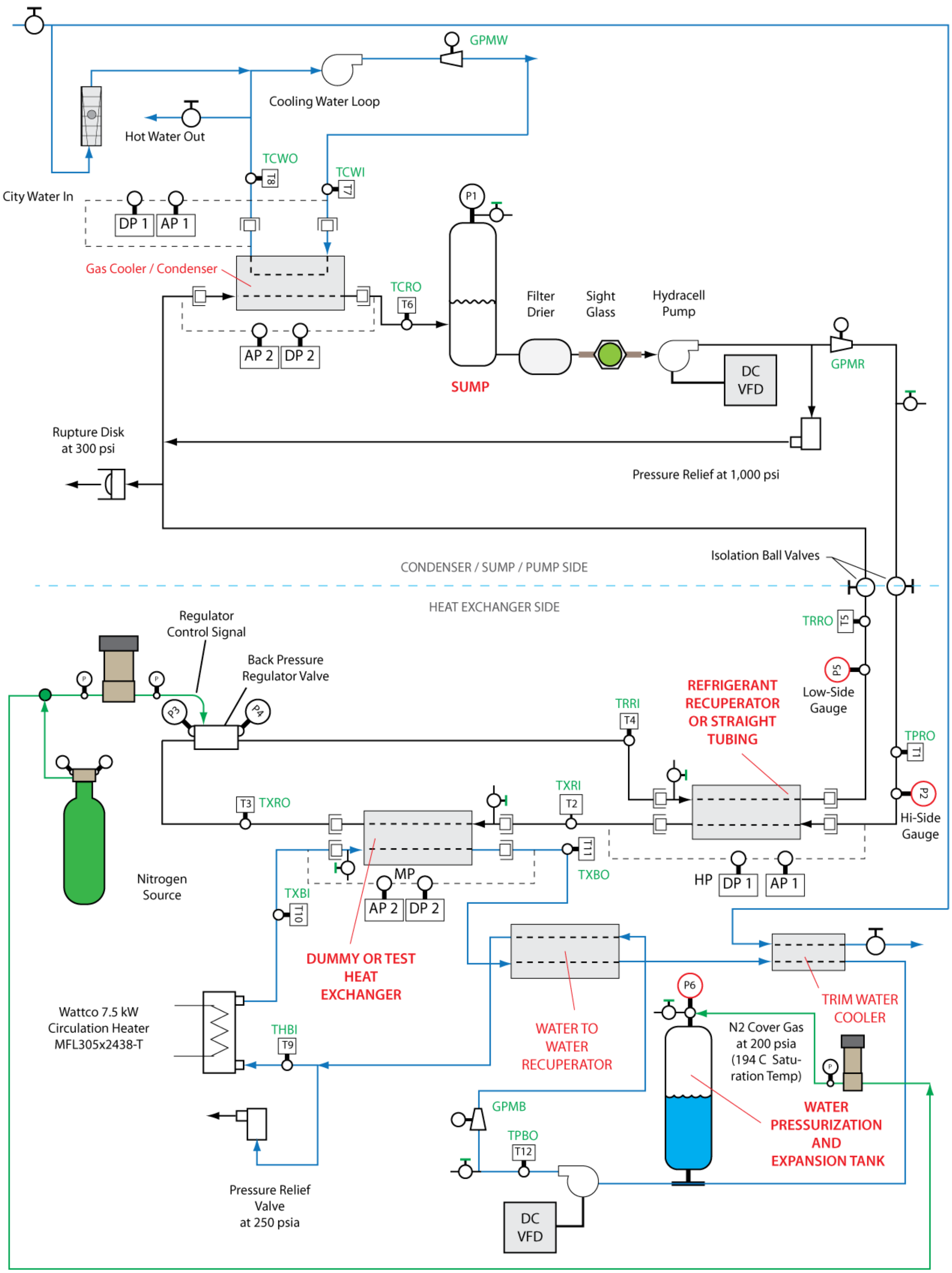


Figure 1. Simplified schematic of the heat exchanger test stand.

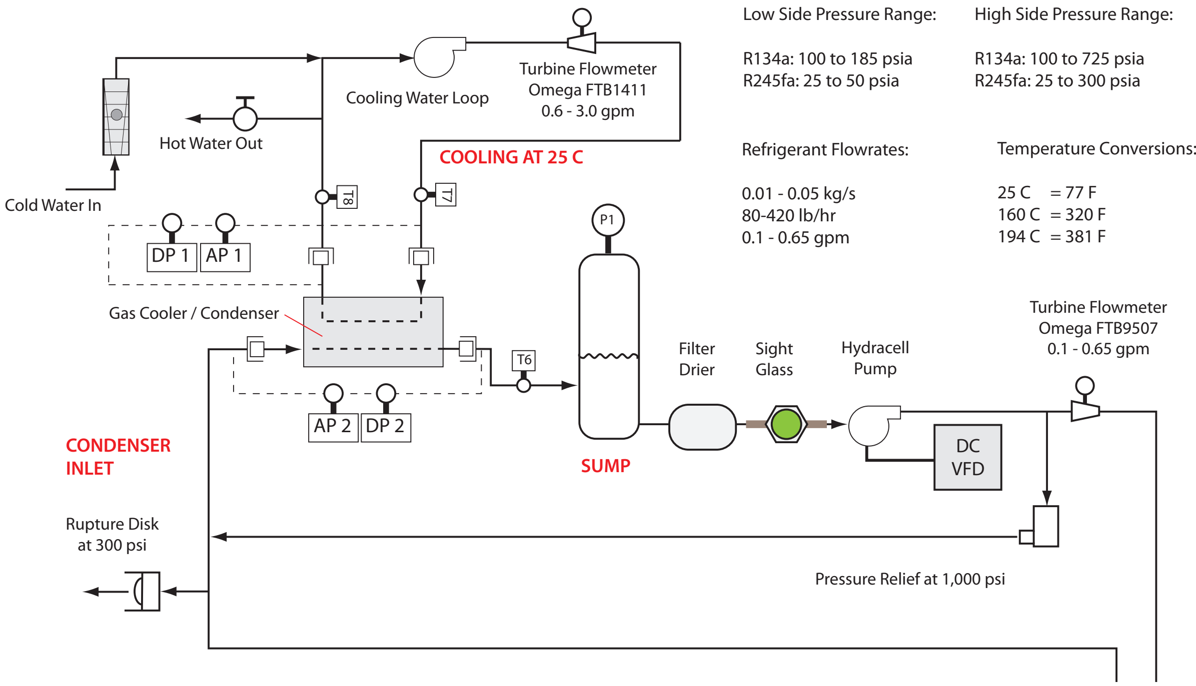


Figure 2. Schematic of the condenser part of the testing loop.

A brine water recuperator is used to protect the brine water pump from overheating and to keep the water passing through the turbine flowmeter at relatively cool temperatures. Brine water leaving the test heat exchanger pre-heats chilled brine before it enters the brine water heater. Additional heat is removed from the brine via a trim cooler located between the hot side of the brine water recuperator and the brine expansion tank and pump. This trim cooler is necessary for proper operation of the recuperator. The brine water in the trim cooler is cooled by a city water flow that taps off of the inlet to the city water to the refrigerant condenser, before the rotameter. The city water flow through the trim cooler is controlled via a throttling valve on the rear of the HXTS. Proper operation of the trim cooler can be observed by monitoring the brine pump outlet temperature.

The Absolute Pressure of the refrigerant entering the test heat exchanger is measured (AP1) along with the Differential Pressure of the refrigerant across the test heat exchanger (DP1). Similarly, the Absolute Pressure of the brine entering the test heat exchanger is measured (AP2) along with the Differential Pressure of the brine across the test heat exchanger (DP2).

The flow rates in each of these fluid loops are measured using turbine flowmeters and the process temperatures and pressures are measured and transferred to a separate data acquisition port jack panel. The temperatures and flowrates are also displayed on the central control panel and the key system pressures are indicated using pressure gauges. This information is provided onboard the HXTS to allow for safe and efficient system operation.

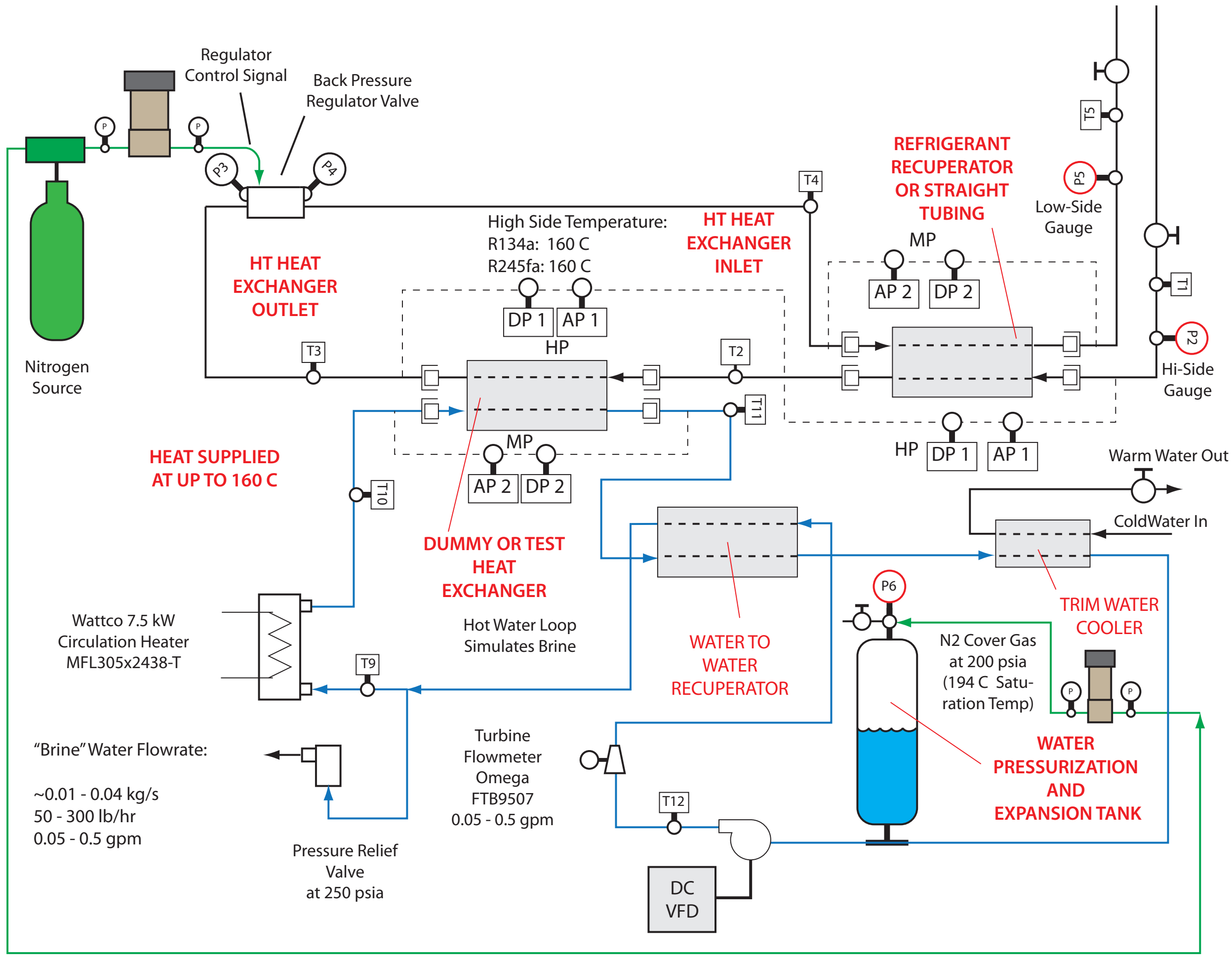


Figure 3. Schematic of the part of the testing loop with an evaporator and a recuperator.

The brine loop and the refrigerant loops both have motor speed controls that allow the flowrates to be set by turning the associated potentiometer on the front panel. The city water flowrate is controlled by a manual valve at the rear of the HXTS and that flowrate can be monitored using the rear facing rotameter. The city water recirculation rate can be varied using the three speeds on the circulation pump as well as by adjusting the cooling water recirculation loop control valve.

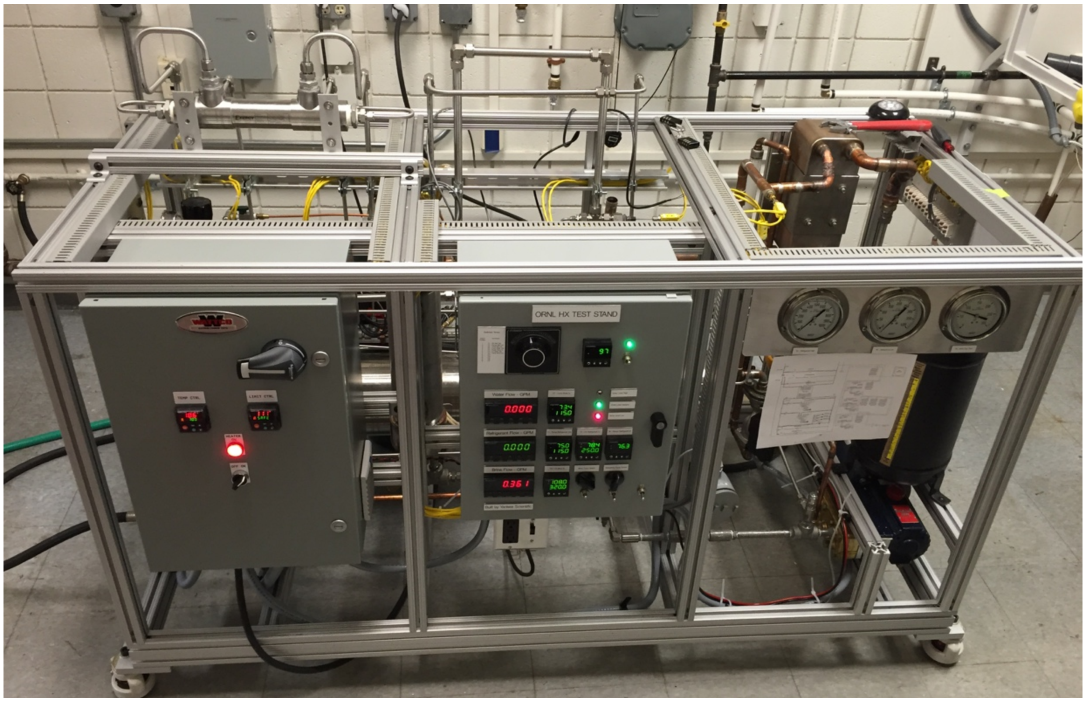


Figure 4. Front view of HXTS.

4. SAFETY SYSTEMS IN THE HXTS

There are several safety systems included in the HXTS. If the refrigerant pump discharge pressure exceeds 750 psig, part of the flow will pass through a proportional relief valve and this flow stream will be delivered to the condenser inlet. This approach to relieve excessive pump discharge pressures is intended to provide this needed protection without releasing refrigerant from the sealed system. If the relatively low pressure condenser side of the system has a pressure that exceeds 300 psig, then a rupture disk will burst and the contents of the refrigerant loop would be discharged. On the brine loop water circuit there is a pressure relief valve set to 250 psig that directs this discharged flow to the floor.

A series of ports are provided with each being isolated from the refrigerant by a high pressure plug valve. These ports are used to fully or partially fill or evacuate the refrigerant system. The heat exchanger side of the loop can be isolated from the Condenser/Sump/Pump side of the system using the small ball valve (high pressure liquid refrigerant from the pump) and the large ball valve (low pressure hot vapor from the heat exchanger). The two sides of the refrigerant flow circuit are indicated in **Error! Reference source not found.** by the horizontal dashed line p assing through both isolation valves. By closing these two ball valves the relatively small quantity of refrigerant on the heat exchanger side is all that needs to be removed to allow the heat exchanger to be replaced.

5. MEASUREMENT ACCURACY FOR HXTS

The test loop was operated with a controller and was instrumented with 11 thermocouples, 5 pressure gauges, 2 pressure transducers, 2 differential pressure transducers, and 3 flow meters. Pressure gauges were used to measure the pressure at the cold sump, recuperator inlet location, BPR outlet, and recuperator outlet. The additional analog pressure transducers used are listed in Table 2.

Turbine flowmeters FTB9507 were used in the test loop with an operating range of 0.03 to 0.65 GPM and an accuracy of +(-)0.5%.

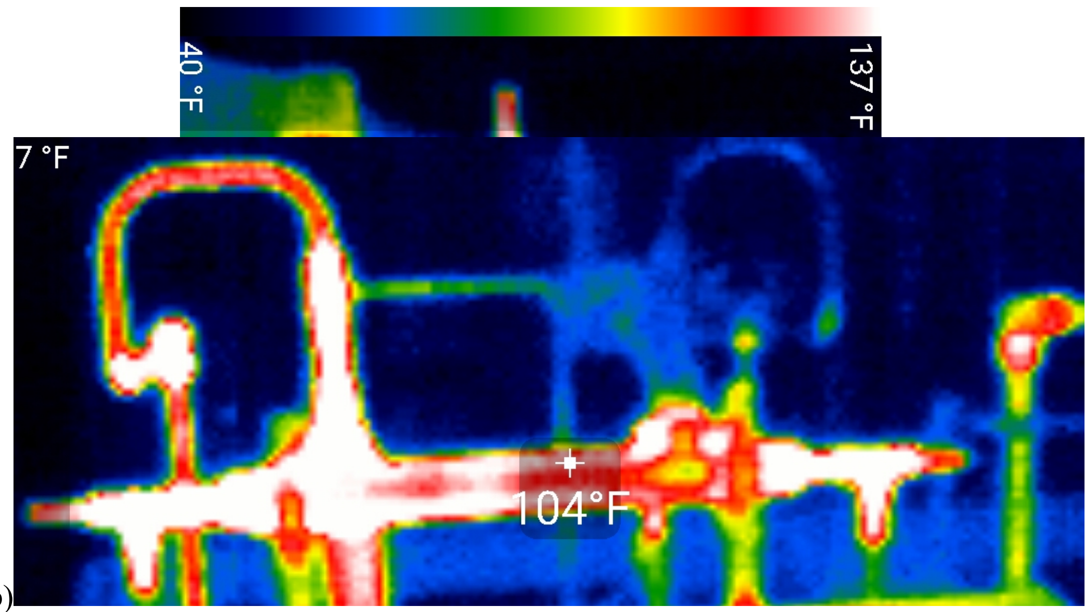
Table 2. Pressure transducer used in the test loop.

Sensor Location	Sensor Type / Model	Min or Delta PSIG	Max Actual PSIG (rating)	Accuracy [%]
Cold HX inlet	PT, PX309-1KGI	0	1,000 (1,000)	+(-)0.25
Cold HX, Differential	DPT, PX509HL-15DWUI-S	0-15 delta	1,000 (2,000)	+(-)0.08
Hot water tank	PT, PX309-300GI	0	300 (600)	+(-)0.25
Hot HX, Diff Differential	DPT, PX409-015DWUI	0-15 delta	300 (500)	+(-)0.08

6. CERTIFICATION EXPERIMENTS FOR HXTS

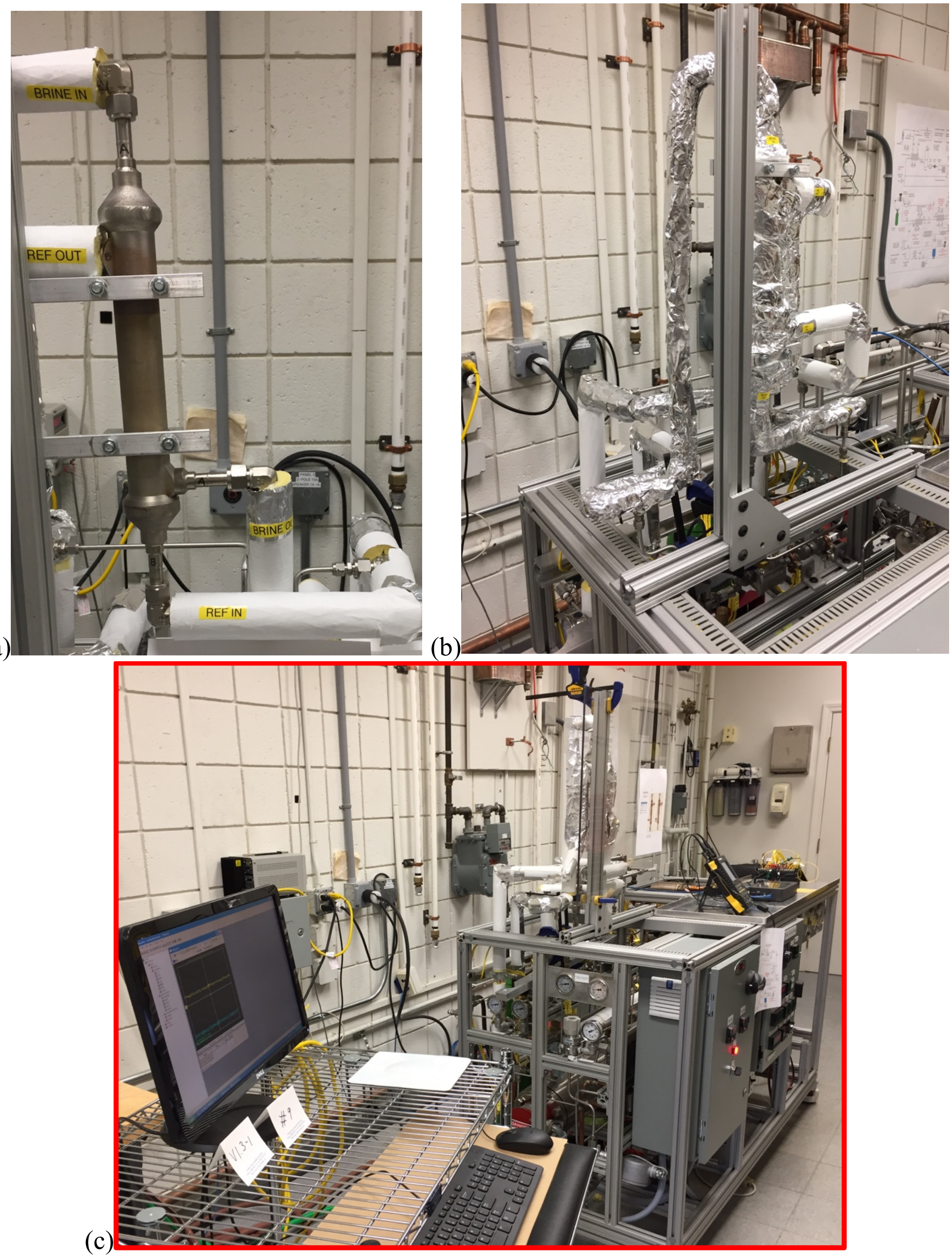
During calibration runs, differential pressure oscillations were observed on the pressure transducer channels. In order to mitigate the pressure oscillations, which were more severe on the refrigerant flow path, a pressure dampener and capacitor were employed. A 10 microF capacitor, which was added across the brine circuit DP2 resistor, was shown to further improve the brine readings. In addition, increasing the data sampling to 10 s on the Graphtec data acquisition system was found to reduce the variations in the differential pressure signal. Each heat exchanger was mounted on a test loop that ORNL as shown in Figure 5 and 6. The piping and HX were insulated to minimize the heat loss to the ambient.

(a)



(b)

Figure 5. Mounting of heat exchanger in horizontal position: (a) picture of uninsulated HX, (b) IR imaging of the mounted HX during one preliminary run.



(a) (b) (c)

Figure 6. Testing of new HX heat exchangers: (a) mounting of HX, (b) HX insulated, (c) test stand with mounted HX and data acquisition.

Figure 7. Typical picture of the the front panels of the test loop during one experiment.

Acceptance tests were conducted on August 8 and 9, 2016 at pressures of 734 and 633 psig using R134a as refrigerant, respectively. Screen shots of the data acquisition were taken during these experiments and are shown in Figure 8 and 9a, respectively. Furthermore, the data aquired at the steady state operation with R134a at 633 psig is shown in Figure 9b, showing excellent steady-state operation of the test loop.

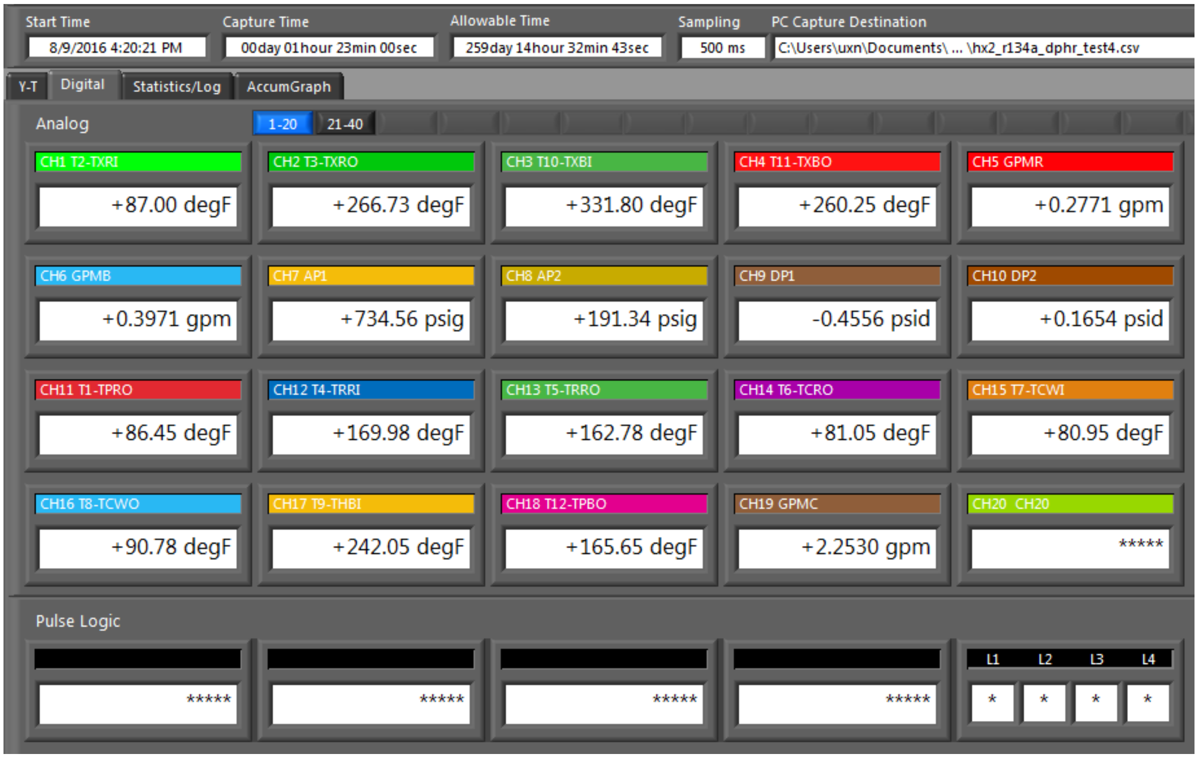


Figure 8. Screen shot with at steady-state for a test with R134a at 734 psig and temperature of 331.8 ºF.

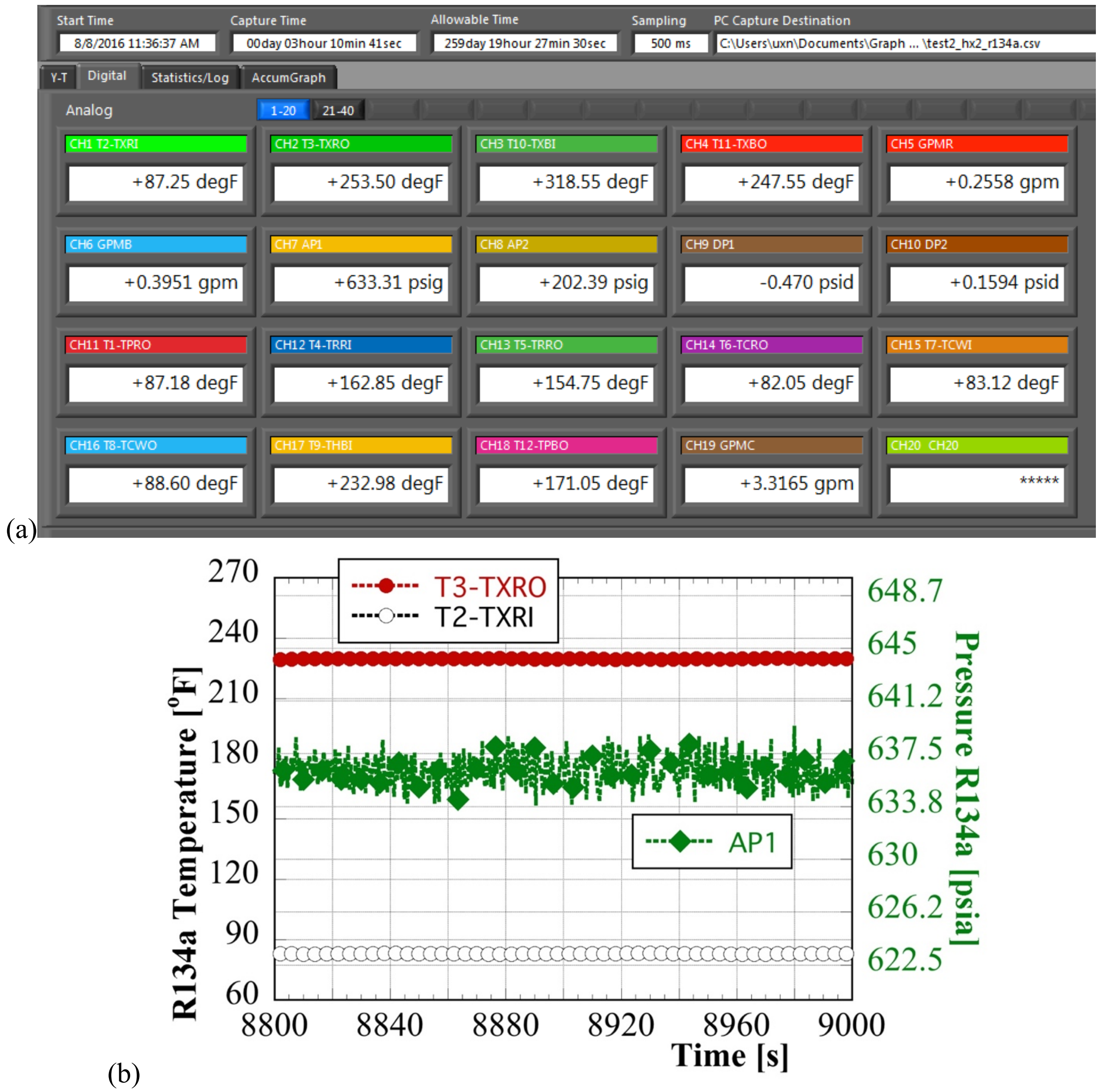
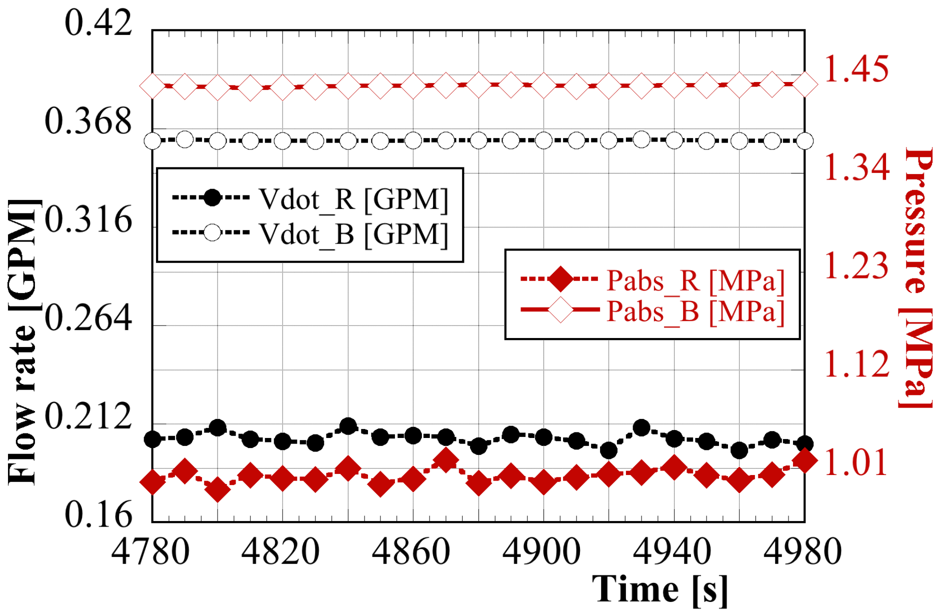
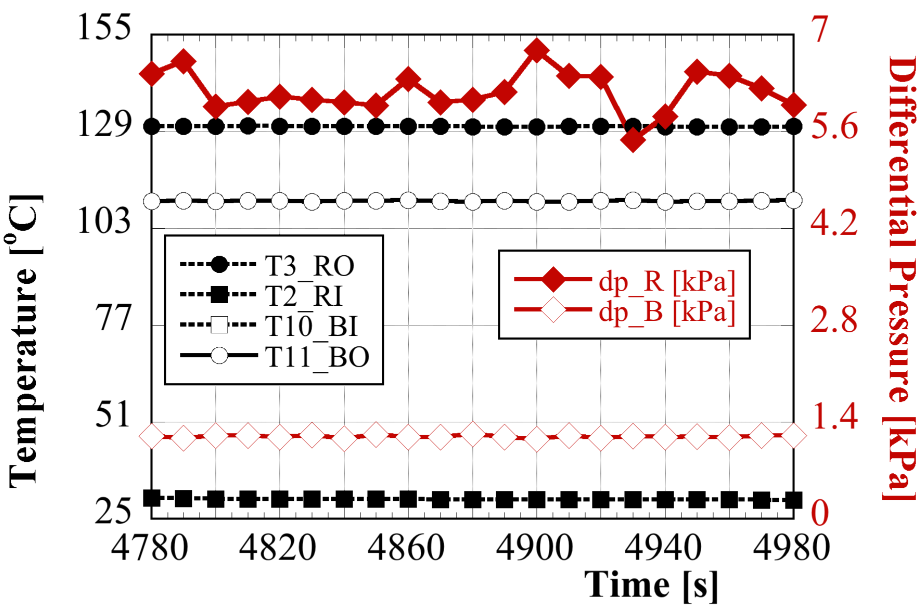


Figure 9. Screen shot with at steady-state for a test with R134a at 633 psig and temperature of 318.55 °F.

Acceptance tests were also conducted at a pressure of 174 psig using R245fa as refrigerant. The test loop operation is very reliable reaching steady state in 10 to 20 min for set points considered. An example of typical variation at the steady-state of the main variables during a test using R245fa as refrigerant are shown in Figure 10. For full reference, the heat exchanger tested here is case 1 (Sabau et al., 2019). The letter “R” or “B” at the end of each variable plotted indicates the refrigerant (cold-fluid) or brine (hot fluid), respectively.



(a)



(b)

Figure 10. Measurement data at steady state for: (a) flow rates and absolute pressures, and (b) inlet temperatures, outlet temperatures, and differential pressures for a heat exchanger.

7. HEAT EXCHANGER TEST STAND OPERATING INSTRUCTIONS

The HXTS has been designed to simplify its operation and to make its operation as safe as possible. Nonetheless, the test stand has high temperature and high pressure vapors circulating within it. To safely operate the HXTS Yankee has developed the following series of operating procedures. In this sections procedures are grouped in five sections on Startup operations, Shutdown operations, Filling of the brine system, Filling of the refrigerant system, and Refrigerant recovery from the system.

7.1 SYSTEM STARTUP OPERATING INSTRUCTIONS

Specific instructions are given in the Startup section for the following systems:

(a) Main control panel,

(b) Water loop,

(c) Inert gas preparation,

(d) Brine loop,

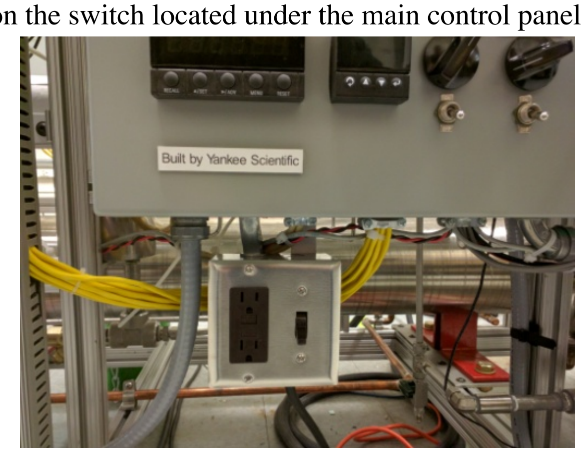
(e) Refrigerant loop,

(f) Heater,

7.1.1 System Control Panel Startup

1. Ensure that ALL switches on the main control panel are in the down/off position
    a. Main power switch

    b. Brine pump switch
    c. Refrigerant pump switch
    d. Condenser water circulator switch
2. Connect power cord to 15A, 120V, single phase outlet.
3. Turn on the switch located under the main control panel.



4. Turn on the power switch located at the top of the main control panel.
5. Ensure that all meters read normally after initial boot.

7.1.2 Water Loops Startup

1. Connect cooling water hose to the supply port on the right, rear side of the test stand.

2. Connect cooling water drain hoses from:
    a. Condenser cooling outlet, located at the right, rear side of the test stand.

    b. Trim cooler outlet, located at the left, rear side of the test stand.

3. Ensure the drain hoses are run to suitable drains.
4. Close the Water Inlet valve located just above the water inlet connection.

5. Turn on the cooling water supply.
6. Slowly open the cooling Water Inlet valve.
7. Adjust condenser cooling outlet throttle valve.
    a. Observe that flow is indicated on the rotameter flow meter.
    b. Adjust flow as necessary using the Condenser Hot Water Out valve near the drain connection.

8. Adjust Trim Cooler Outlet Throttle valve.
    a. Observe that water is flowing from the trim cooler drain hose.
    b. Adjust flow as necessary using the Trim Cooler Outlet valve near the drain connection.
    c. **CAUTION:** If no flow is present in the trim cooler, water may boil and open relief valve.

9. Turn on the condenser water circulator switch located on the main control panel.
10. Ensure Condenser Cooling Throttle valve is not fully closed.

11. The flowrate of the water through the condenser can be controlled by two means:
   a. Set the pump speed on the pump itself.

   b. Use the Condenser Cooling Throttle.

7.1.3 Inert Gas Preparation

1. Connect inert gas (nitrogen, argon, etc.) bottle to regulator assembly.
2. Connect hose or hard piping from regulator outlet to inert gas inlet port on the back, left of the test stand.

3. Loosen inert gas fitting adjacent to Inert Gas Isolation valve.
4. Turn gas bottle regulator counterclockwise until backed out fully.
5. Open gas bottle valve.
6. Increase gas bottle regulator until gas is heard at loose inert gas inlet port fitting.
7. While gas is escaping, tighten fitting.
    a. This ensures that as little air as possible is introduced into the system.
8. Increase regulator pressure to above final desired refrigerant system pressure.
9. Turn Back Pressure Regulator knob counterclockwise until backed out fully.

10. Turn Brine Cover Gas regulator counterclockwise until backed out fully.

7.1.4 Brine System Startup

1. Turn on brine pump.
2. Set flowrate by rotating the brine loop pump speed potentiometer.
3. Monitor the flowrate on the main panel.
4. Adjust as necessary.

7.1.5 Refrigerant System Startup

1. Turn on refrigerant pump.
2. Set flowrate by rotating the refrigerant loop pump speed potentiometer.
3. Monitor the flowrate on the main panel.
4. Adjust as necessary.

7.1.6 Heater Startup

1. Ensure the heater control panel door is closed.
2. Ensure both latches on the control panel door are closed.
3. Ensure the heater permit switch is in the “OFF” position.

4. Connect power cord to 3-phase, 208VAC outlet
   a. The L-shaped prong on the connector is the ground.

5. Rotate the main power disconnect on the heater control panel 90 degrees so that the indicator points to “ON”.

6. Adjust the LIMIT CTRL to below the current brine temperature.

   a. Press RESET button to display brine temperature.
   b. Press green button until set point is displayed in red.
   c. Press (up, down) to adjust.
   d. Press red to return to main screen.
   e. Turn heater permit switch to “ON”

7. Observe that the TEMP Control is now on.

a. Press (up, down) to set brine water target temperature
8. To start heating:
   a. Adjust Limit CTRL temperature setpoint to 20-30 degrees F above TEMP CTRL setting.
9. To change the setpoint:
   a. Adjust the TEMP CTRL to the new setpoint by pressing (up, down)
   b. Adjust the Limit CTRL temperature setpoint to 20-30 degrees F above TEMP CTRL setting.

7.2 SYSTEM SHUTDOWN OPERATING INSTRUCTIONS

1. When testing is complete, switch the Heater Permit switch to "OFF"
2. Allow brine, refrigerant, water condenser, and trim cooler loops to continue running to cool off brine.
   a. To speed cooling:
      i. Open Condenser Hot Water Out valve.
      ii. Open Trim Cooler Outlet Throttle valve.
3. When brine heater core temperature, as read at the LIMIT CTRL, falls below 140 degrees F, switch off:
   a. Brine pump
   b. Refrigerant pump
   c. Condenser water circulation pump
   d. Heater main power disconnect
   e. Main power switch on front panel
   f. System power switch below front panel
4. Shut off water supply to:
   a. Condenser water inlet
   b. Brine fill/drain port
5. Unplug:
   a. System power
   b. Heater power

7.3 FILLING OF THE BRINE SYSTEM

1. Run water through a hose to force all air out.
2. Check that the Brine Fill/Drain valve, located on the bottom left of the test stand, is closed.

3. Connect hose to fill port loosely.
4. Crack open the supply valve to hose to push the remainder of the air out of the hose up to the Brine Fill/Drain valve.
5. Tighten fill port fitting fully.
6. Briefly open the Brine Fill/Drain valve to push any remaining air into the brine system.
7. Ensure Inert Gas Isolation valve is closed.

8. Connect vacuum pump via gauge manifold (if available) to Brine Vent valve (located at the top of the brine expansion tank).

9. Start vacuum pump.
10. Open Brine Vent valve.
11. Evacuate air until pressure is <29inHg.
12. Close Brine Vent valve.
13. Shut down vacuum pump according to its procedure.
14. Disconnect vacuum hose.
15. Ensure System Control Panel Startup procedure has been completed.
16. Slowly open Brine Fill/Drain valve until brine flow is established between 0.10 and 0.15 gpm.
17. As water is added, observe Red "Brine Level Low" LED, located on the main control panel, illuminate.
18. When Green "Brine Level Medium" LED illuminates, count 15 additional seconds.
19. Close the Brine Fill/Drain valve.
20. Ensure Inert Gas Preparation procedure has been completed.
21. Slowly open Inert Gas Isolation valve

22. Adjust Cover Gas pressure regulator to 50psi.

    a. This will cause water vapor in the system to condense and the brine level to fall.
23. Turn brine pump on using the switch on the control panel.
24. Turn brine pump to full speed for one minute.
25. Turn brine pump off.
26. Slowly open Brine Fill/Drain valve until brine flow is established between 0.10 and 0.15 gpm.
27. When Green "Brine Level Medium" LED illuminates, count 15 additional seconds.
28. Close the brine Fill/Drain valve.
29. Adjust cover gas pressure for test conditions

a. Note: Brine will expand as it heats. Set cover gas pressure for ¾ of final pressure desired and adjust as necessary as the brine heats up.

30. **If the pressure becomes higher than desired**:
    a. Turn the regulator several turns counter-clockwise.
    b. **SLOWLY** open the brine expansion tank top port to relieve pressure
    c. **USE EXTREME CAUTION** as superheated steam at high pressure could be expelled from this port.

7.4 FULL OR PARTIAL FILLING OF THE REFRIGERANT SYSTEM

The procedure for the FULL refrigerant filling is to be used for an initial refrigerant fill of the system or when changing refrigerants, after the other refrigerant has been completely removed.

The procedure for the PARTIAL refrigerant filling is to be used after refrigerant has been removed from the high or low pressure side of the system in order to do perform some kind of work on the system, for example when a test heat exchanger has been switched out for another.

7.4.1 Filling of the Full Refrigerant System

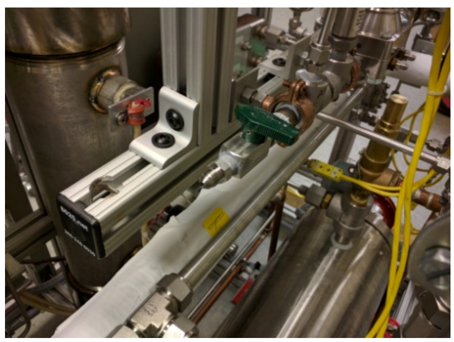
This procedure is to be used for an initial refrigerant fill of the system or when changing refrigerants, after the other refrigerant has been completely removed.

7.4.1.1 Filling of the full refrigerant system with the refrigeration 4-port gauge manifold

1. Weigh the refrigerant supply tank and record the value ____.
2. Ensure the system division isolation valves are open.

3. Prepare to evacuate the system:
    a. Connect vacuum hose to 4-port gauge manifold.
    b. Connect hoses from the manifold to:
        i. Refrigerant receiver tank top port

        ii. Refrigerant supply tank liquid port (if there is only a single port, refer to the tank or its instructions on the orientation necessary to transfer liquid)
        iii. Refrigerant pressure transducer port



4. Ensure the following valves are closed:
    a. Refrigerant supply tank liquid port
    b. Receiver tank top port
    c. Refrigerant pressure transducer port
    d. Refrigerant pump discharge port
    e. Refrigerant back pressure regulator port
5. Turn vacuum pump on.
6. Open the following valves:
    a. All valves on the gauge manifold
    b. Receiver tank top port
    c. Refrigerant pressure transducer port
7. Evacuate system to 600 microns or less.
8. Close vacuum port to gauge manifold.
9. Shut down vacuum pump according to its procedure.
10. Ensure the refrigerant supply tank is oriented properly for liquid transfer.
11. Place the refrigerant supply tank on a scale with transfer lines connected.

12. Record the weight of the refrigerant tank before any refrigerant is transferred _____.
13. Decide how much refrigerant needs to be added to the system ____.
14. Subtract the above value from the current tank weight:
    a. Tank weight _____ - Amount of refrigerant being added to system _____ = Target tank weight ______.
15. Open the following valves:
    a. Gauge manifold to refrigerant supply tank
    b. Gauge manifold to receiver tank top port
    c. Refrigerant supply tank liquid valve
16. Monitor refrigerant supply tank weight as refrigerant is transferred.
17. When the target weight of the refrigerant supply tank is reached, close the refrigerant supply tank valve.
18. Drain the hoses and gauge manifold of any liquid refrigerant into the receiver tank top port and refrigerant pressure transducer port.
19. Close:
    a. Receiver tank top port
    b. Refrigerant pressure transducer port
20. Disconnect gauge manifold and hoses from system.
21. Weigh the refrigerant supply tank and record the value _____.

22. TIPS:
    a. The time it takes to transfer the refrigerant will depend on several factors.
    b. Faster transfer times can be achieved by utilizing any or all of the following aides:
        i. Operating the condenser to subcool the refrigerant.
            - See "Water Loops Startup" procedure in this document.
            - Complete the startup without opening the trim cooler outlet valve.
        ii. Heating the refrigerant supply tank to increase the pressure in it.
        iii. Chilling the refrigerant receiver tank to reduce the receiver pressure.

7.4.1.2 Filling of the full refrigerant system without the refrigeration gauge manifold

1. Weigh the refrigerant supply tank and record the value _____.
2. Ensure the system isolation valves are open.

3. Prepare to evacuate the system:

   a. Connect hoses from vacuum pump to:

      i. Refrigerant back pressure regulator port and vacuum pump.

      ii. Refrigerant pressure transducer port

b. Connect hose from the refrigerant supply tank liquid port to refrigerant receiver tank top port.

i. If there is only a single port on the refrigerant supply tank, refer to the tank or its instructions on the orientation necessary to transfer liquid.

4. Ensure the following valves are closed:
- **a.** Refrigerant supply tank liquid port
- **b.** Refrigerant pump discharge port

5. Ensure the following valves are open:
- **a.** Refrigerant back pressure regulator port
- **b.** Refrigerant receiver tank top port
- **c.** Refrigerant pressure transducer port

6. Turn vacuum pump on.

7. Evacuate system to 600 microns or less.

8. Close:
- **a.** Refrigerant back pressure regulator port
- **b.** Refrigerant pressure transducer port

9. Shut down vacuum pump according to its procedure.

10. Ensure the refrigerant supply tank is oriented properly for liquid transfer.

11. Place the refrigerant supply tank on a scale with transfer lines connected.

12. Record the weight of the refrigerant tank before any refrigerant is transferred _____.

13. Decide how much refrigerant needs to be added to the system ____.

14. Subtract the above value from the current tank weight:
- **a.** Tank weight _____ - Amount of refrigerant being added to system _____ = Target tank weight ______.

15. Open refrigerant supply tank liquid valve

16. Monitor refrigerant supply tank weight as refrigerant is transferred.

17. When the target weight of the refrigerant supply tank is reached, close the refrigerant supply tank valve.

18. Drain the supply hose of any liquid refrigerant into the receiver tank top port.

19. Close receiver tank top port

20. Disconnect hoses from system.

21. Weigh the refrigerant supply tank and record the value _____.

22. TIPS:
    a. The time it takes to transfer the refrigerant will depend on several factors.
    b. Faster transfer times can be achieved by utilizing any or all of the following aides:
        i. Operating the condenser to subcool the refrigerant.
            - See "Water Loops Startup" procedure in this document.
            - Complete the startup without opening the trim cooler outlet valve.
        ii. Heating the refrigerant supply tank to increase the pressure in it.
        iii. Chilling the refrigerant receiver tank to reduce the receiver pressure.

7.4.2 Partial Filling of the Refrigerant System

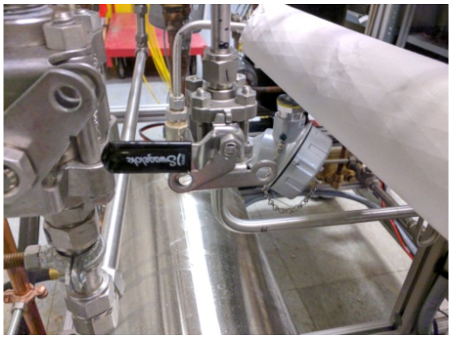
This procedure is to be used after refrigerant has been removed from the high or low pressure side of the system in order to do perform some kind of work on the system, for example when a test heat exchanger has been switched out for another.

See the section on Refrigerant Removal in this manual for information on how to remove refrigerant from the system properly.

For the procedure below, use either the **HEAT EXCHANGER** instructions for adding refrigerant to the high pressure side of the system, which includes the test heat exchanger, refrigerant recuperator (if installed), and back pressure regulator, or **CONDENSER/SUMP/PUMP** instructions for adding refrigerant to the low pressure side of the system including the condenser, refrigerant sump, and up to the suction side of the refrigerant pump.

7.4.2.1 Partial Filling of the Refrigerant With the refrigeration 4-port gauge manifold:

1. Weigh the refrigerant transfer tank and record the value ____.
2. Ensure the system division valves are CLOSED.

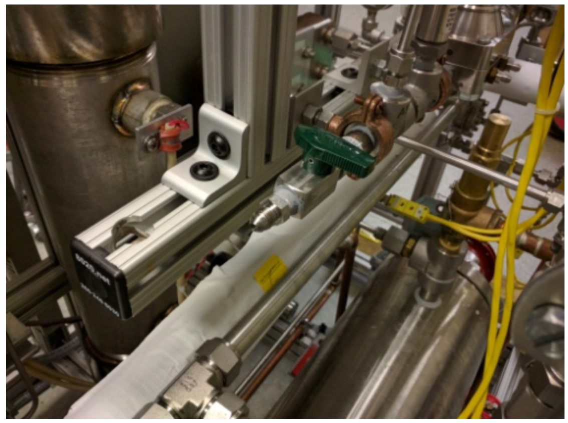


3. Prepare to evacuate the system:
    a. Connect vacuum hose to 4-port gauge manifold.

b. Connect hoses from the manifold to:

i. HEAT EXCHANGER Side of System

- Vacuum pump
- Refrigerant pressure transducer port

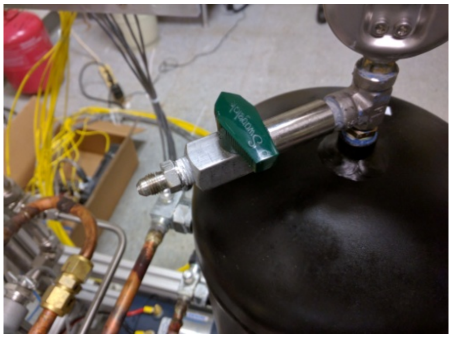


- Refrigerant back pressure regulator port and vacuum pump.

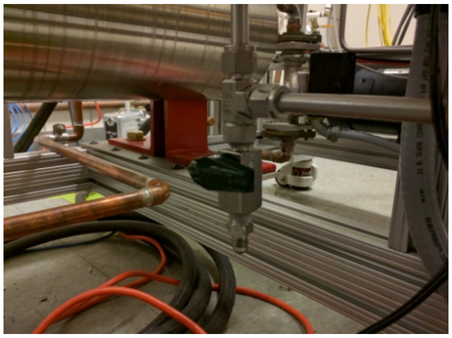
- Refrigerant transfer tank liquid port (if there is only a single port, refer to the tank or its instructions on the orientation necessary to transfer liquid)

ii. CONDENSER/SUMP/PUMP Side of System

- Vacuum pump
- Refrigerant receiver tank top port



- Refrigerant pump discharge port



- Refrigerant transfer tank liquid port (if there is only a single port, refer to the tank or its instructions on the orientation necessary to transfer liquid)

4. Ensure the following valves are closed:
   - **a.** Refrigerant transfer tank liquid port
   - **b.** Receiver tank top port
   - **c.** Refrigerant pressure transducer port
   - **d.** Refrigerant pump discharge port
   - **e.** Refrigerant back pressure regulator port

5. Turn vacuum pump on.

6. Open the following valves:
   - **a. HEAT EXCHANGER**
     - **i.** All valves on the gauge manifold
     - **ii.** Refrigerant pressure transducer port
     - **iii.** Refrigerant back pressure regulator port
   - **b. CONDENSER/SUMP/PUMP**
     - **i.** All valves on the gauge manifold
     - **ii.** Receiver tank top port
     - **iii.** Refrigerant pump discharge port

7. Evacuate system to 600 microns or less.

8. Close vacuum port to gauge manifold.

9. Shut down vacuum pump according to its procedure.

10. Ensure the refrigerant transfer tank is oriented properly for liquid transfer.

11. Place the refrigerant transfer tank on a scale with transfer lines connected.

12. Record the weight of the refrigerant tank before any refrigerant is transferred _____.
13. Decide how much refrigerant needs to be added to the system ____.
14. Subtract the above value from the current tank weight:
  - **a.** Tank weight _____ - Amount of refrigerant being added to system _____ = Target tank weight ______.

15. Open the following valves:
  - **a. HEAT EXCHANGER**
    - **i.** Refrigerant pressure transducer port
    - **ii.** Refrigerant back pressure regulator port
    - **iii.** Refrigerant transfer tank liquid valve
  - **b. CONDENSER/SUMP/PUMP**
    - **i.** Receiver tank top port
    - **ii.** Refrigerant pump discharge port
    - **iii.** Refrigerant transfer tank liquid valve

16. Monitor refrigerant transfer tank weight as refrigerant is transferred.
17. When the target weight of the refrigerant transfer tank is reached, close the refrigerant transfer tank valve.
18. Drain the hoses and gauge manifold of any liquid refrigerant into the:
  - **a. HEAT EXCHANGER**
    - **i.** Receiver tank top port
  - **b. CONDENSER/SUMP/PUMP**
    - **i.** Refrigerant pressure transducer port.

19. Close/Check Closed:
  - **a.** Receiver tank top port
  - **b.** Refrigerant pressure transducer port
  - **c.** Refrigerant back pressure regulator port
  - **d.** Refrigerant pump discharge port
  - **e.** Refrigerant transfer tank liquid valve

20. Disconnect gauge manifold and hoses from system.
21. Weigh the refrigerant transfer tank and record the value ____.

22. TIPS:
  - **a.** The time it takes to transfer the refrigerant will depend on several factors.
  - **b.** Faster transfer times can be achieved by utilizing any or all of the following aides:
    - **i.** Heating the refrigerant supply tank to increase the pressure in it.
    - **ii.** Chilling the refrigerant receiver tank to reduce the receiver pressure.

7.5 REFRIGERANT RECOVERY FROM SYSTEM

This procedure is intended to be used to removal ALL refrigerant from the system and as a first step in changing to a different refrigerant. If only a part of the system needs to be worked on, refer to

This procedure is to be used to remove refrigerant from EITHER the high or low pressure side of the system in order to do perform some kind of work on the system, for example when a test heat exchanger has been switched out for another.

7.5.1 Full Refrigerant Recovery from System

This procedure is intended to be used to removal ALL refrigerant from the system and as a first step in changing to a different refrigerant. If only a part of the system needs to be worked on, refer to the next section **Partial Refrigerant Recovery from System** in this manual to remove refrigerant from one side only.

1. Weigh the refrigerant transfer tank and record the value ____.
2. Ensure the system division valves are open.

3. Prepare to evacuate the transfer lines and refrigerant recovery unit
    a. Connect 4-port gauge manifold to:
        i. Vacuum pump
        ii. Refrigerant receiver tank top port
        iii. Refrigerant pump discharge port
        iv. Refrigerant recovery unit IN port
    b. Connect refrigerant recovery unit OUT port to refrigerant transfer tank vapor port
4. Open the following valves:
    a. All gauge manifold valves
    b. Refrigerant recovery unit IN
    c. Refrigerant recovery unit OUT

5. Turn vacuum pump on.
6. Evacuate the gauge manifold and transfer lines until to 600 microns or less.
7. Close vacuum port to gauge manifold.
8. Shut down vacuum pump according to its procedure.
9. Place the refrigerant transfer tank on a scale with transfer lines connected.
10. Record the weight of the refrigerant tank before any refrigerant is transferred _____.
11. Estimate how much refrigerant needs to be added to the system ____ (refer to refrigerant fill notes for how much refrigerant is in the system).
12. Add the above value to the current tank weight:
    a. Tank weight _____ + Amount of refrigerant being removed from system _____ = Target tank weight ______.
13. Set refrigerant recovery unit selector switch to RECOVER.
14. Power ON the refrigerant recovery unit.
15. Open the refrigerant transfer tank vapor valve.
16. Start the refrigerant recovery unit compressor.
17. Open:
    a. Refrigerant receiver tank top port
    b. Refrigerant pump discharge port
18. Monitor refrigerant transfer tank weight as refrigerant is transferred.
19. When the target weight of the refrigerant transfer tank is reached, or when the weight of the transfer tank no longer increases after 10+ minutes, close:
    a. Refrigerant receiver tank top port
    b. Refrigerant pump discharge port
    c. Refrigerant recovery unit IN
20. Power OFF the refrigerant recovery unit.
21. Close:
    a. Refrigerant transfer tank vapor valve.
    b. Refrigerant recovery unit OUT
22. Disconnect hoses (CAUTION: There may still be refrigerant in the hoses.)
23. Refer to refrigerant recovery unit instructions for purging any trapped refrigerant.
24. Weigh the refrigerant transfer tank and record the value ____.

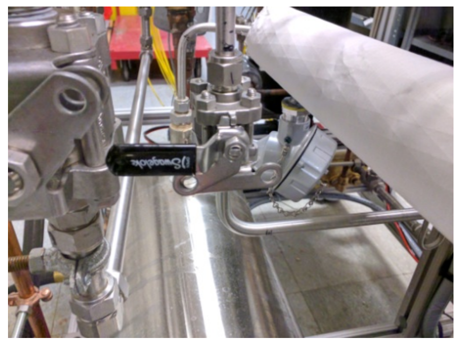
25. TIPS:
    a. The time it takes to transfer the refrigerant will depend on several factors.
    b. Faster transfer times can be achieved by utilizing any or all of the following aides:
        i. Heating the refrigerant receiver tank to increase the pressure in it.
        ii. Chilling the refrigerant transfer tank to reduce the pressure.

7.5.2 Partial Refrigerant Recovery from System

This procedure is to be used to remove refrigerant from EITHER the high or low pressure side of the system in order to do perform some kind of work on the system, for example when a test heat exchanger has been switched out for another.

To remove ALL the refrigerant from the system, refer to the previous section **Full Refrigerant Recovery from System** in this manual.
For the procedure below, use either the **HEAT EXCHANGER** instructions for removing refrigerant from the high pressure side of the system, which includes the test heat exchanger, refrigerant recuperator (if installed), and back pressure regulator, or **CONDENSER/SUMP/PUMP** instructions for removing refrigerant from the low pressure side of the system including the condenser, refrigerant sump, and up to the suction side of the refrigerant pump.

1. Weigh the refrigerant transfer tank and record the value ____.
2. Ensure the system division valves are CLOSED.

3. Prepare to evacuate the transfer lines and refrigerant recovery unit
   a. Connect 4-port gauge manifold to:
      i. **HEAT EXCHANGER**
         - Vacuum pump
         - Refrigerant pressure transducer port
         - Refrigerant back pressure regulator port
         - Refrigerant recovery unit IN port
      ii. **CONDENSER/SUMP/PUMP**
         - Vacuum pump
         - Refrigerant receiver tank top port
         - Refrigerant pump discharge port
         - Refrigerant recovery unit IN port
   b. Connect refrigerant recovery unit OUT port to refrigerant transfer tank vapor port
4. Open the following valves:
   a. All gauge manifold valves
   b. Refrigerant recovery unit IN
   c. Refrigerant recovery unit OUT
5. Turn vacuum pump on.
6. Evacuate the gauge manifold and transfer lines to 600 microns or less.
7. Close vacuum port to gauge manifold.
8. Shut down vacuum pump according to its procedure.
9. Place the refrigerant transfer tank on a scale with transfer lines connected.

10. Record the weight of the refrigerant tank before any refrigerant is transferred _____.
11. Estimate how much refrigerant needs to be added to the system ____ (refer to refrigerant fill notes for how much refrigerant is in the system).
12. Add the above value to the current tank weight:
    a. Tank weight _____ + Amount of refrigerant being removed from system _____ = Target tank weight ______.
13. Set refrigerant recovery unit selector switch to RECOVER.
14. Power ON the refrigerant recovery unit.
15. Open the refrigerant transfer tank vapor valve.
16. Start the refrigerant recovery unit compressor.
17. Open:
    a. **HEAT EXCHANGER**
        i. Refrigerant pressure transducer port
        ii. Refrigerant back pressure regulator port
    b. **CONDENSER/SUMP/PUMP**
        i. Refrigerant receiver tank top port
        ii. Refrigerant pump discharge port
18. Monitor refrigerant transfer tank weight as refrigerant is transferred.
19. When the target weight of the refrigerant transfer tank is reached, or when the weight of the transfer tank no longer increases after 10+ minutes, close:
    a. **HEAT EXCHANGER**
        i. Refrigerant pressure transducer port
        ii. Refrigerant back pressure regulator port
        iii. Refrigerant recovery unit IN
    b. **CONDENSER/SUMP/PUMP**
        i. Refrigerant receiver tank top port
        ii. Refrigerant pump discharge port
        iii. Refrigerant recovery unit IN
20. Power OFF the refrigerant recovery unit.
21. Close:
    a. Refrigerant transfer tank vapor valve.
    b. Refrigerant recovery unit OUT
22. Disconnect hoses (CAUTION: There may still be refrigerant in the hoses.)
23. Refer to refrigerant recovery unit instructions for purging any trapped refrigerant.
24. Weigh the refrigerant transfer tank and record the value ____.

25. TIPS:
    a. The time it takes to transfer the refrigerant will depend on several factors.
    b. Faster transfer times can be achieved by utilizing any or all of the following aides:
        i. Heating the refrigerant receiver tank to increase the pressure in it.
        ii. Chilling the refrigerant transfer tank to reduce the pressure.

8. APPENDIX A. DESIGN SPECIFICATIONS FOR THE HEAT EXCHANGER TEST LOOP

The specifications for the heat exchanger test loop are as described below:

1) Be able to utilize multiple refrigerants, including R134a and R245fa;
2) Be able to deliver refrigerant to a heat exchanger at pressures up to 725 psia (5 MPa) and temperatures of about 100 F;
3) Be able to be configured to also measure the performance of a test condenser with refrigerant entering at about 100 psia and with superheated temperatures. The normal test loop condenser would be swapped with the gas cooler or condenser to be tested;
4) Have a pressurized water loop that will be a substitute for a geothermal brine loop that can deliver to the test heat exchanger a controlled water temperature of up to 392 F (200 C) at 217.6 psia (1.5MPa) and can provide at least 5 kW (7.5 kW if possible) of electric heating to the water delivered to the test heat exchanger section;
5) Have a means to throttle the high pressure refrigerant flow leaving the high temperature heat exchanger to drop the pressure to the gas cooler / condenser pressure;
6) Have a sufficient refrigerant receiver volume to handle the varying vapor quality conditions within the flow circuit;
7) Have the ability to control the refrigerant volume flow rate with a nominal flow rate of 0.02 kg/s (160 lb/hr);
8) Use the facilities cold water supply as the cooling fluid in a gas cooler / condenser;
9) Have provisions for evacuating, filling and draining the refrigerant test loop;
10) Have provisions for valving off the heat exchanger test section without draining the entire loop;
11) Have appropriate safety systems to protect for over pressure and over temperature conditions.

The specifications for the instrumentation and data acquisition Interface are:

1) The test loop will have onboard controls in place for safe manual operation;
2) Have a means to provide for data transfer from an external data acquisition system to the test loop to allow the external data acquisition system to record test data;
3) Have turbine flowmeters for the refrigerant loop, the simulated brine loop and for the cooling loop;
4) Have thermocouples to measure system temperatures and appropriate pressure sensors and gauges;

9. APPENDIX B. MAJOR COMPONENTS OF THE TEST LOOP AND SAFETY FEATURES

Drawings of the assembly of the major components of the test loop are shown in Figures 11a and 11b. All the electrical components are NRTL certified as shown in Tables 3 and 4. The wiring diagram for the temperature controller of the Wattco heater is shown in Figure 12. The wiring diagram for the entire test stand is shown Figure 13, 14, and 15. Due to the small font used in the wiring diagram, the left-hand side and right-hand side parts of the wiring diagram are shown separate in Figures 14 and 15.

1) WattcoElectric Heater
    •Vessel
    –3 inch pipe vessel diameter with 44 inch length
    –300 lbflange vessel
    –0.5 gpm
    –Heat Input 7.5 kW
    •208 V 3 Phase, 20 Amps
    •Control Panel
    –Temperature control
    –Over Temp limit

2) Refrigerant Sump
    •Rated to 450 psi
    •Steel Construction

3) Refrigerant Pump
    –HydacellM03XKBJHFEHA
    –DC Power Supply
    –DC Variable Speed Drive
    •2 HP
    •80-250 rpm

4) Pneumatic Operated Back Pressure Regulator
    •Uses N2 supply to regulate refrigerant back pressure directly
    •Wetted seals: Kalrez Grade 7075
    •One valve can control pressure for both fluids

5) Turbine Flowmeters
    •Cooling Water:
    –FTB1411: 0.6 to 3 gpm
    –15 to 50 F rise at 7.5 kW
    •Refrigerant Loop:
    –FTB9507: 0.03 to 0.65 gpm
    –Flow: 0.1 to 0.65 gpm
    •Brine Loop:
    –FTB9507: 0.03 to 0.65 gpm
    –Flow: 0.05 to 0.5 gpm

6) Absolute Pressure Transducers: PX309 Transducer
    •Used for Brine and Refrigerant Pressures

•Ranges: 0-300 psi and 0-1000 psi
•Proof pressure = 2x max range
•4-20 ma signal for local and DAC use

7) Custom "Brine" HP Water Vessel
•Fabricated from SS 4 in Pipe and End Caps with 0.8 gallon capacity
•Components rated to over 650 psi at 350 F
•Maintain minimum pressure with Nitrogen regulator at 200 psi and max pressure with 220 psi back pressure regulator
•Welded Construction
•Should operate at room temperature but designed for transient high temperatures
•Three heat resistant level switches to sense:
–1) High water level
–2) Nominal fill level
–3) Low water level

8) Pressure Safety Systems for Refrigerant Loop
High Pressure Side (to low pressure side)
•Swagelok SS-4R3A5 High Pressure Proportional Relief Valve from pump discharge to condenser inlet (set to 800 psig)

Low Pressure Side (to ambient)
•BS&B Rupture Disk "Type B" set to 292-300 psig. Obtaining 5 spare disks.

9) Safety Systems for Brine Loop
Brine Loop
–Pressure relief set to 250 psig
–Heater controller with OTC connected to max brine temp sensor

10) Structural Frame
•Structural frame constructed from 8020 Aluminum bar
•HX mounts to top shelf plate
•Added heavy duty casters for up to 2400 lbframe load
•Actual Dimensions: 32 in deep, 72 in wide, 38 in tall

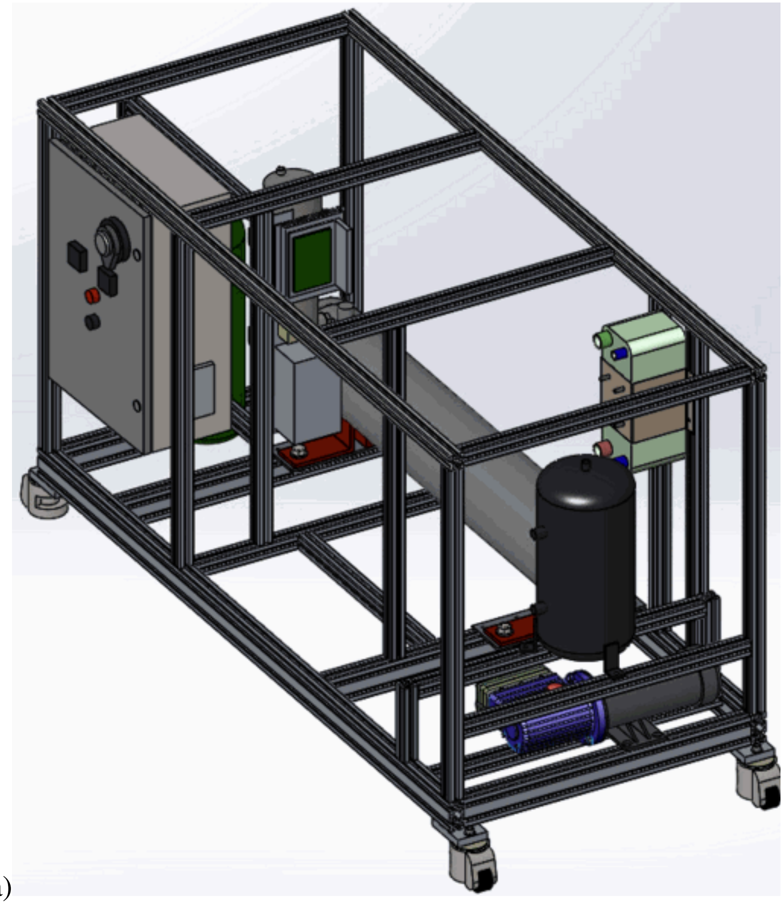
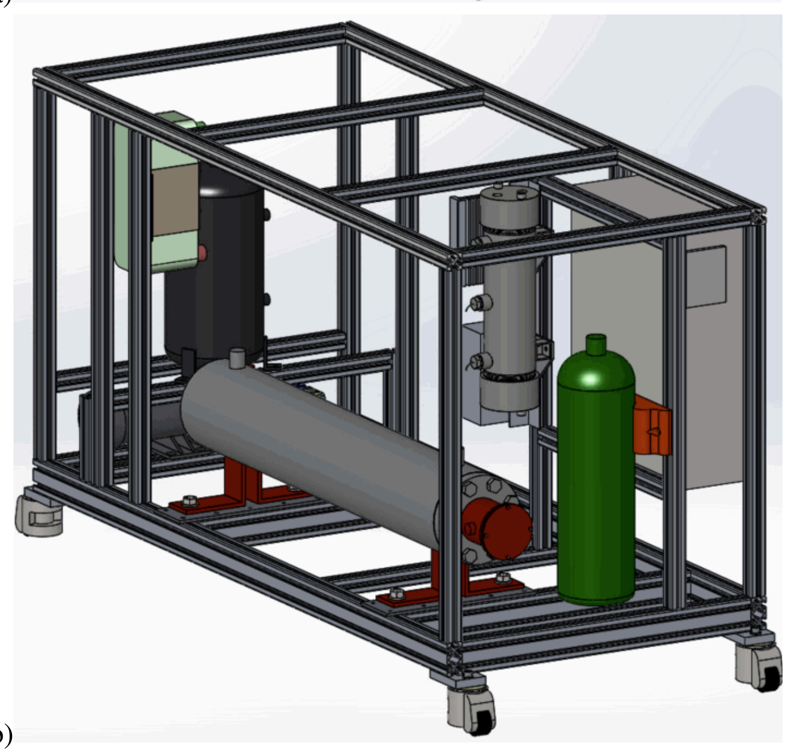

(a)

(b)

Figure 11. Drawings of the major components of the test loop: (a) front view and (b) back view.

Table 3. Electrical components and their certification – part I.

Component Name	Manufacturer/ trademark	Type / model	Technical data and securement means	Mark(s) of conformity
"Brine" water circulation heater	Wattco	FLS3-75X2438T-36307	7.5 kW 208 VAC, 3 phase, 20 A, TC for limit control and TC for temperature control of outlet water. Source: sales order and nameplate.	UL Recognized, CSA Listed
Heater temperature controller	Wattco	Control Panel	SCR Heater Controller for 7.5 kW 208/240 VAC, 3 phase heater. Source: sales order; product label.	UL Listed (Number A 06834354
DC power supply	Lambda	SWS600-24	600 W. 24 VDC power supply, Source: product literature.	UL60950-1, CSA60950-1, CE mark.
City water circulator	Armstrong	Astro 230SS	Thermally protected, Type 2 Enclosure, Class H. Source: product label.	ETL (Intertek#3195880), Conforms to UL Std. 778, Certified to CSA Std C22.2 No. 108-01.
"Brine" water pump	Tuthill Corp	DGS.57PPPV1NN690E0	Magnetically coupled, sealless, gear pump. Source: manufacturers literature.	confirmation on status
"Brine" pump DC speed control	Minarik	DC16-12/24	16 Amp current capacity, Source: manufacturers literature.	UL listed
Refrigerant pump and motor	Wanner Eng. pump with Leeson motor	Hydra-Cell M03EKBPHFEPA pump with C4D17FK98 motor	Diaphragm pump: up to 2.2 gpm at 1200 psi. Motor: 24 vdc, 1 HP, 1800 rpm, XS56C frame, TEFC motor. Source: product nameplate	Motor is CSA listed.
Refrigerant pump DC speed control	Minarik	DC60-12/24	60 Amp current capacity. Source: manufact. lit.	UL Listed.

Table 4. Electrical components and their certification - part II.

Component Name	Manufacturer/ trademark	Type / model	Technical data and securement means	Mark(s) of conformity
Temperature displays - Conrollers (x6)	Omega	CNi1653	Limit temperature setpoint and display values are displayed, relay outputs. Source: manufact. label	UL certified.
Flowrate display	Newport	INFCTRA-0210-R/E-01	Pulse Input, 4-20 mA output, green display. Source: manufacturers label	CE listed.
Flowrate display (x2)	Newport	INFCTRA-0100-R/E-01	Pulse Input, 4-20 mA output, red display, Source: manufacturers label	CE listed.
Thermocouple selector switch	Omega	SW142-12-M	Thermocouple selector switch - low voltage signals.	none
Relay - 120 VAC coil	Omron	G7L-1A-TUBJ-CB	Switches load up to 15 A at 120 VAC.	UL recognized, CSA certified, CE mark.
Relay - 24 VDC coil (2x)	Omron	G7L-1A-BUBJ-CB	Switches load up to 15 A at 120 VAC.	UL recognized, CSA certified, CE mark.
Toggle switch (x4)	Mexico	Model 1546	15 A at 125 VAC. Source: distributor literature.	UL recognized, CSA certified.
Test Stand Controller Electrical Enclosure	Pentair Technical Products, Hoffman	Cat No. CSD20168, Type: Concepts®	Type 4, 12 enclosure, Source: manufacturer label.	UL Listed, Issue No. A-1958

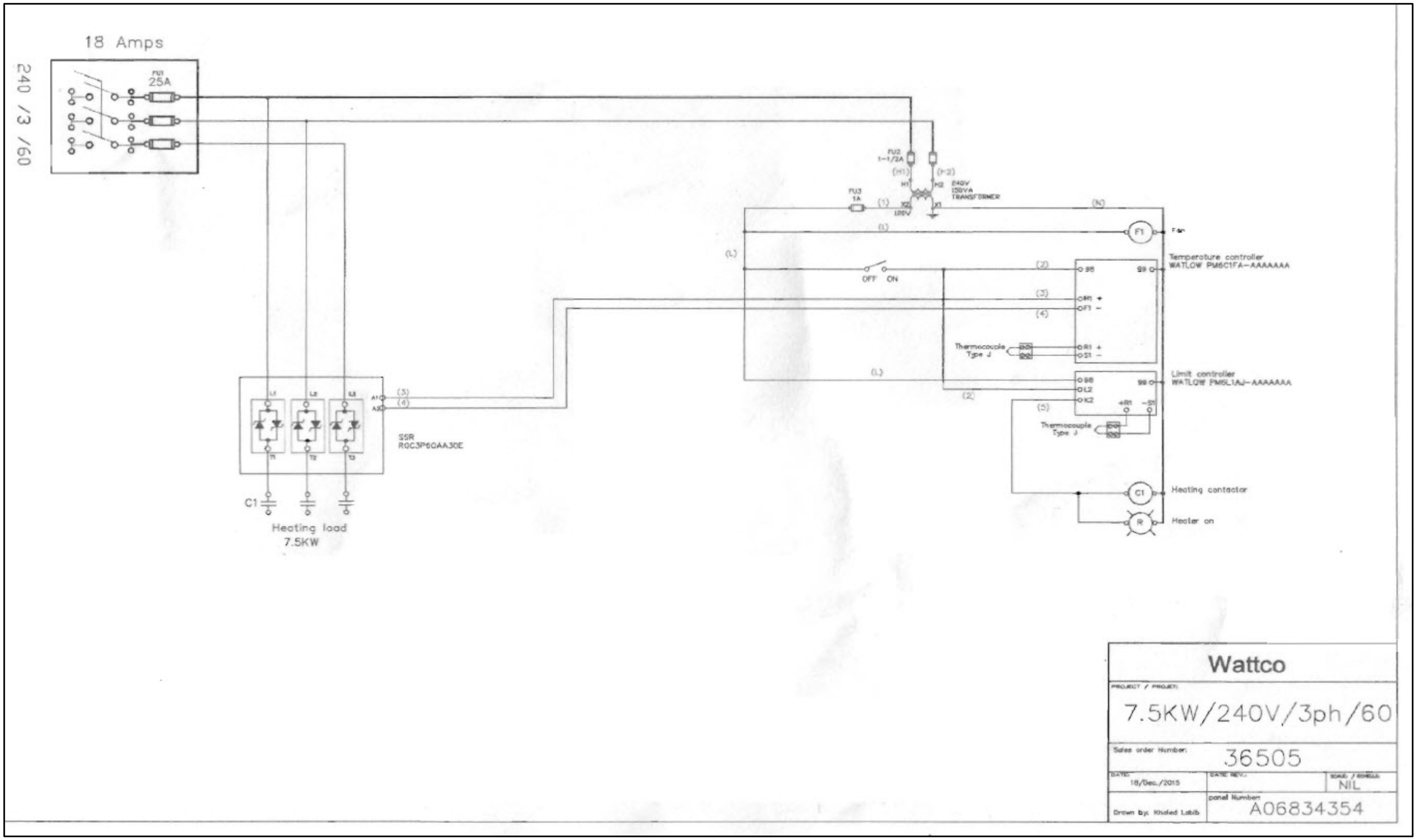


Figure 12. Wiring diagram for Wattco heater temperature controller.

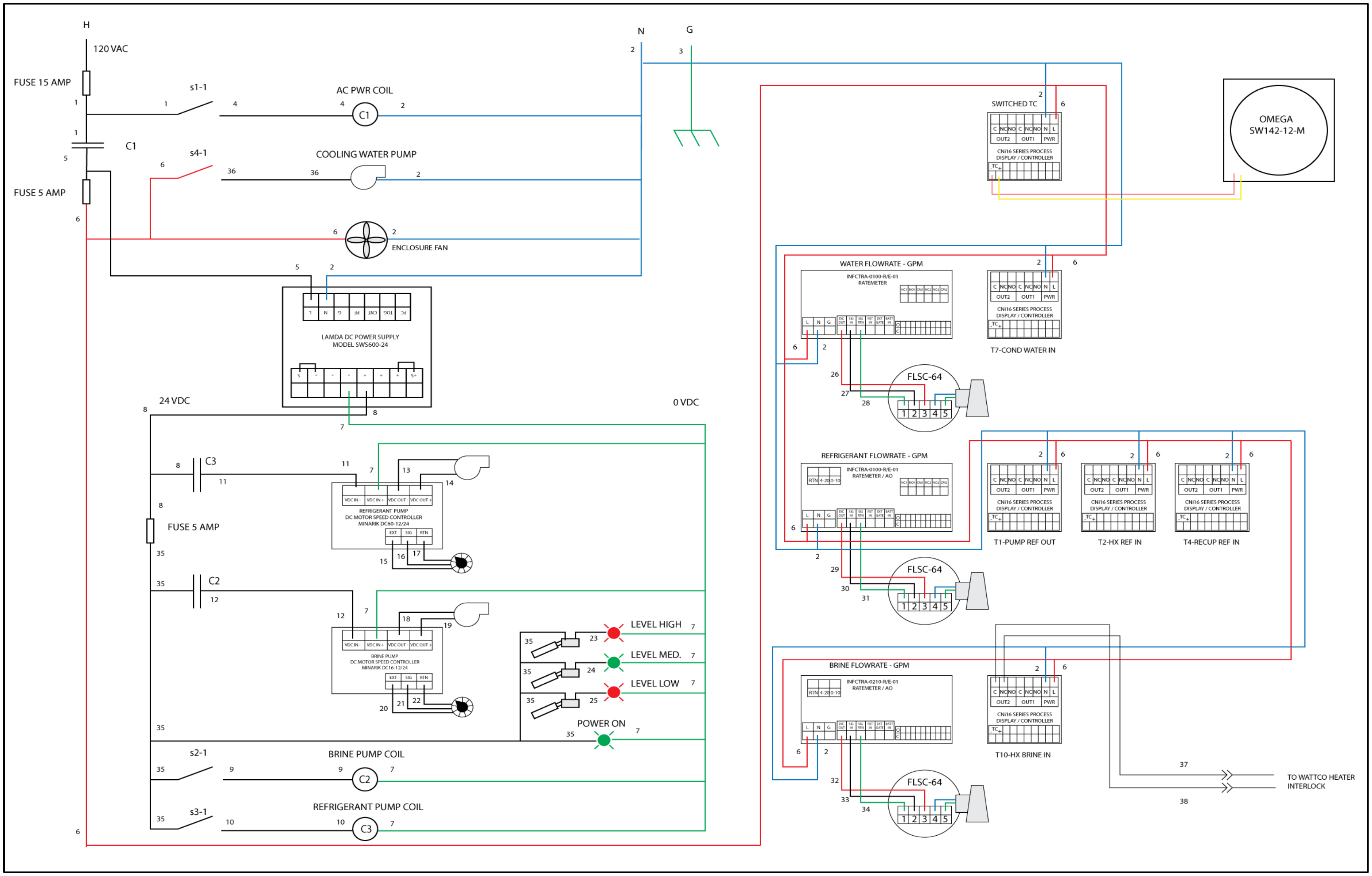


Figure 13. Entire wiring diagram for the Test Stand excluding heater components.

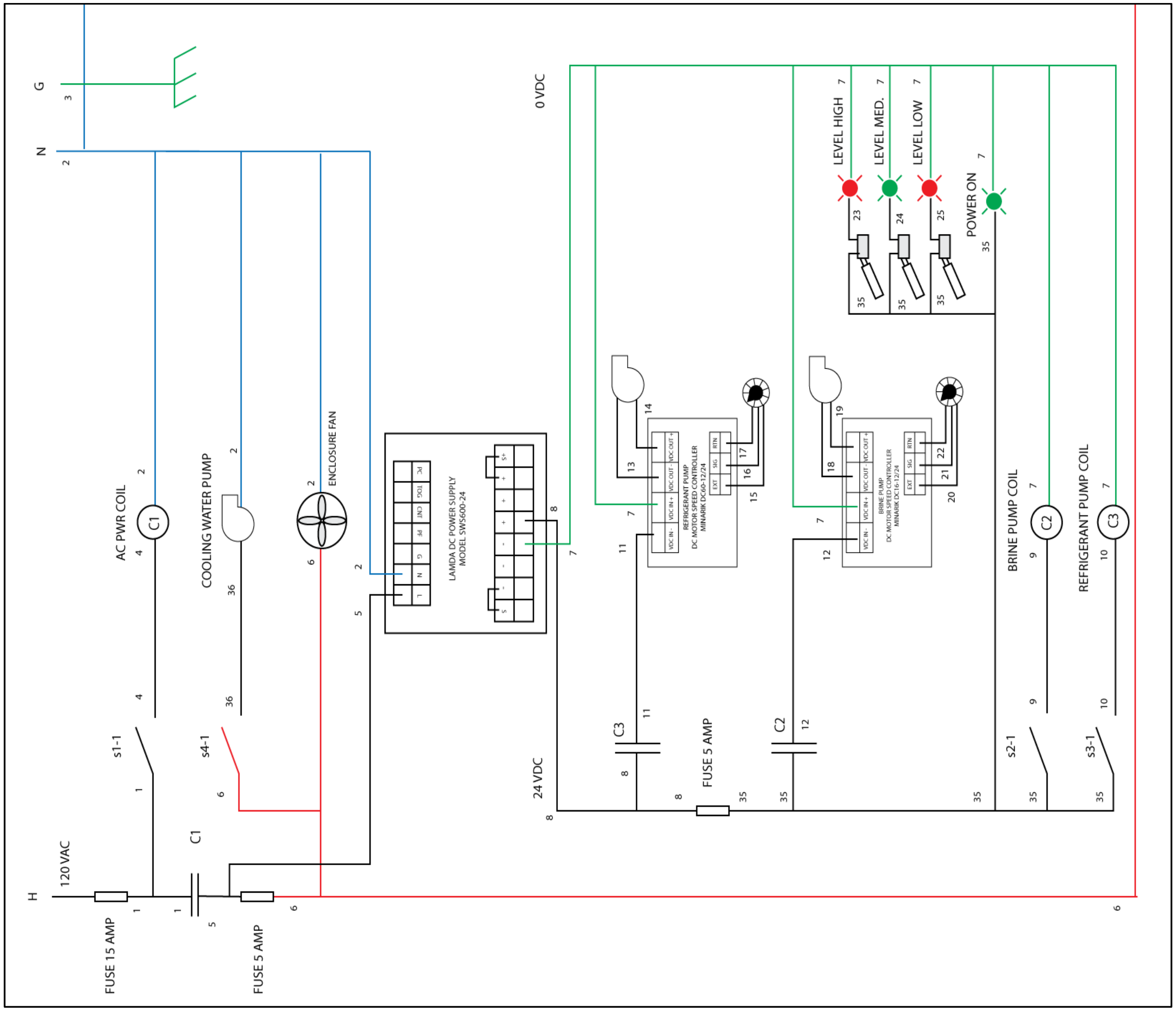


Figure 14. Left-hand side wiring diagram for the Test Stand excluding heater components.

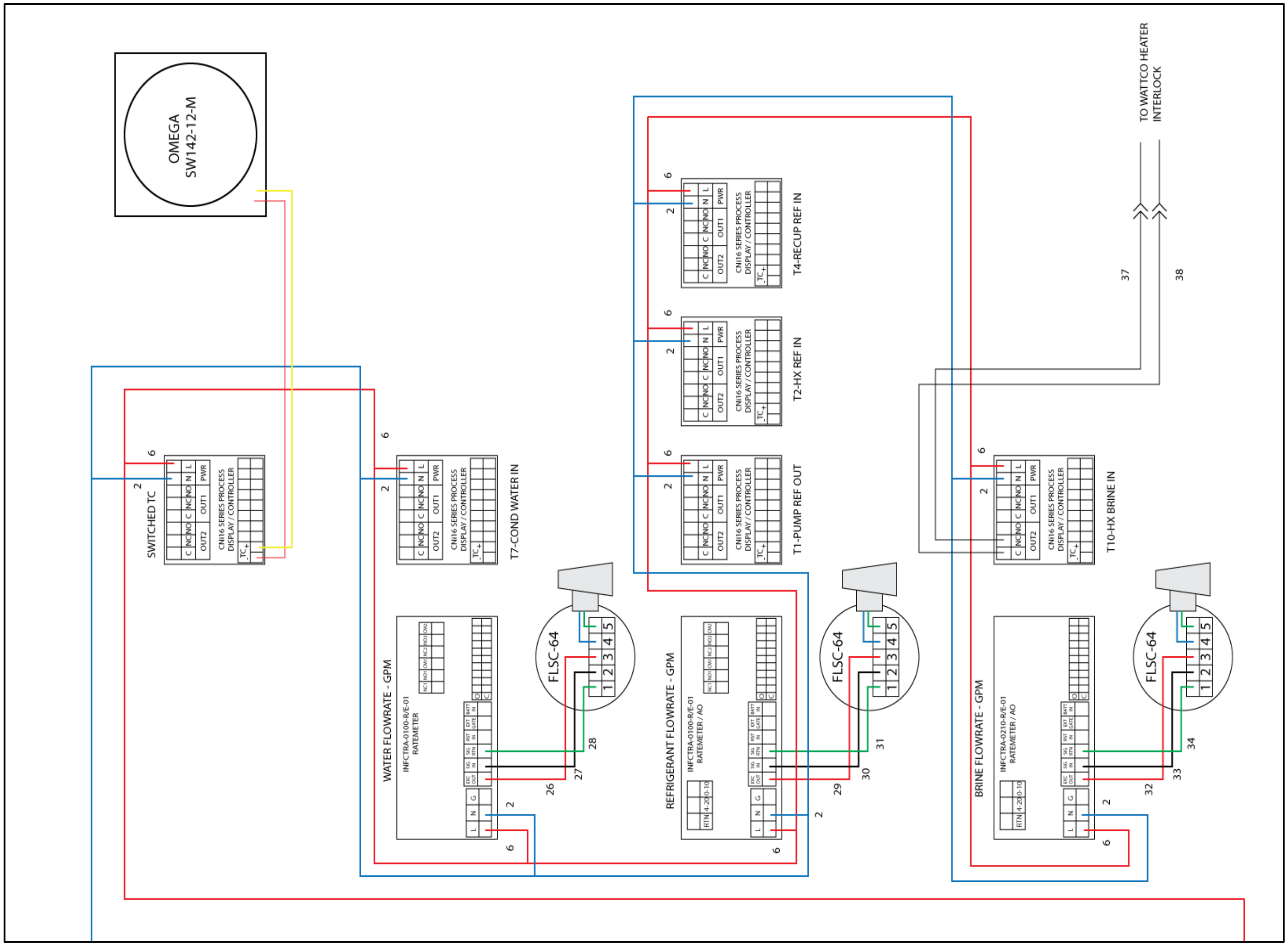


Figure 15. Right-hand side wiring diagram for the Test Stand excluding heater components.