ASHRAE RP1785 - PMS meeting

EXPERIMENTAL VALIDATION OF REFRIGERANT CHARGE MODELS IN COILS FOR RESIDENTIAL SPLIT SYSTEMS

Sponsor TC 8.11, Unitary and Room Air Conditioners and Heat Pumps
Co-sponsor TC 8.4, Air-to-Refrigerate Heat Transfer Equipment and
Co-sponsor TC 6.3, Central Forced Air Heating and Cooling Systems

06/23/2019

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- Project management subcommittee (PMS)
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  - TC 8.11, TC 8.4, and TC 6.3
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- Harrison-Orr, especially Damon McClure
- Danfoss, especially Dan Schillinger
- Temprite, especially Jim Nonnie
- Henry Technologies, especially Aaron M. Arnold

Agenda

1. Refrigerant Conditioning Loop
2. Removable Heat eXchanger Charge Test Module(RHXCT)
3. Volume-Measurement Device (VMD)
4. Project Schedule
5. Appendix

Experimental Setup
- Refrigerant Conditioning Loop

Refrigerant Conditioning Loop (Current status)

- **The loop is ready to operate[1]**
- **Data acquisition software has been developed[1]**

1) This loop built by Saad Saleem, to be used for RP1785 as well as OCAST project

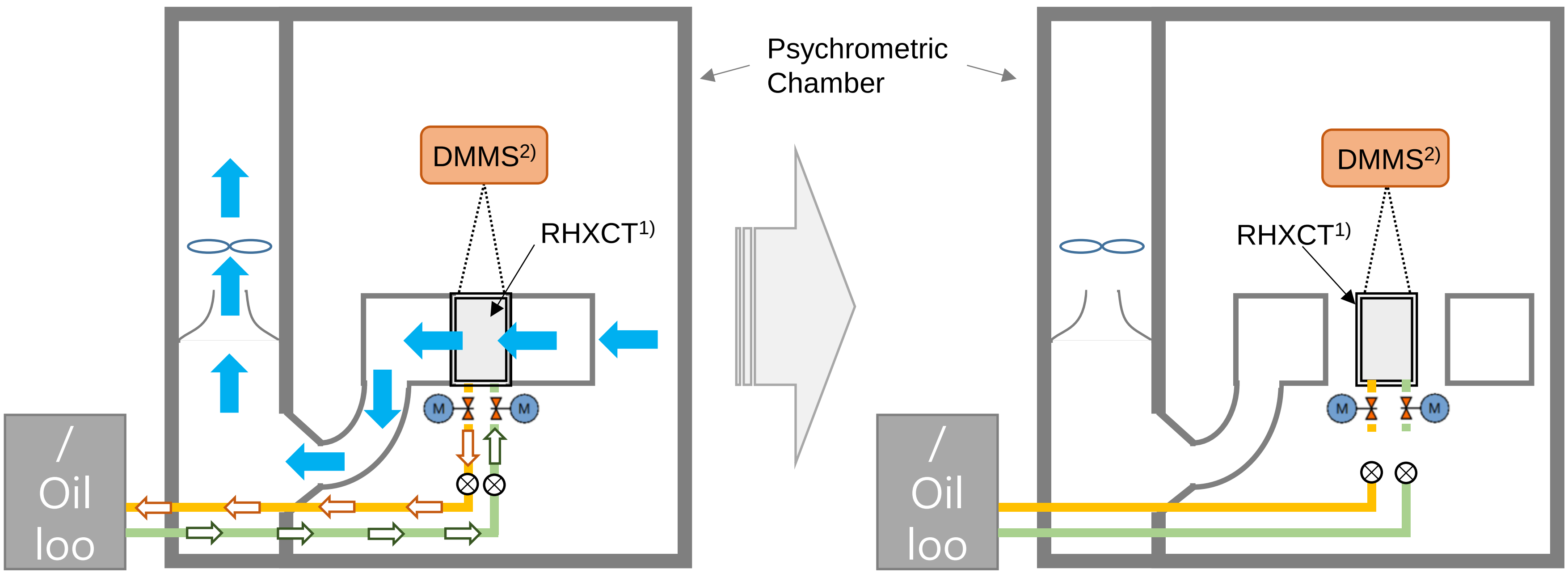
Removable
Heat
eXchanger
Charge
Test module

(RHXCT)

Background

- RHXCT should
  : Detachable / Quick sampling/ Compact

- **Operating Mode (steady-state)**
- **Charge Sampling Mode**

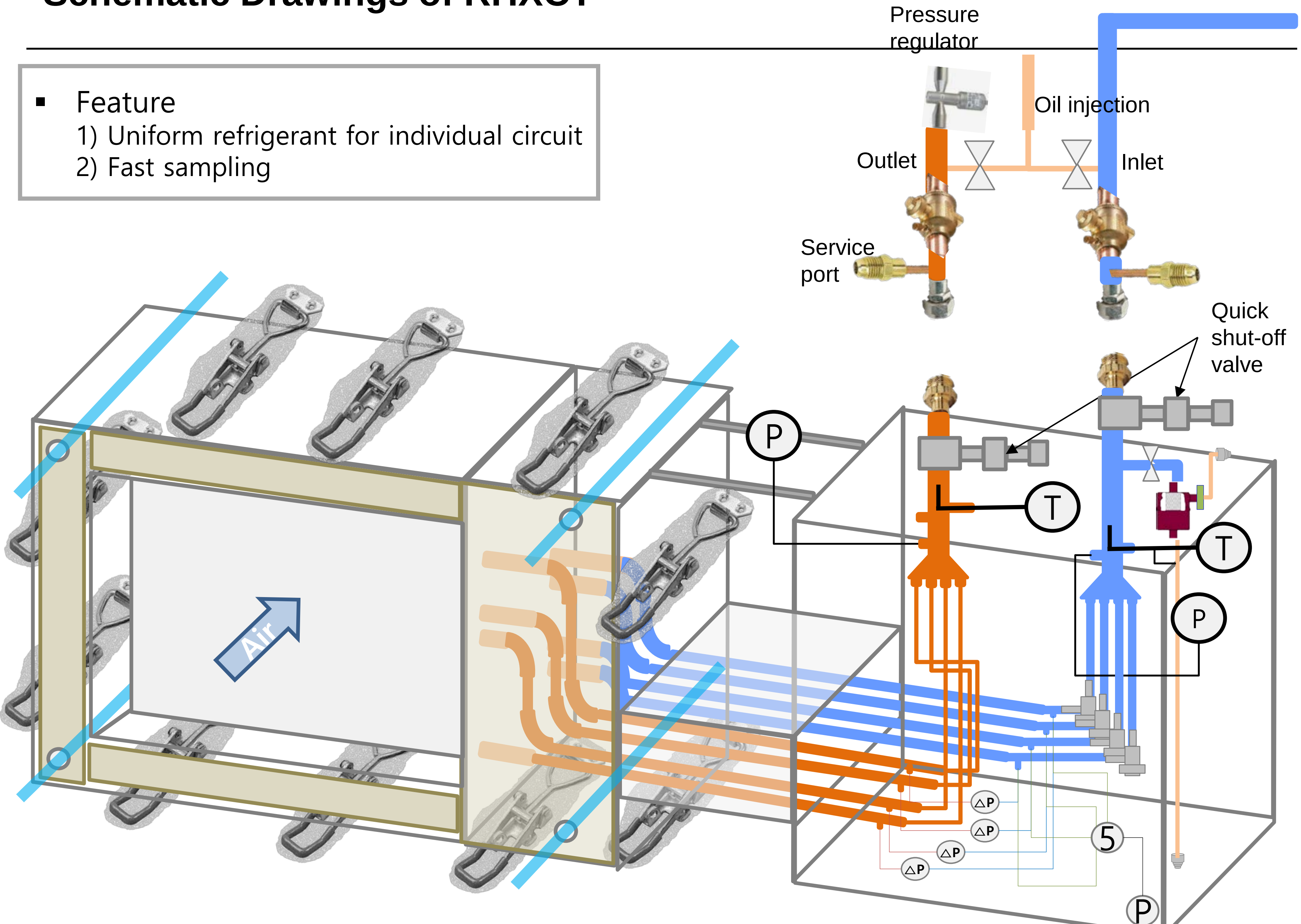


(Motorized fast ball valves)

1) Removable Heat exchanger Charge Test Module
2) Differential Mass Measurement Scale
3) Round tube plate fin heat exchanger

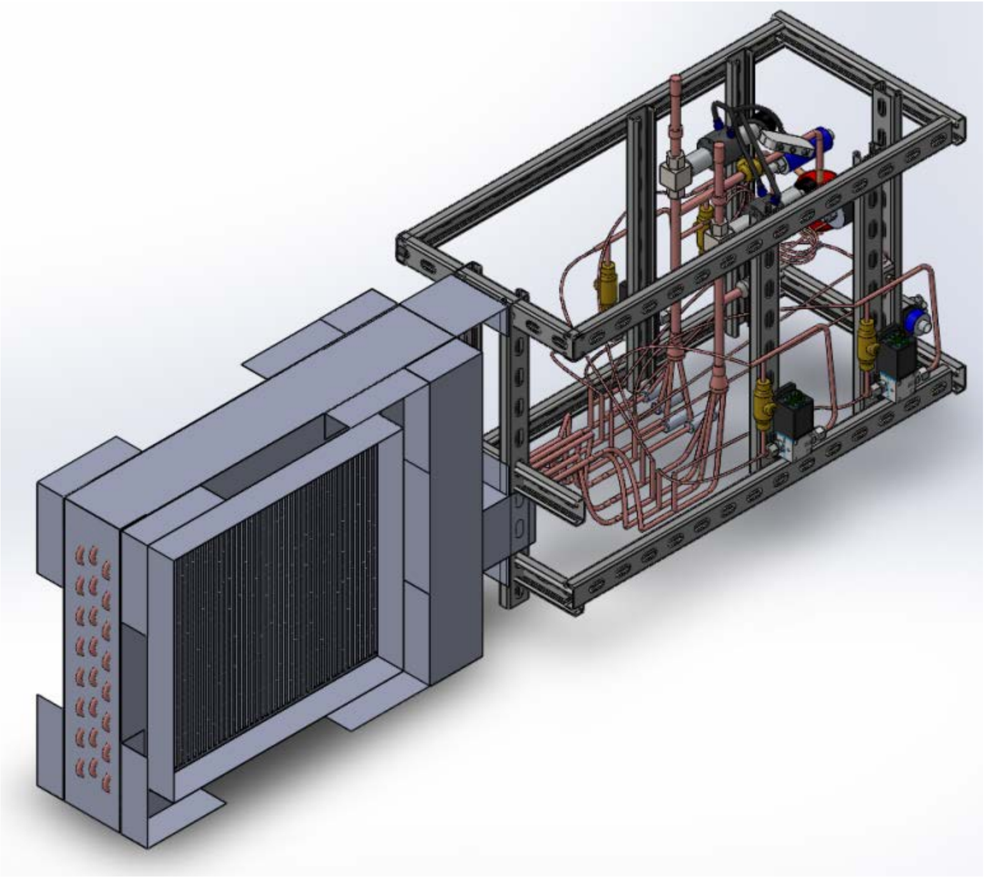
Schematic Drawings of RHXCT

- Feature
  1) Uniform refrigerant for individual circuit
  2) Fast sampling

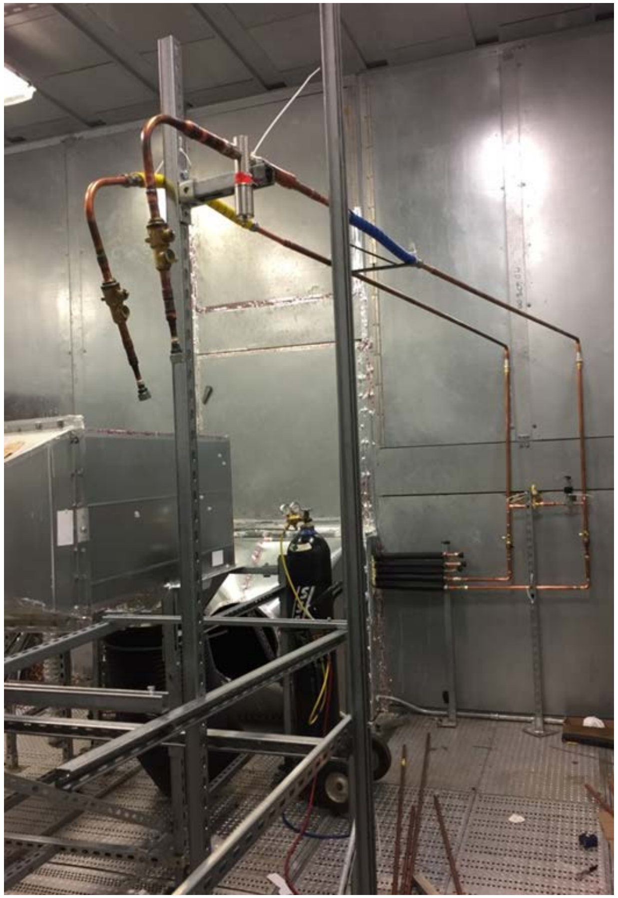


Detailed Drawings of RHXCT

- **3D modeling**



- **Piping connections**



1) …

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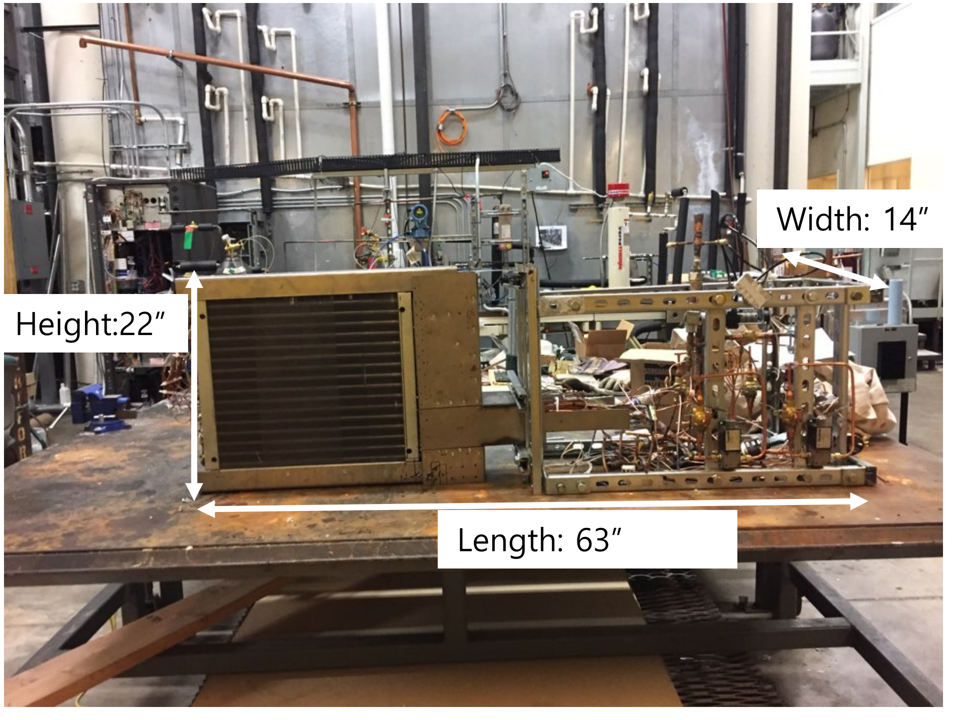
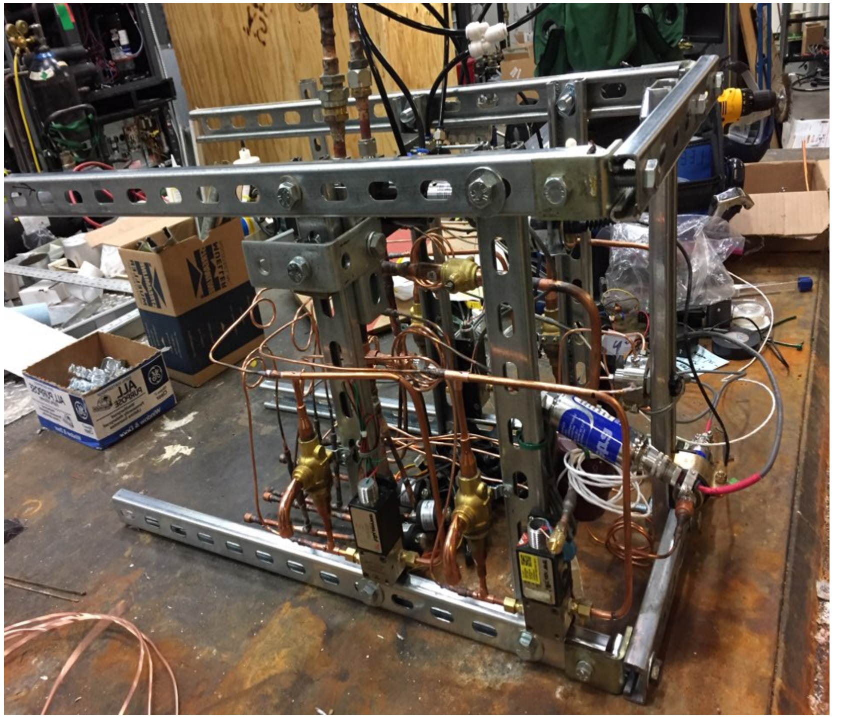
RHXCT (Current status)

- **Module assembling is in progress**

- **RHXCT (in progress)**



- **Module part of RHXCT**



Individual Circuit Pressure Transducers

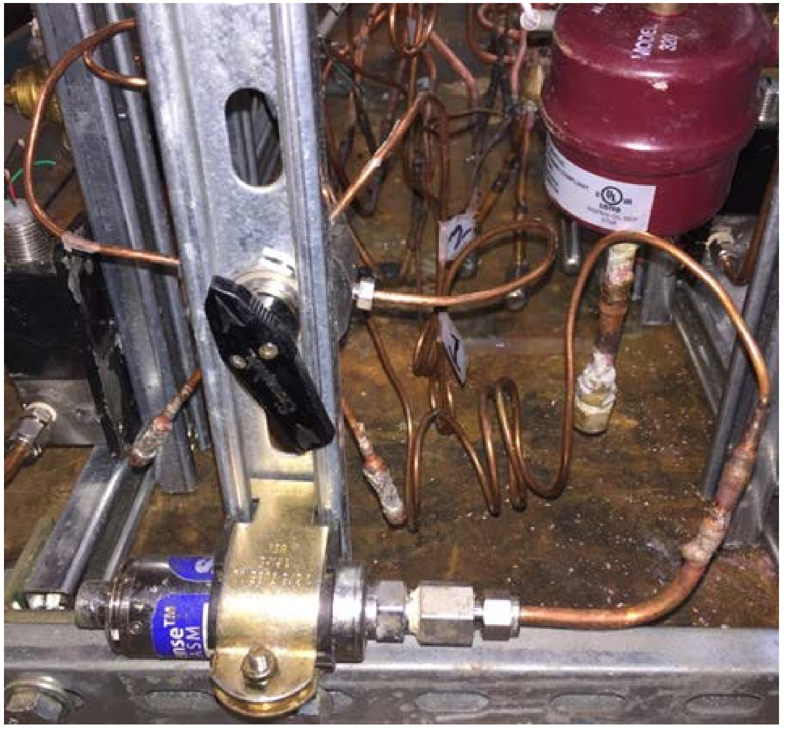
- **To check pressure drop across the circuits for uniform refrigerant distribution.**
- **Calibrated in house w/ an accuracy of 0.07 PSI**

1) Accuracy of calibration reference pressure sensor: +/- 0.0075 psig

Pressure Sensors

- **Two pressure sensors at the coil inlet (Rated accuracy of 0.25 psi)**
  : Before and after expansion valves
- **Coil outlet pressure sensor (Rated accuracy of 0.65 PSI)**

- **Coil Inlet pressure sensor**



- **Coil outlet pressure sensor**

1) Accuracy of calibration reference pressure sensor: +/- 0.375 psig

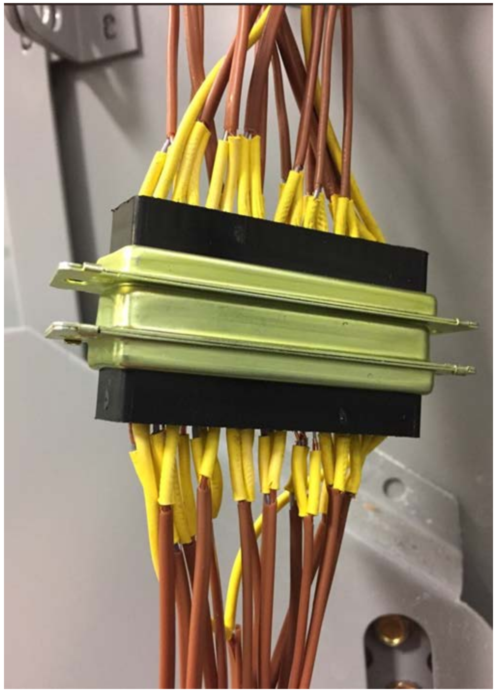
RTDs and Thermocouple Quick Connectors

- **RTD - Installed to module's inlet and outlet pipes**
  (In-house calibration: Accuracy within 0.04 °F of reference thermometer reading)

- **TC - Installed to every return bends and hair pins**
  (In-house calibration: Accuracy within 0.4 °F of reference thermometer reading)

- **RTD**

- **TC**

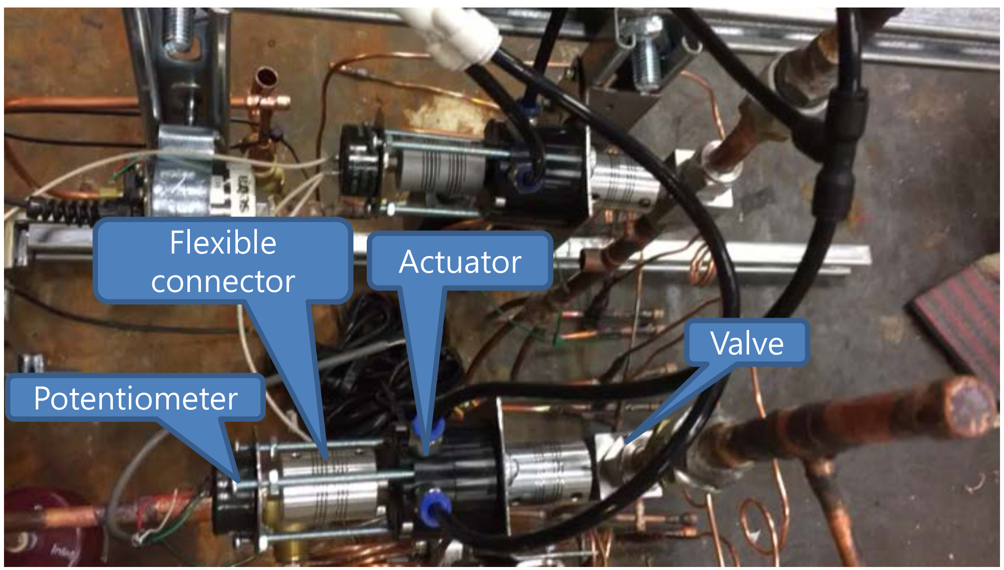


1) Accuracy of calibration reference thermometer: 0.1 °F

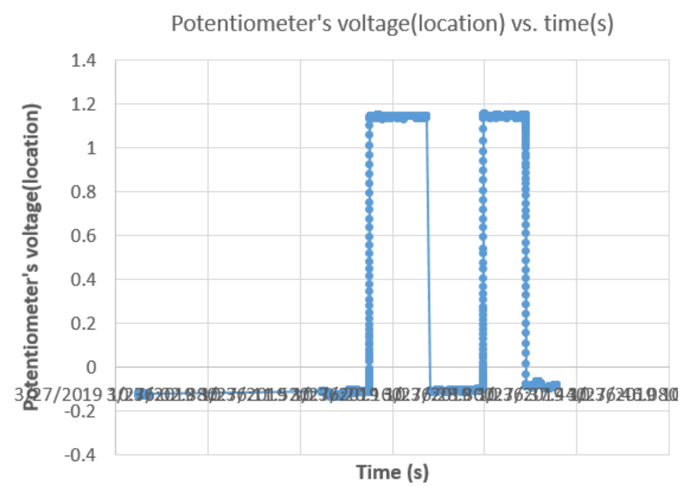
Pneumatic Fast Acting Shut-off Valves

- **To sample refrigerant charge and oil retention installed at the inlet and outlet of RHXCT**
- **Measured closing time using a potentiometer on the valve's shaft is 0.06 sec. with good repeatability.**

- **Operation of the valve**



- **Closing time of the valve**

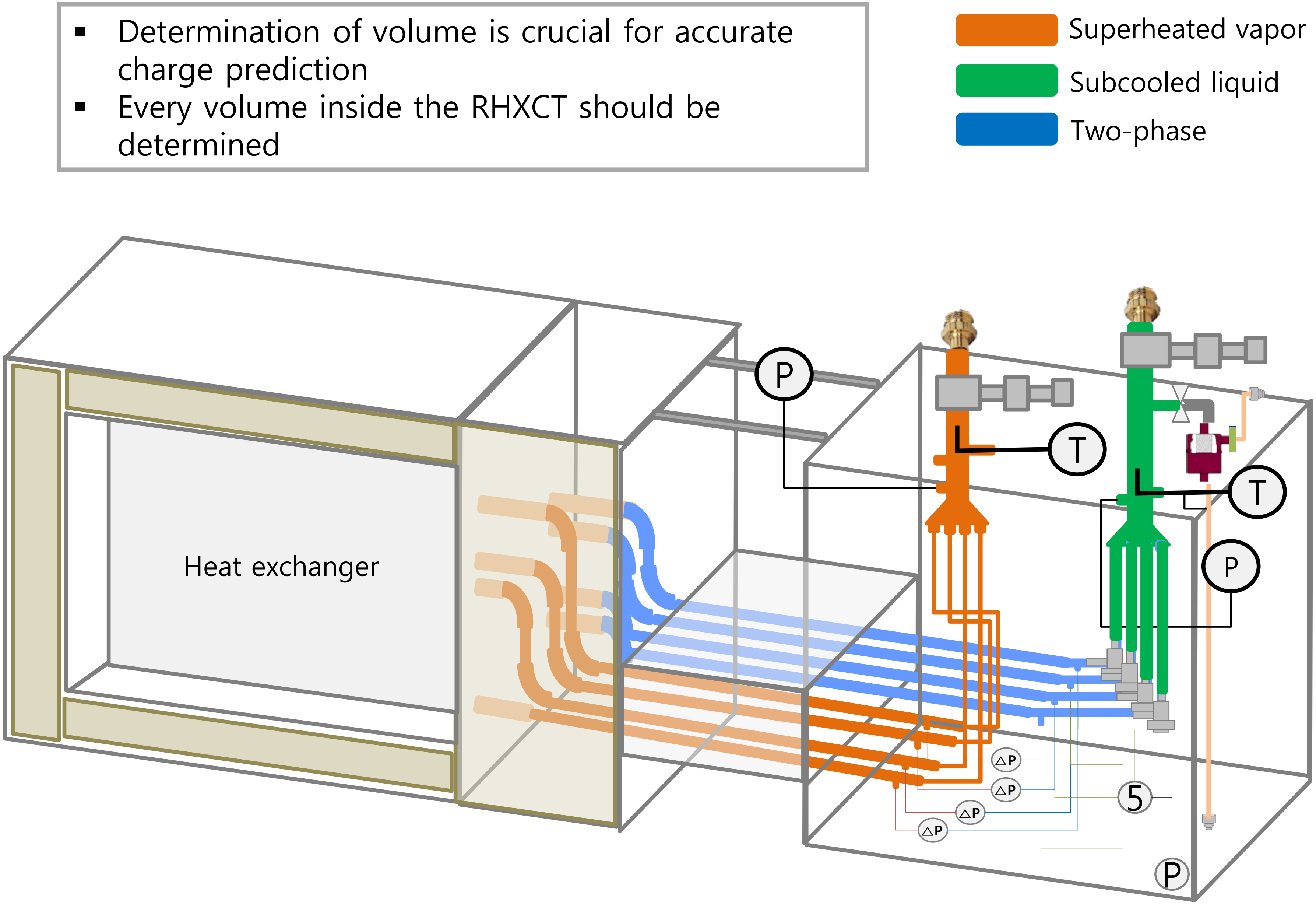


	1st	2nd	3rd
Each closing time(S)	0.059	0.062	0.048
Average closing time(s)	**0.06**		

Volume-Measurement Device (VMD)

Motivation of Volume-Measurement Device (VMD)

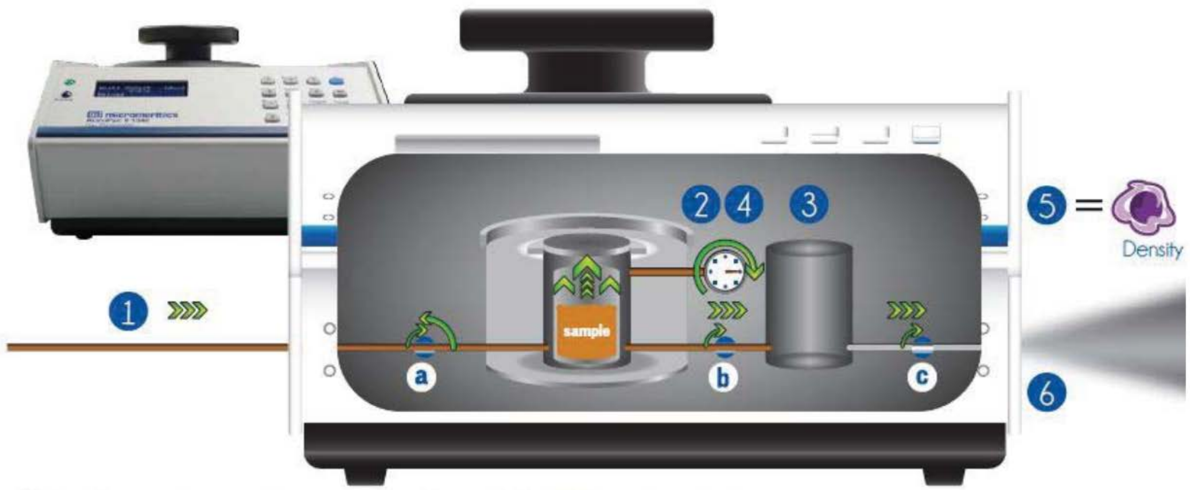
- Determination of volume is crucial for accurate charge prediction
- Every volume inside the RHXCT should be determined



Volume-Measurement Device (VMD)

- A volume-measurement device (VMD) to measure internal volume of the RHXCT has been developed using "Gas Pycnometry"
- VMD has been developed with ±0.1% volume accuracy

- **Commercial gas pycnometer (Accuracy of volume measurement: 0.02 ~ 0.2 %[1])**



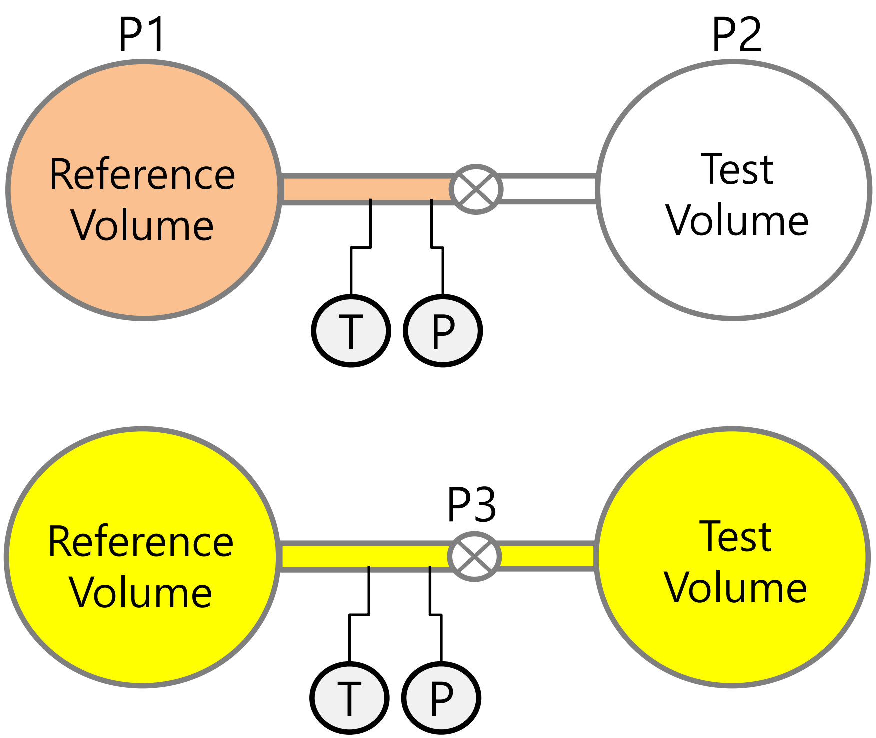
1. **Inert gas flows into a sample chamber**
   - valve **a** opens then closes
2. **Equilibrium is reached**
3. **Gas flows into second chamber for volume measurement** - valve **b** opens
4. **Equilibrium is reached yet again**
5. **Volume is divided into sample weight determines density**
6. **Pressure vented off to atmosphere**
   - valve **c** opens

1) Quntachrome Instruments (PentaPyc 5200 e)
2) Picture source: Micromeritics Instrument Corp.

Principle

- **Volume is determined by applying ideal gas law**

$$Test\ volume = \left[\left(\frac{P_1 T_3}{T_1} - P_3\right) \times V_1\right] / \left(P_3 - \frac{P_2 T_3}{T_2}\right)$$



$$P_1 V_1 = m_1 R T_1$$
$$P_2 V_2 = m_2 R T_2$$
$$P_3 V_3 = m_3 R T_3$$
$$P_3 V_3 = (m_1 + m_2) R T_3$$

$$P_3 (V_1 + V_2) = \frac{P_1 V_1 T_3}{T_1} + \frac{P_2 V_2 T_3}{T_2}$$

$$V_2 = \frac{\left[\left(\frac{P_1 T_3}{T_1} - P_3\right) \times V_1\right]}{P_3 - \frac{P_2 T_3}{T_2}}$$

If $T_1 = T_2 = T_3$, then

$$V_2 = \frac{(P_1 - P_3) \times V_1}{P_3 - P_2}$$

Target Accuracy of VMD

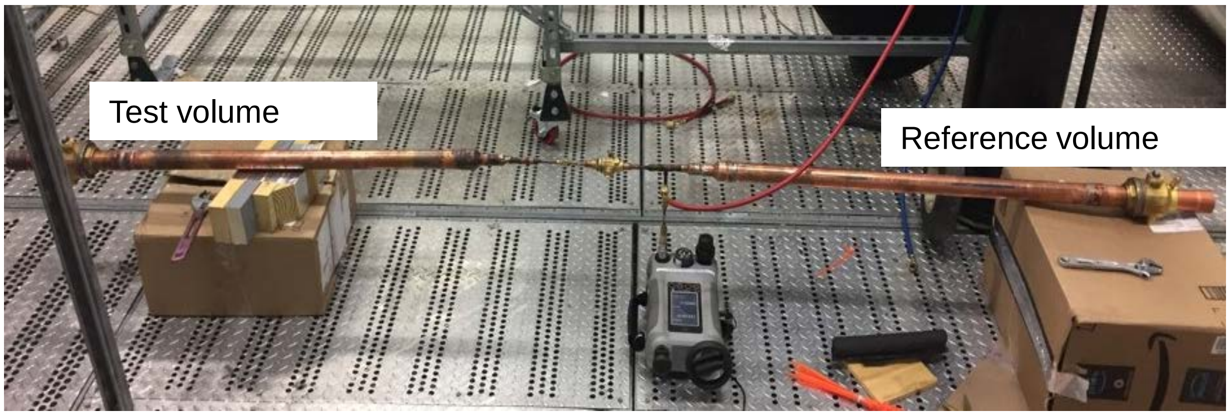
- **Target accuracy: 4.9 ml**
- **% error (vol. error / V_estimated) = 4.9/1650 *100 % = 0.3 (%)**

- IC1 coil Condenser test
- Target accuracy of mass measurement = 1 g
- Estimated approximate coil volume using internal diameter : 1650 ml
- Estimation of mass of coil = 336.8 g[1]
- Add 1g uncertainty : 337.8 g of coil mass
- Revised volume of coil to have 337.8 g = 1654.9 ml
- Allowable Volume error = 4.9 ml
- % error (vol. error / Vol._estimated) = 4.9ml/1650ml *100 % = 0.30 (%)

- Assumed constant quality(0.5) and T_cond (110 °F)

Validation of VMD

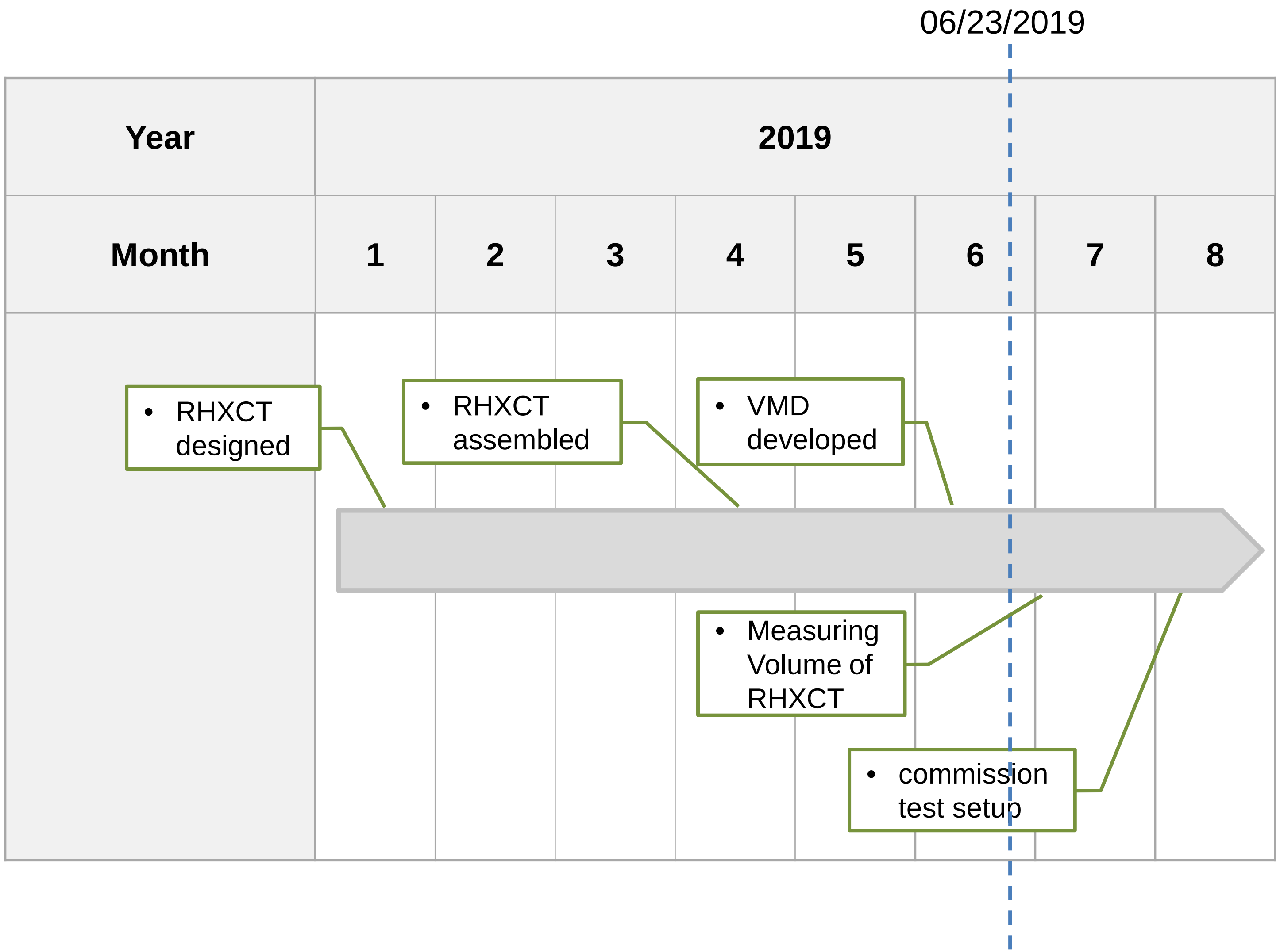
- ± 0.1 % error (within the target %error, 0.3%)[1)]
- ± 1.0 ml error (within the target error, 4.9 ml)[1)]



- VMD total uncertainty = ±2.5 ml
- Water total uncertainty = ±0.8 ml

1) Against water filling method
2) GE Druck ±0.0075 psig, ThermoProbe Inc.(TL1-A): ±0.1 °F

Project Schedule



Future Work

- Complete volume measurement of RHXCT
- Commissioning overall setup
- Developing refrigerant & oil loop (independent task)

Appendix

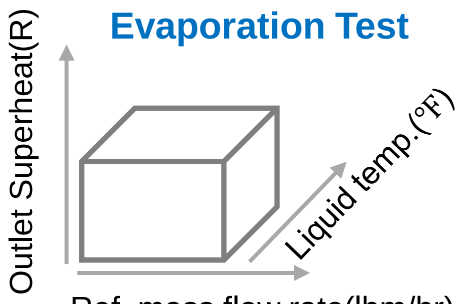
Evaporator_Target_accuracy of volume measurement – Using EES

- **Target accuracy of mass measurement = 1 g**
- For IC1 coil
- Estimated coil volume using internal diameter : 1650 ml
- Assume quality=0.5, t_eva = 50 F
- Estimated mass of coil = 133.4 g
- Add 1g uncertainty → 134.4 g of coil mass
- Revised volume of coil to have 134.4 g = 1662 ml
- **Allowable Volume difference = 12 ml**
- **% error (vol. diff. / V_estimated) = 12/1650 *100 % = 0.75 (%)**

Initial Test Matrix

- Initial test matrix as per TRP is shown below

- **Three factors**



- **Test matrix[1),2)]**
(Black dots represent test runs that will be done)

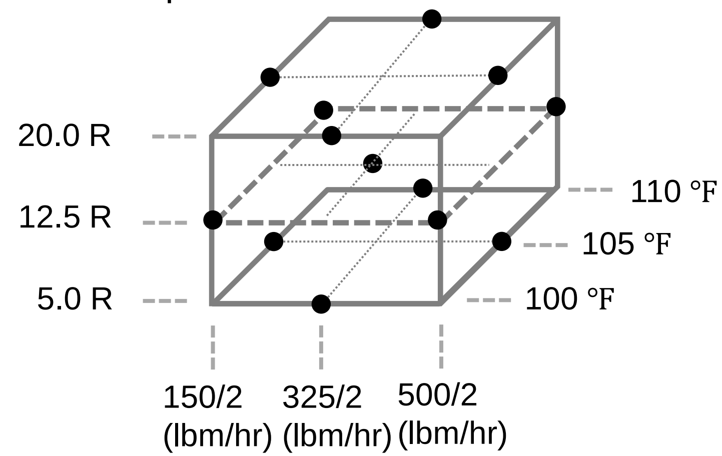


Table 8: Evaporator Mode Test Conditions (1785-TRP's Table 2)

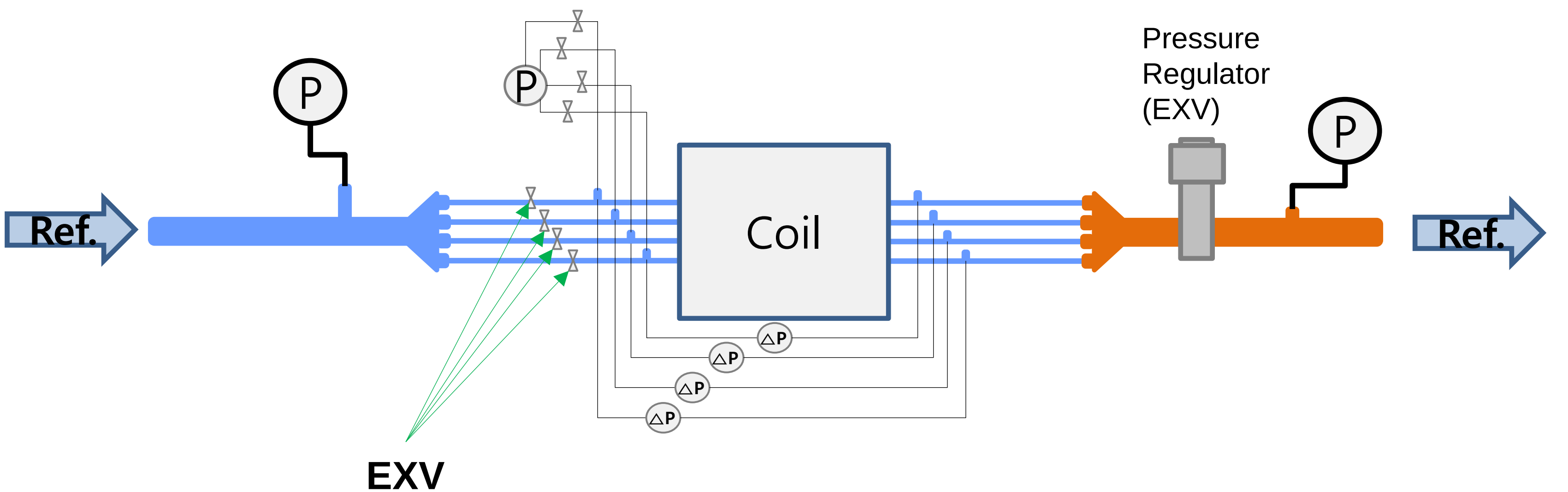
Evaporator Independent Variables		Indoor Coil (AC)	Outdoor Coil (HP)
Airflow	CFM	As required	As required
Reference liquid temperature	(°F)	100-110	90-100
Outlet superheat	(R)	5-20	5-20
Refrigerant Flow	lb/hr	150, 350, 500	100, 300, 400
Air Inlet Temperature(s)	(°F)	80	47

1) The subcooling will be determined and fixed
2) Keep the same inlet quality

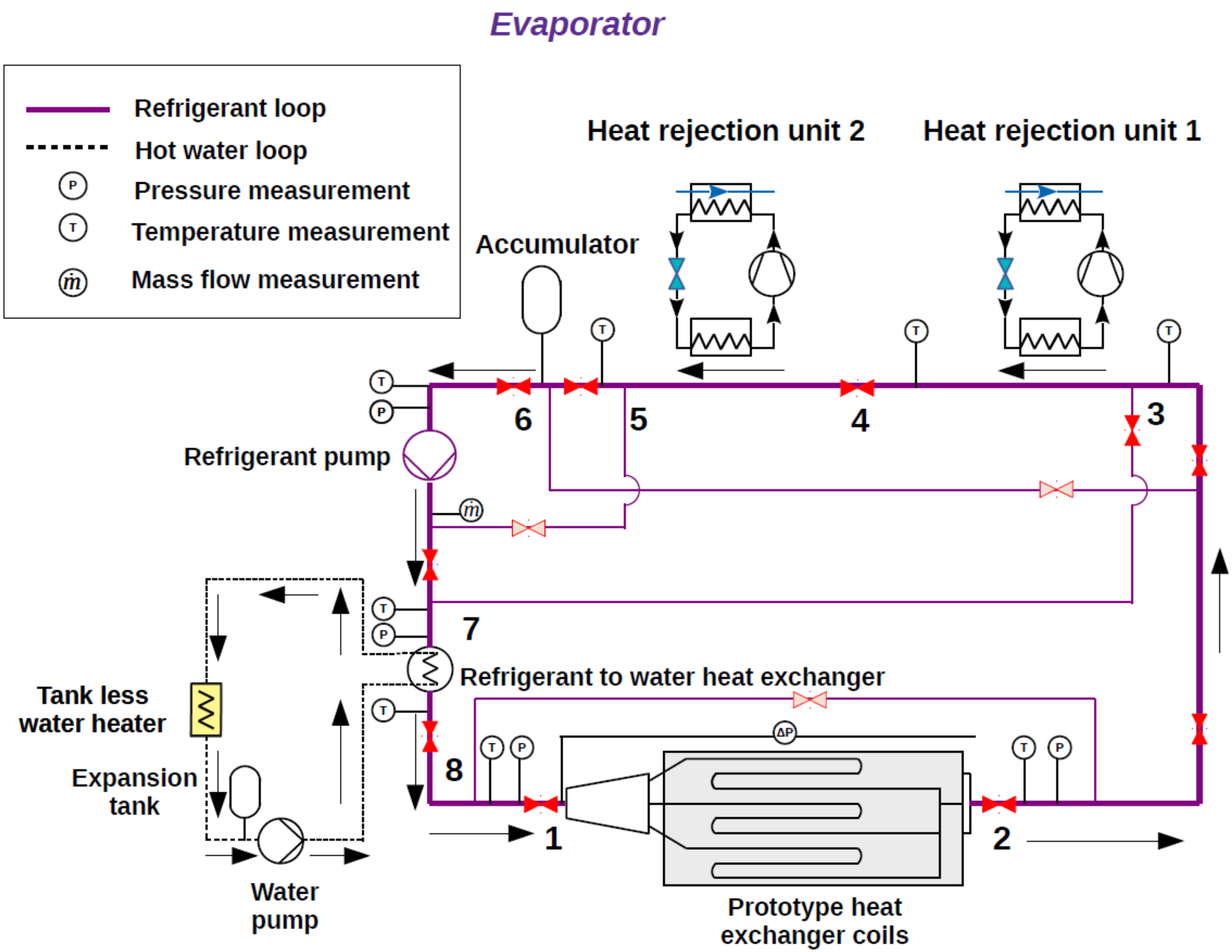
Refrigerant Flow in RHXCT

- **Four EXVs control mass flow rate in each circuit**
- **Pressure regulator controls evaporation temperature**

- **Schematic of the refrigerant flow in "Evaporator Test"**

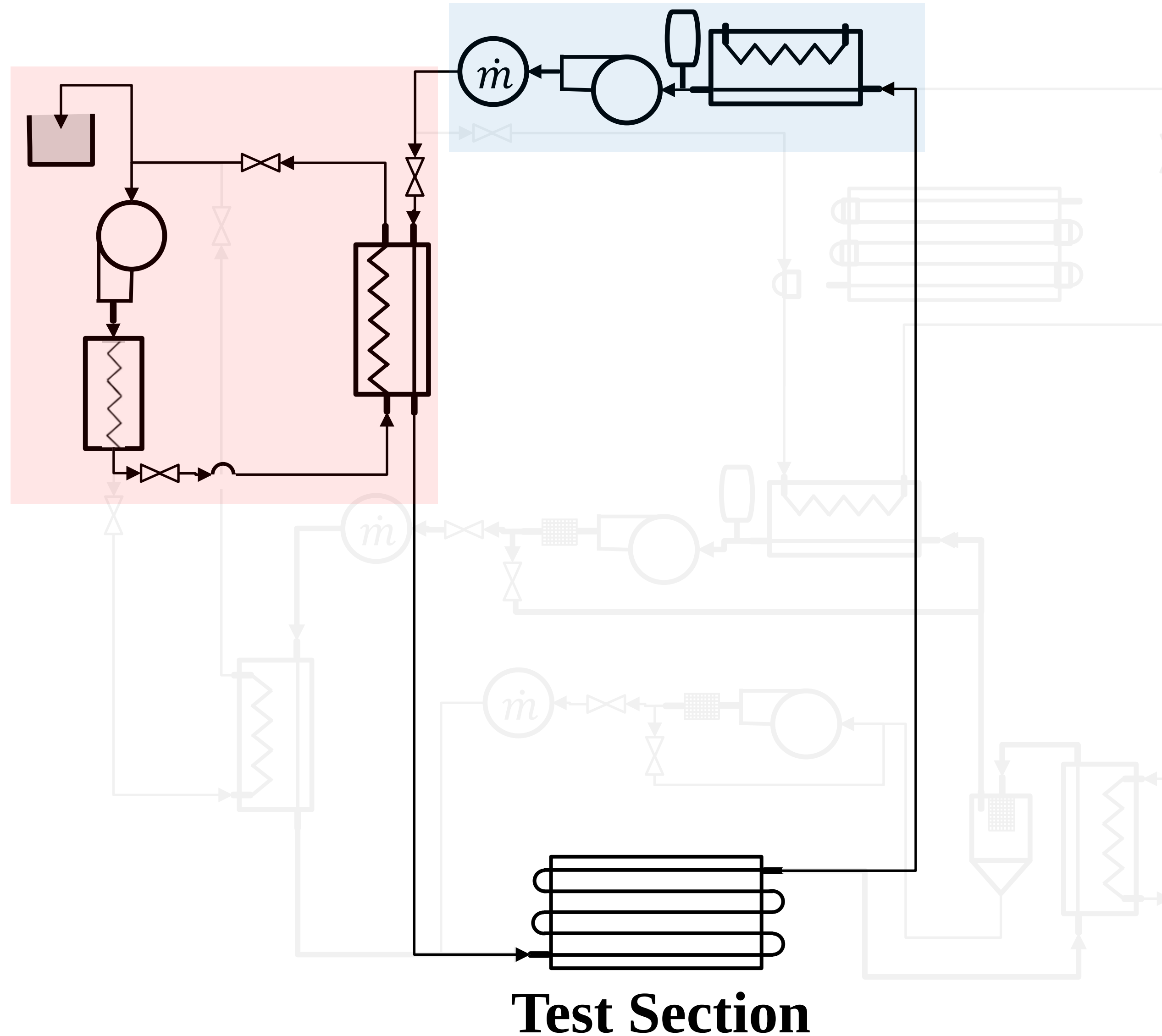


Refrigerant Loop Diagram



Refrigerant Loop for no-oil Tests as Part of Task 3

- **Oil loop to be added as parallel task for future tests with refrigerant-oil mixtures.**



- **Legend**

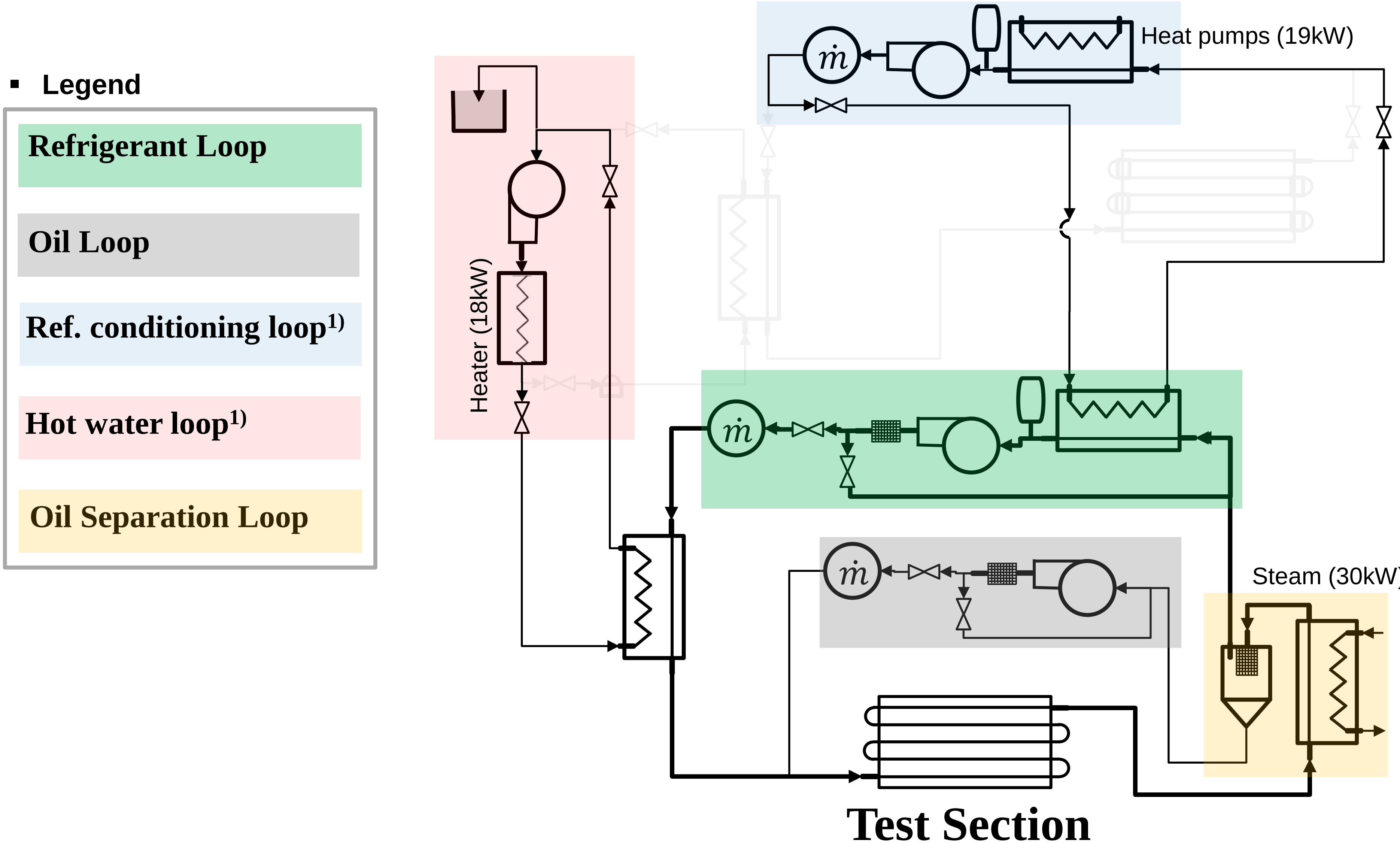
Ref. conditioning loop[1)]

Hot water loop[1)]

1) Built by Saad Saleem, to be used for RP1785 as well as OCAST project

Refrigerant & Oil Conditioning Loop (Planed[2])

- **Legend**



1) Built by Saad Saleem, to be used for RP1785 as well as OCAST project

Test Conditions

Table 7: Condenser Mode Test Conditions (1785-TRP's Table 1)

Condenser Independent Variables		Indoor Coil (HP)	Outdoor Coil (AC)
Airflow	CFM	As required	As required
Inlet Superheat	(R)	30-60	30-60
Liquid temperature	(°F)	90-100	100-110
Refrigerant Flow	lb/hr	100, 300, 400	150, 350, 500
Air Inlet Temperature(s)	(°F)	70/60	95/75

Table 8: Evaporator Mode Test Conditions (1785-TRP's Table 2)

Evaporator Independent Variables		Indoor Coil (AC)	Outdoor Coil (HP)
Airflow	CFM	As required	As required
Reference liquid temperature	(°F)	100-110	90-100
Outlet superheat	(R)	5-20	5-20
Refrigerant Flow	lb/hr	150, 350, 500	100, 300, 400
Air Inlet Temperature(s)	(°F)	80	47

(Source: 1785-TRP)

- Note, Indoor coil tests require 1slab airflow rate and refrigerant flow rate (e.g. (150/2) lbm/hr, (500/2) lbm/hr)

The Selected Coils

- **PMS[3] has selected several sets of coils**

- **Naming[4]**

OC : Outdoor Coils
IC : Indoor Coils

- **Test condition(Air flow rate)**
  : By experiment[5]

- **The selected coils' internal volume[1] ratio**

OC/IC ratio[1]		Denominator	
		IC1[2]	IC2[2)4)]
Numerator	OC1	160%	89%
	OC2	182%	101%
	OC3	N.A	212%

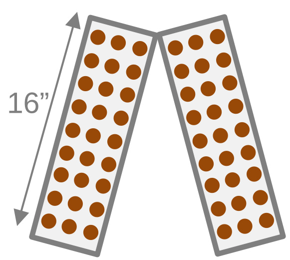
1) OC/IC = the internal volume of outdoor coil / the internal volume of indoor coil
2) The indoor coils are two slabs
3) (Research) Project Management Subcommittee
4) Coil name changed; ID7→IC2, ID1 →IC1, OD1→OC1, OD2→OC2, OD3→OC3
5) Airflow rate will be determined by the experiments
   : Outdoor coils@3ton capacity as per Proposal for Research on ASHRAE Project 1785-TRP
   : Indoor coils@1.5ton capacity as per Proposal for Research on ASHRAE Project 1785-TRP
   : RP1785 Objectives(Obtaining data for 3-ton indoor/outdoor coils)

The Indoor Coil’s Information

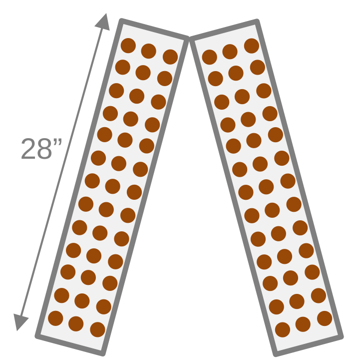
- **Coil’s information**

	Name	Row	Tube length	Coil Height	Tube Type	Tube Thickness	Fin Type	FPI[1)]	Note
Indoor	**IC1**	3	17.5”	16”	Smooth	**0.012**	Sine	14	2 slab
	IC2	3	17.5”	28”	Smooth	**0.012**	Sine	14	2 slab

Unit=inch



IC1



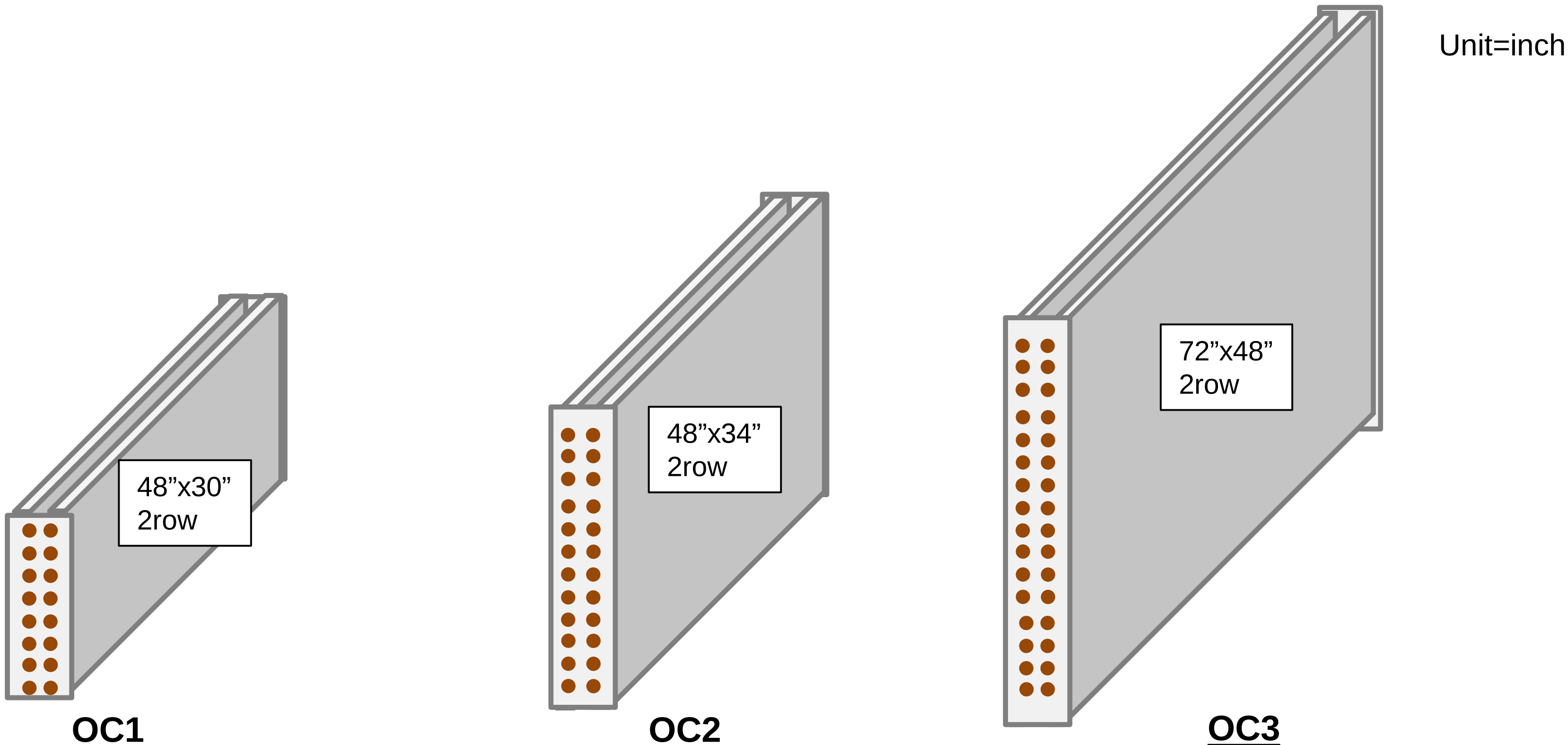
IC2

1) Fins per inch; JCI plant standard

The Outdoor Coil's Information

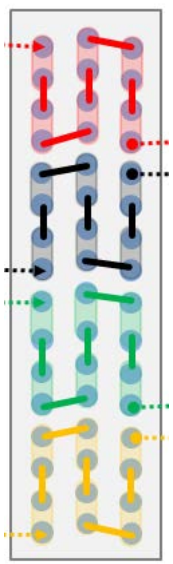
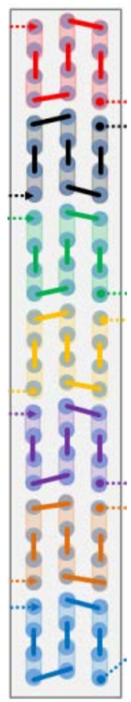
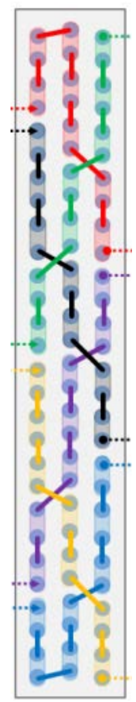
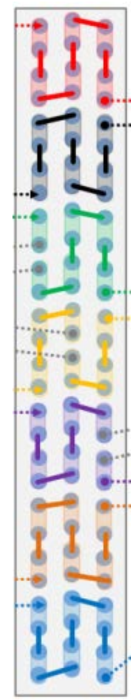
- **Coil's information**

	Name	Row	Tube length	Coil Height	Tube Type	Tube Thickness	Fin Type	FPI[1)]
Outdoor	OC1	2	48"	30"	Smooth	0.020	Sine	20
	OC2	2	48"	34"	Smooth	0.020	Sine	20
	OC3	2	72"	48"	Rifled	0.012	Louver	20



1) Fins per inch; JCI plant standard

Coil circuit

IC1	IC2	IC2-INTERLACED	IC2-SUBSECTION
			

OC1	OC2	OC3