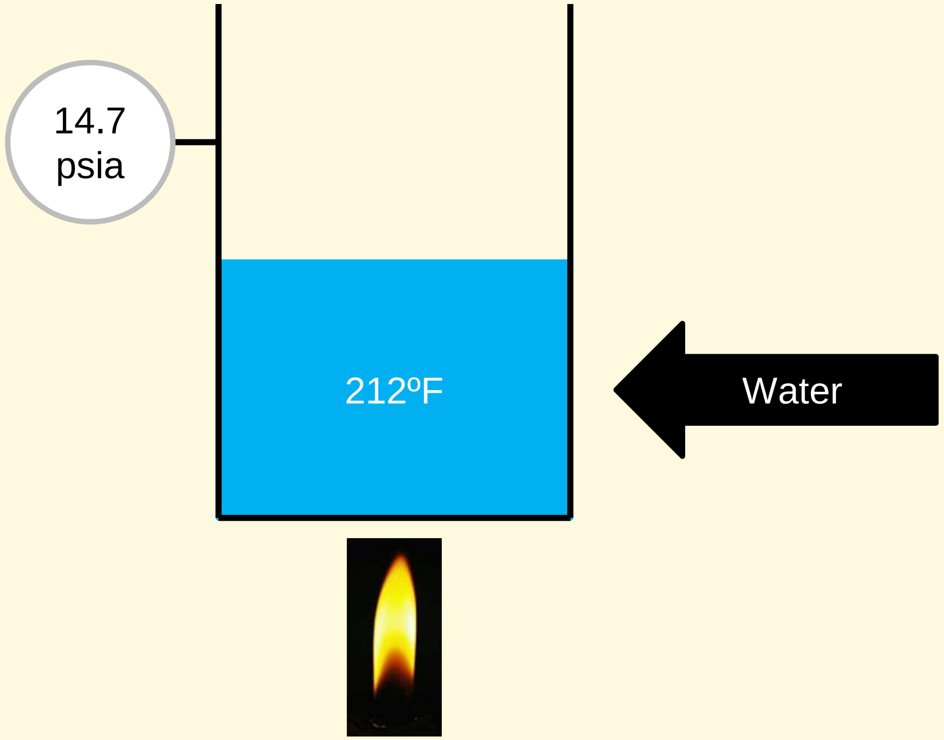
Principles of Refrigeration

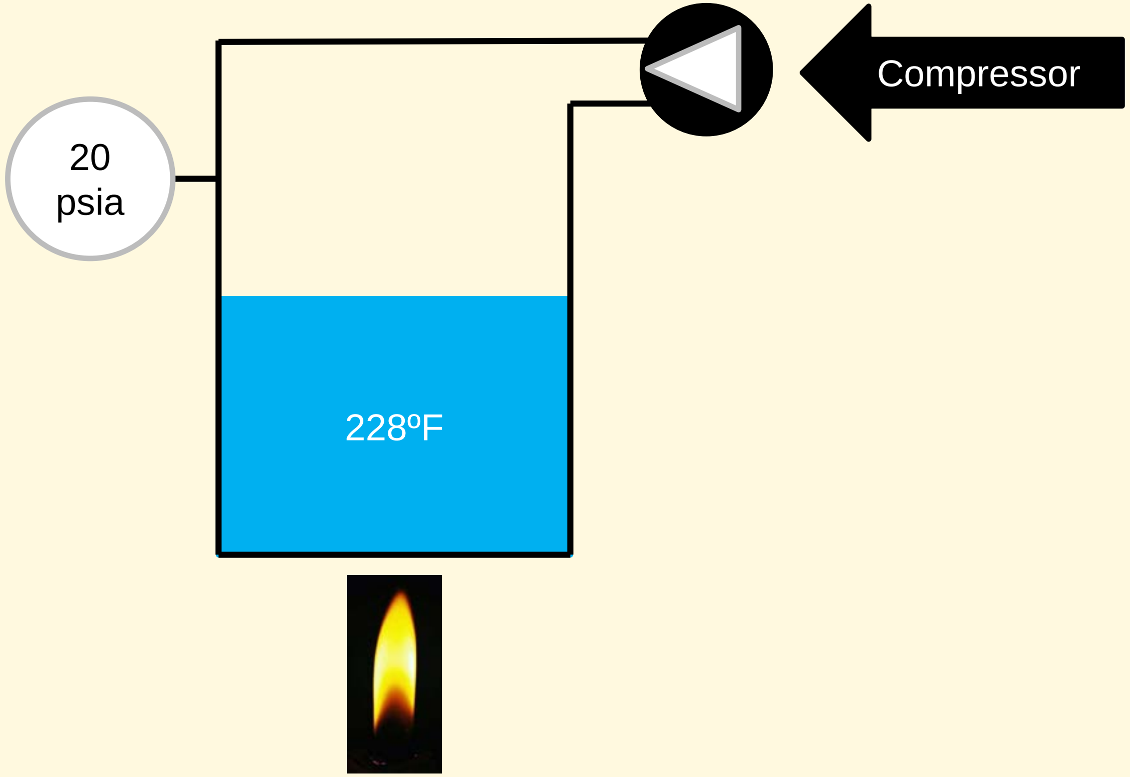
Peter Thomas, P.E., CSP – Resource Compliance, Inc.

What is Refrigeration?

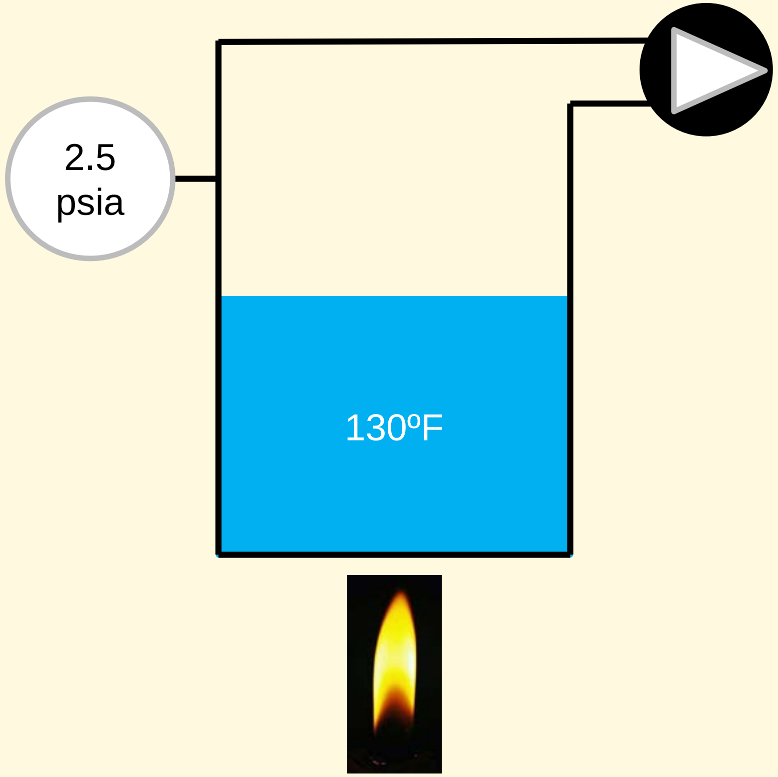
State 1



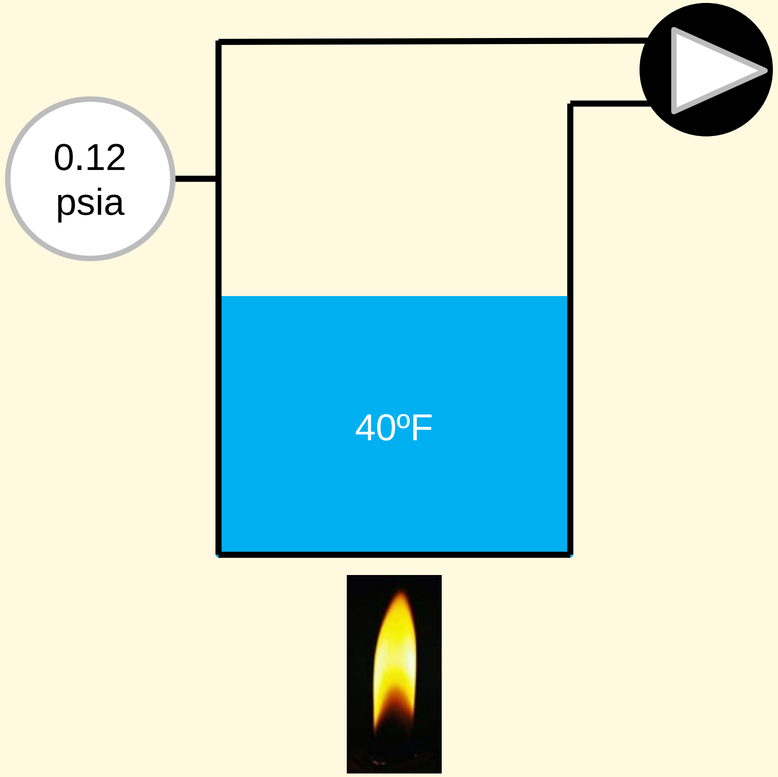
State 2



State 3



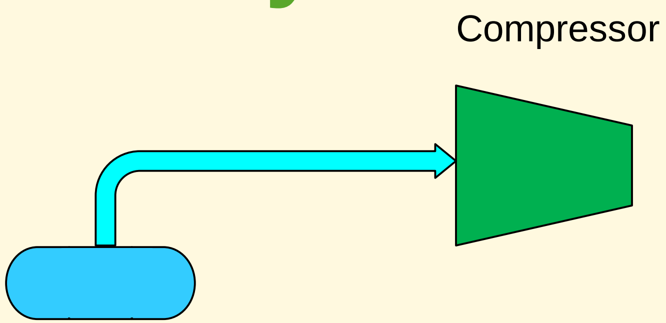
State 4



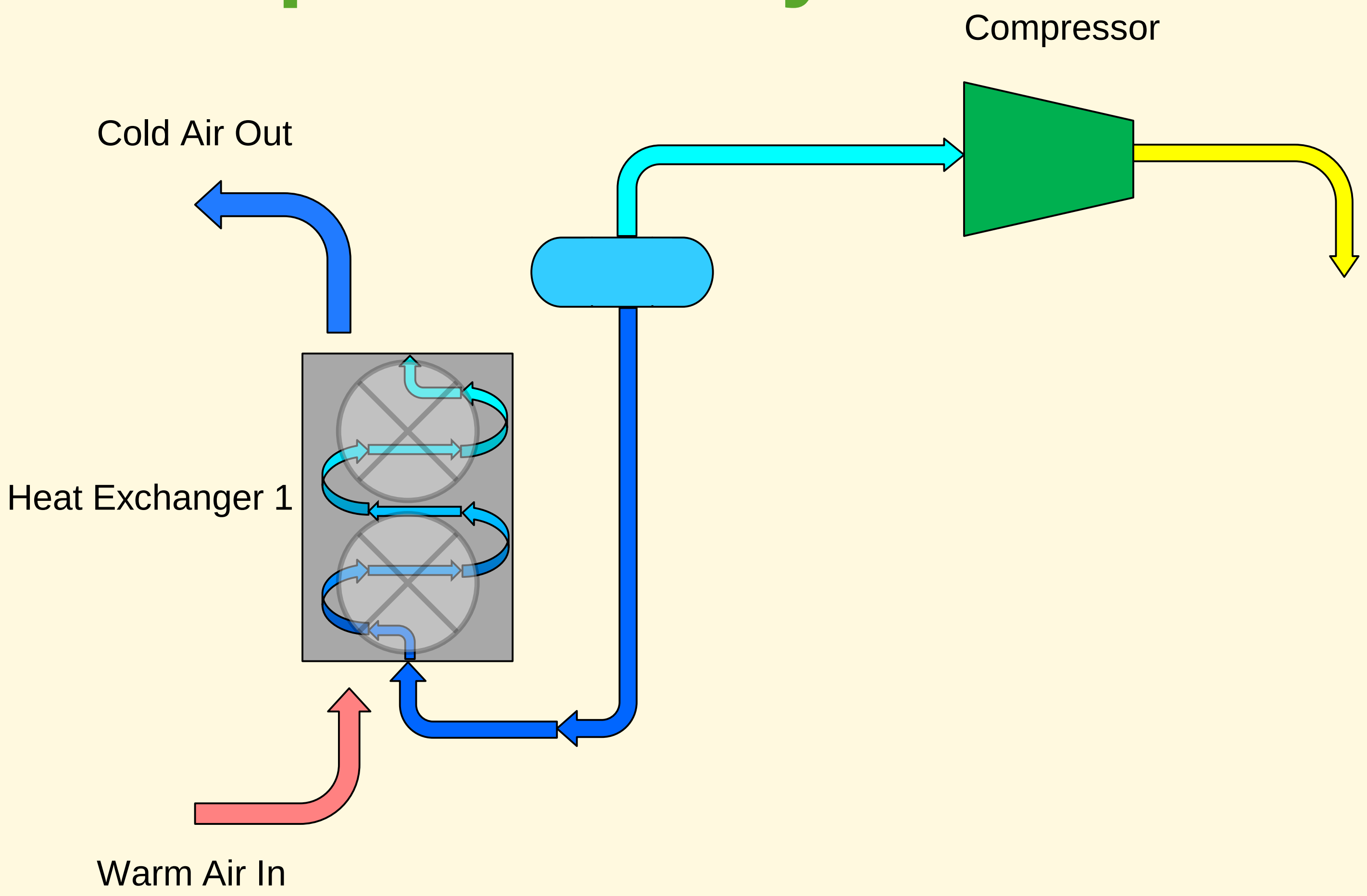
Saturation

- At ***equilibrium***, the rate of evaporation is equal to the rate of condensation.
- This mixture is said to be ***saturated*** and composed of liquid and vapor.
- When saturated, the temperature and pressure of a substance are dependent.

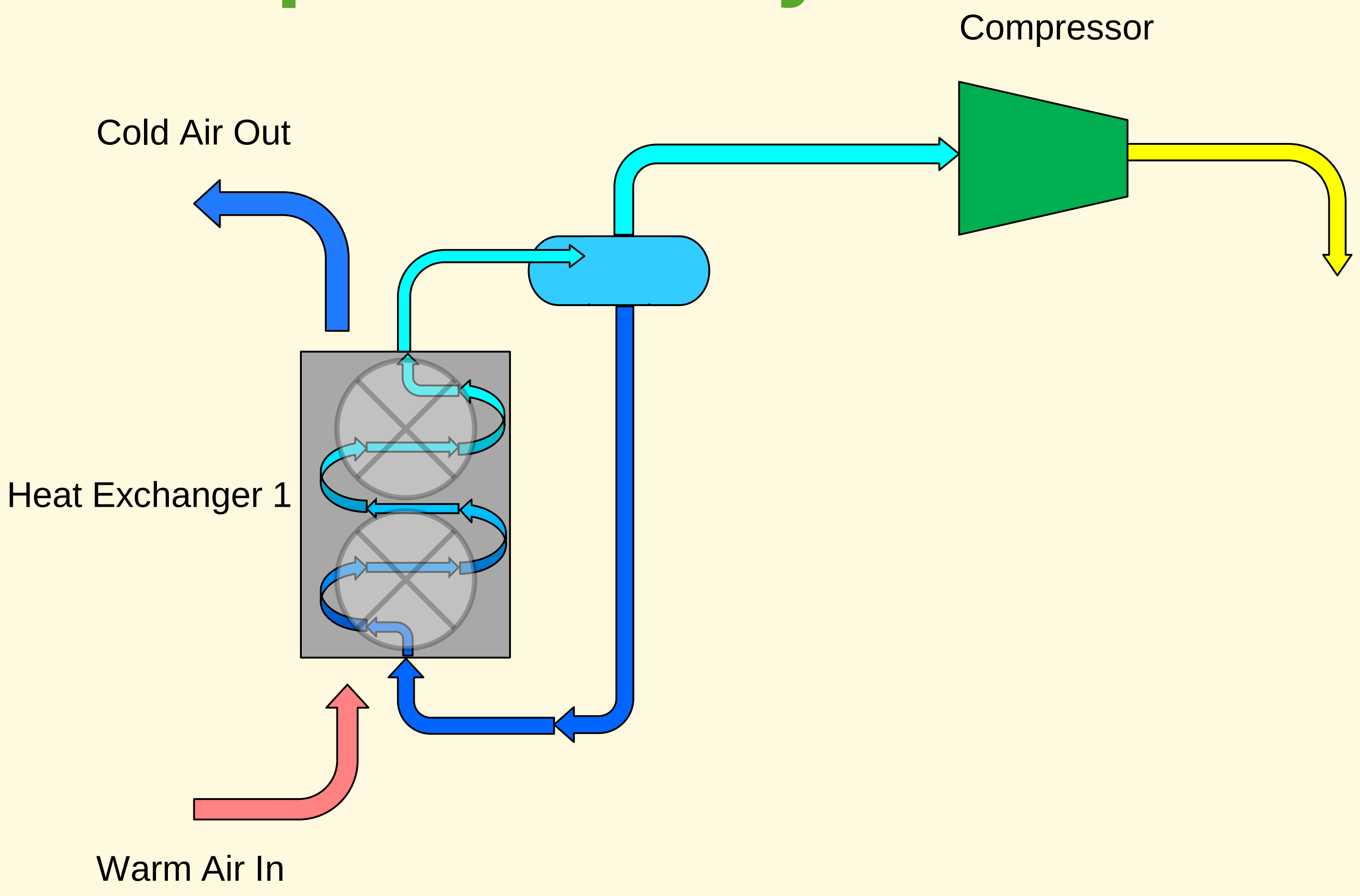
Vapor Compression Cycle



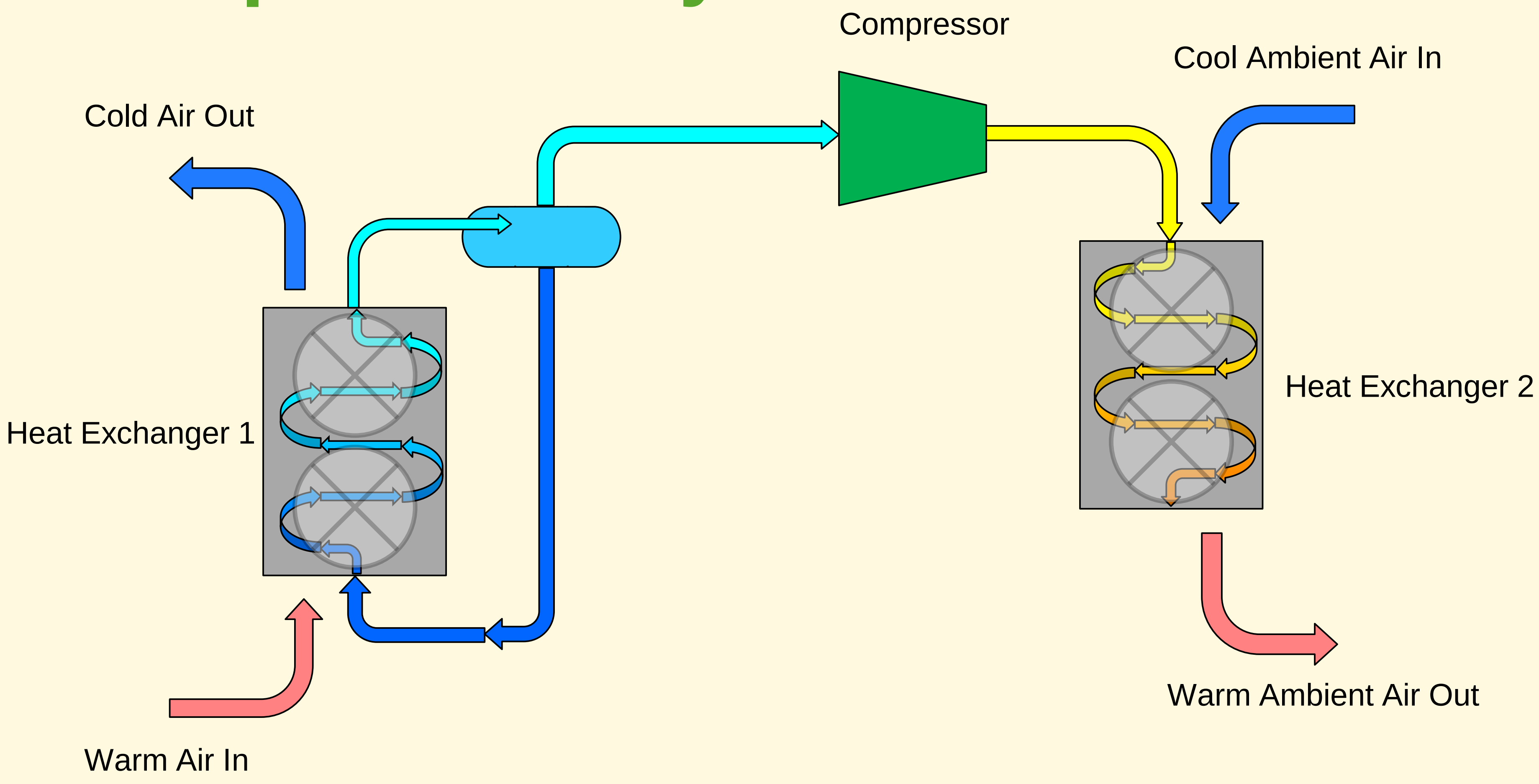
Vapor Compression Cycle



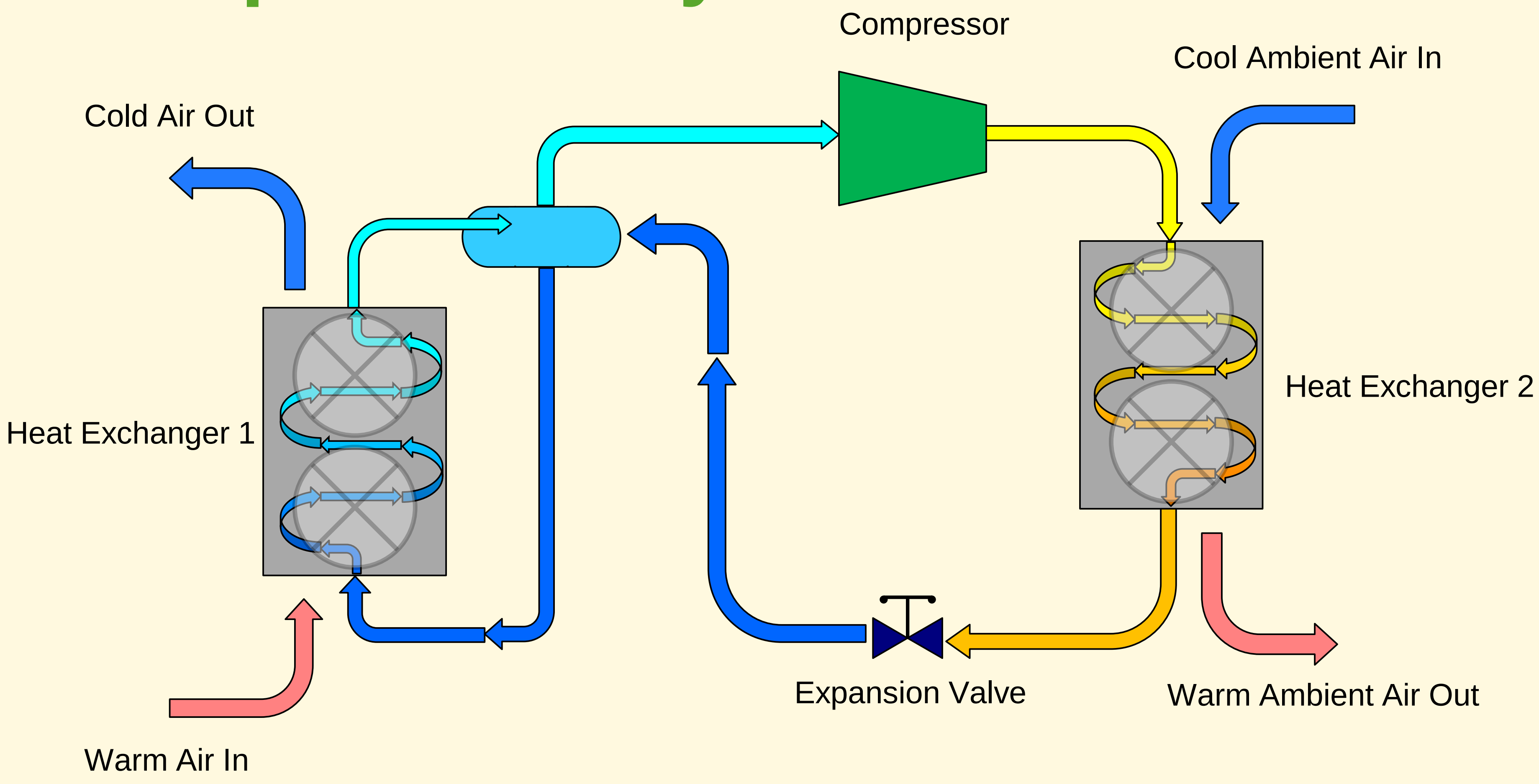
Vapor Compression Cycle



Vapor Compression Cycle



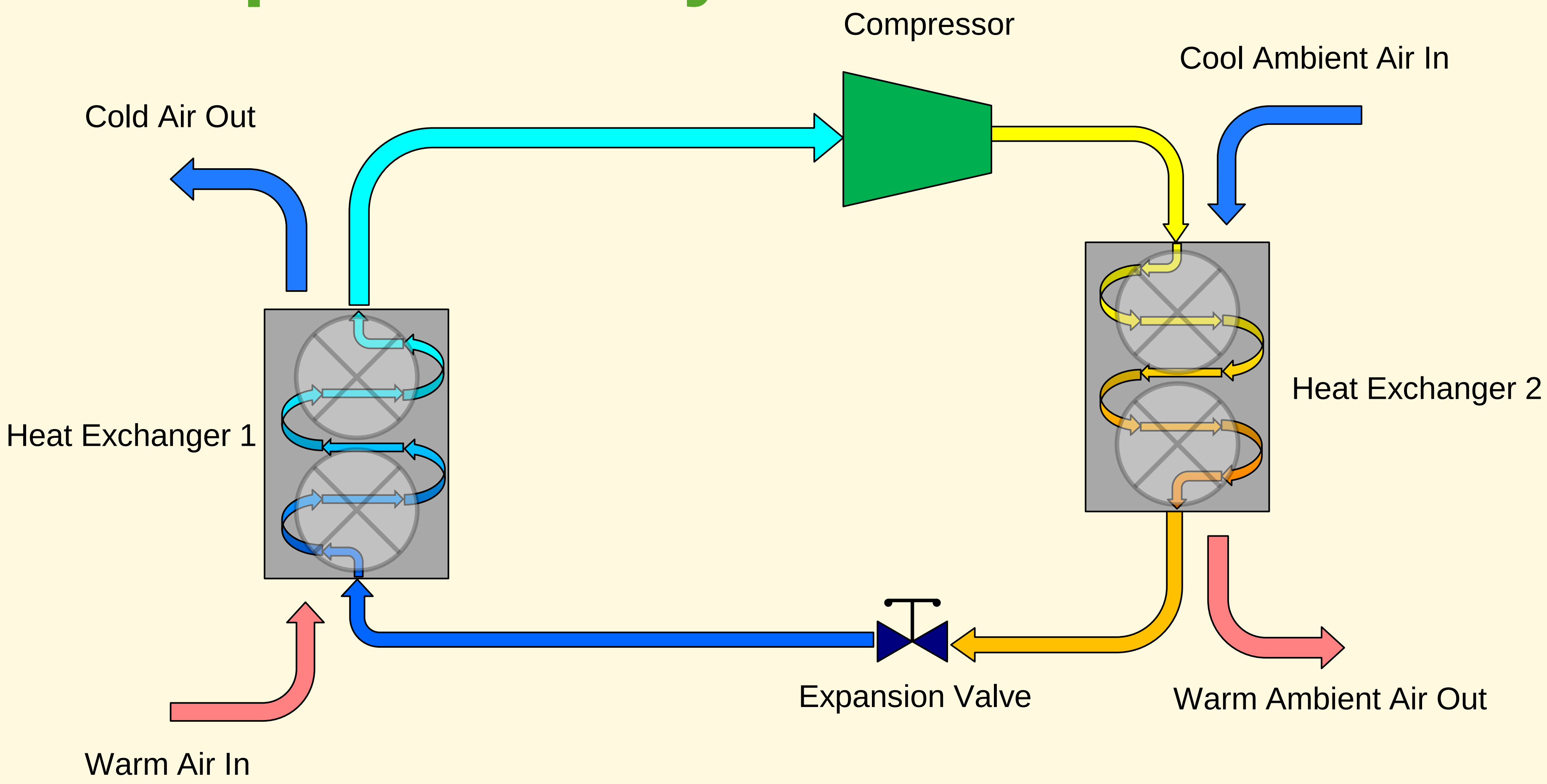
Vapor Compression Cycle



RESOURCE COMPLIANCE

Providing Solutions. Simplifying Regulation.

Vapor Compression Cycle



Refrigeration

- Manipulation of the of the pressure of **Substance 1** in order to reduce the temperature of **Substance 1** for the purpose of achieving a desired lower temperature in **Substance 2**.
- *Substance 1* = Refrigerant
- *Substance 2* = Air, water, grapes, wine, apples, beef, wine, oranges, peaches, chicken, ice…..

Definitions

- **Refrigeration** – The process of cooling or maintaining temperature in a space or object by removing heat
- **Pressure** – A force per unit area applied directly to a surface
- **Temperature** – The measurement of the intensity of heat (energy) in an object
- **Sensible Heat** – Heat energy that causes a change in temperature
- **Latent Heat** – Heat energy that causes a change in state

Heat Transfer Equation - Sensible

$$Q = M \times C \times \Delta T$$

- Where:
  - Q = heat required (BTU)
  - M = mass of substance (lb)
  - C = specific heat capacity (BTU/lb-ºF)
  - $\Delta T = T_2 - T_1$ = Difference between the starting temperature and the ending temperature (ºF)

Example 1

- Determine the BTUs required to warm 2 lb of water from 40ºF to 70ºF.

$$Q = M \times C \times \Delta T$$

$$Q = 2lb \times 1\frac{BTU}{lb \cdot ºF} \times (70ºF - 40ºF)$$

$$\underline{\boldsymbol{Q = 60\ BTU}}$$

Example 2

- Determine the BTUs required to warm 2 lb of iron from 40ºF to 70ºF.

$$Q = M \times C \times \Delta T$$

$$Q = 2lb \times 0.118 \frac{BTU}{lb \cdot ºF} \times (70ºF - 40ºF)$$

$$\underline{\boldsymbol{Q = 7.08\ BTU}}$$

Heat Transfer Equation - Latent

$$Q = M \times h_L$$

- Where:
  - Q = heat required (BTU)
  - M = mass of substance (lb)
  - h_L = specific enthalpy (BTU/lb)

Example 3

- Determine the BTUs required to boil 2 lb of 212ºF water into steam.

$$Q = M \times h_L$$

$$Q = 2lb \times 970\frac{BTU}{lb}$$

$$\underline{\boldsymbol{Q = 1,940\ BTU}}$$

Heat Transfer Equation - Combined

$$Q_{Total} = Q_{Sensible} + Q_{Latent}$$

- Where:
  - Q_{Total} = total heat required (BTU)
  - $Q_{Sensible}$ = sensible heat (BTU)
  - Q_{Latent} = latent heat (BTU)

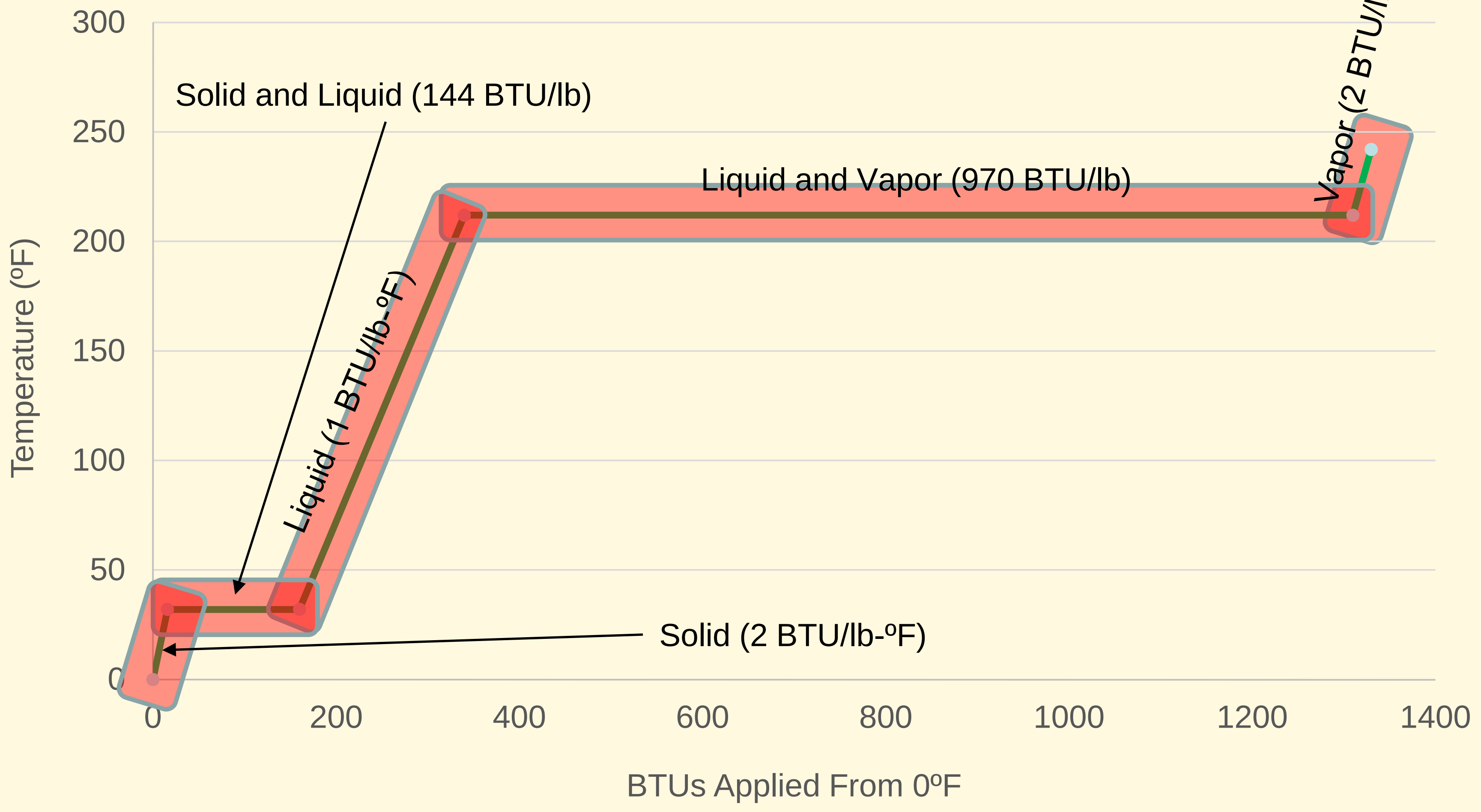
Example 4

- Determine the BTUs required to boil 2 lb of 40ºF water into steam.

$$Q_{Total} = Q_{Sensible} + Q_{Latent}$$
$$Q_{Sensible} = M \times C \times \Delta T$$
$$Q_{Latent} = M \times h_L$$
$$Q_{Total} = (M \times C \times \Delta T) + (M \times h_L)$$
$$Q_{Total} = \left(2lb \times 1 \frac{BTU}{lb \cdot ºF} \times (212ºF - 40ºF)\right) + (2lb \times 970 \frac{BTU}{lb})$$
$$\underline{\boldsymbol{Q_{Total} = 2,284 BTU}}$$

Providing Solutions. Simplifying Regulation.

Heat Energy Profile for Water



Example 5

- Determine the BTUs required to freeze 2,000 lb (1 ton) of 32ºF water into ice.

$$Q = M \times h_L$$

$$Q = 2{,}000 lb \times 144 \frac{BTU}{lb}$$

$$\underline{\boldsymbol{Q = 288{,}000\ BTU}}$$

Example 6

- If 2,000 lb of ice must be formed in 24 hours, what is *rate of heat transfer*?

$$\dot{Q} = \frac{Q}{t}$$

$$\dot{Q} = \frac{288{,}000 BTU}{24 hr}$$

$$\dot{Q} = 12{,}000 \frac{BTU}{hr}$$

$$\underline{\boldsymbol{\dot{Q} = 1\,Tr}}$$

Refrigeration Tonnage

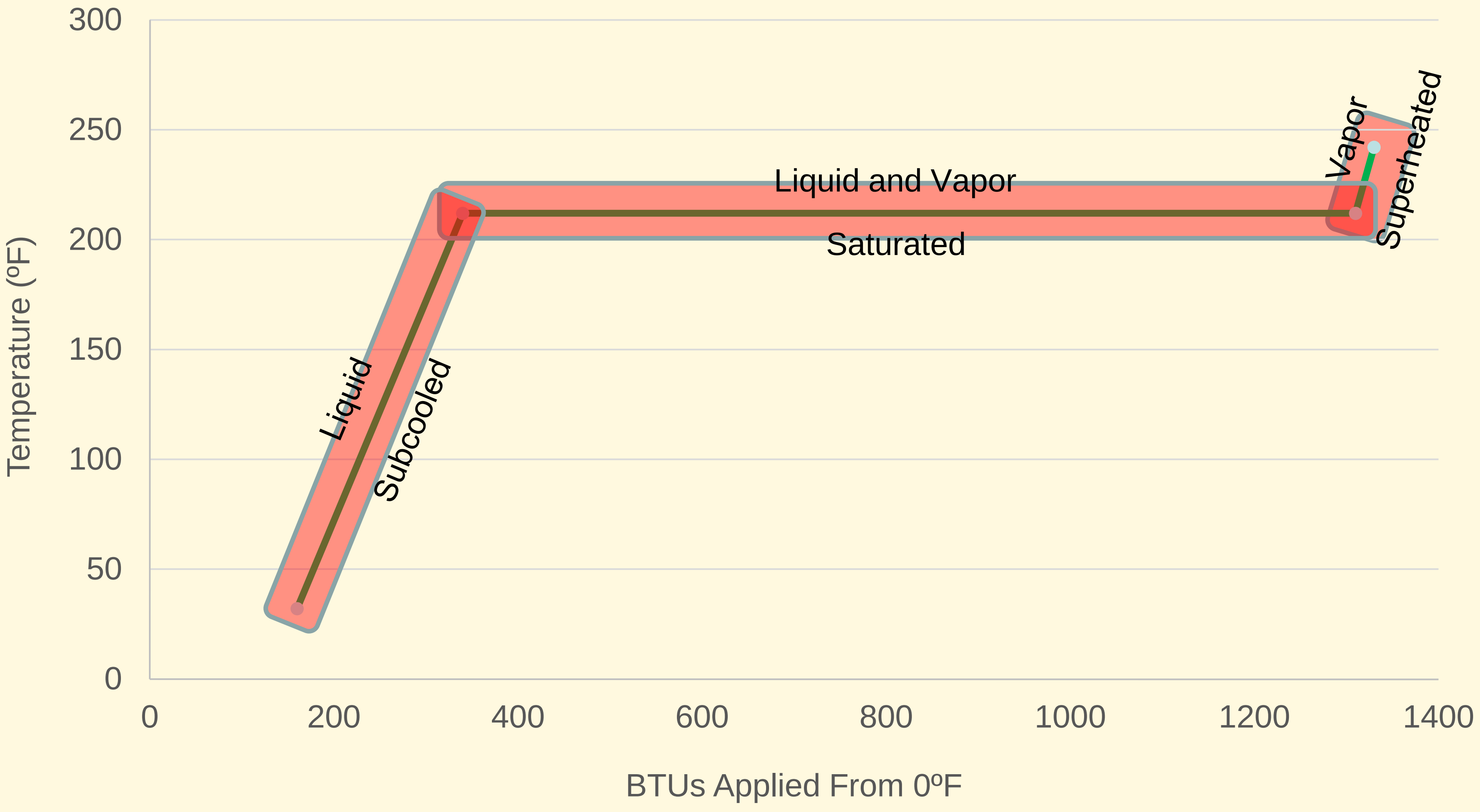
- 1 Ton of Refrigeration (Tr) is defined as the amount of heat required to freeze 2,000 lb of 32ºF water into ice.
- 1 Tr = 12,000 BTU/hr

Phase Changes

- **Boiling Point** – At a given pressure, the temperature at which a substance changes from a liquid to a vapor
- **Saturation** – When a substance is at its boiling temperature and is a liquid, vapor, or mixture between the two, it is saturated
- **Superheated Vapor** – A vapor that has increased in temperature after all of the liquid has boiled away without a change in pressure
- **Subcooled Liquid** – A liquid that exists below its saturation temperature

Providing Solutions. Simplifying Regulation.

Heat Energy Profile



1. Compressor

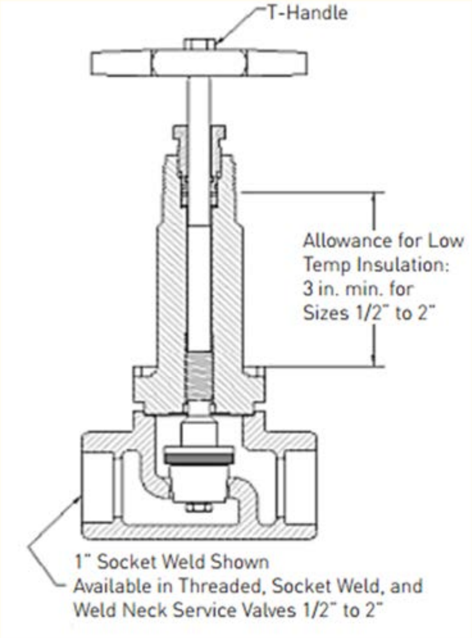
- Requires energy input from surroundings
- Refrigerant enters the compressor as a low pressure saturated vapor
- Refrigerant is compressed, and exits under high temperature and high pressure as a superheated vapor

2. Condenser

- Uses circulated water and ambient air to reject heat from the superheated refrigerant
- Desuperheats discharge vapor, and condenses to high pressure liquid

3. Expansion Valve

- High Pressure Liquid refrigerant is pushed through the expansion valve, causing the pressure and temperature to drop adiabatically
- The expansion valve meters refrigerant flow into the evaporator coil based on current refrigeration load

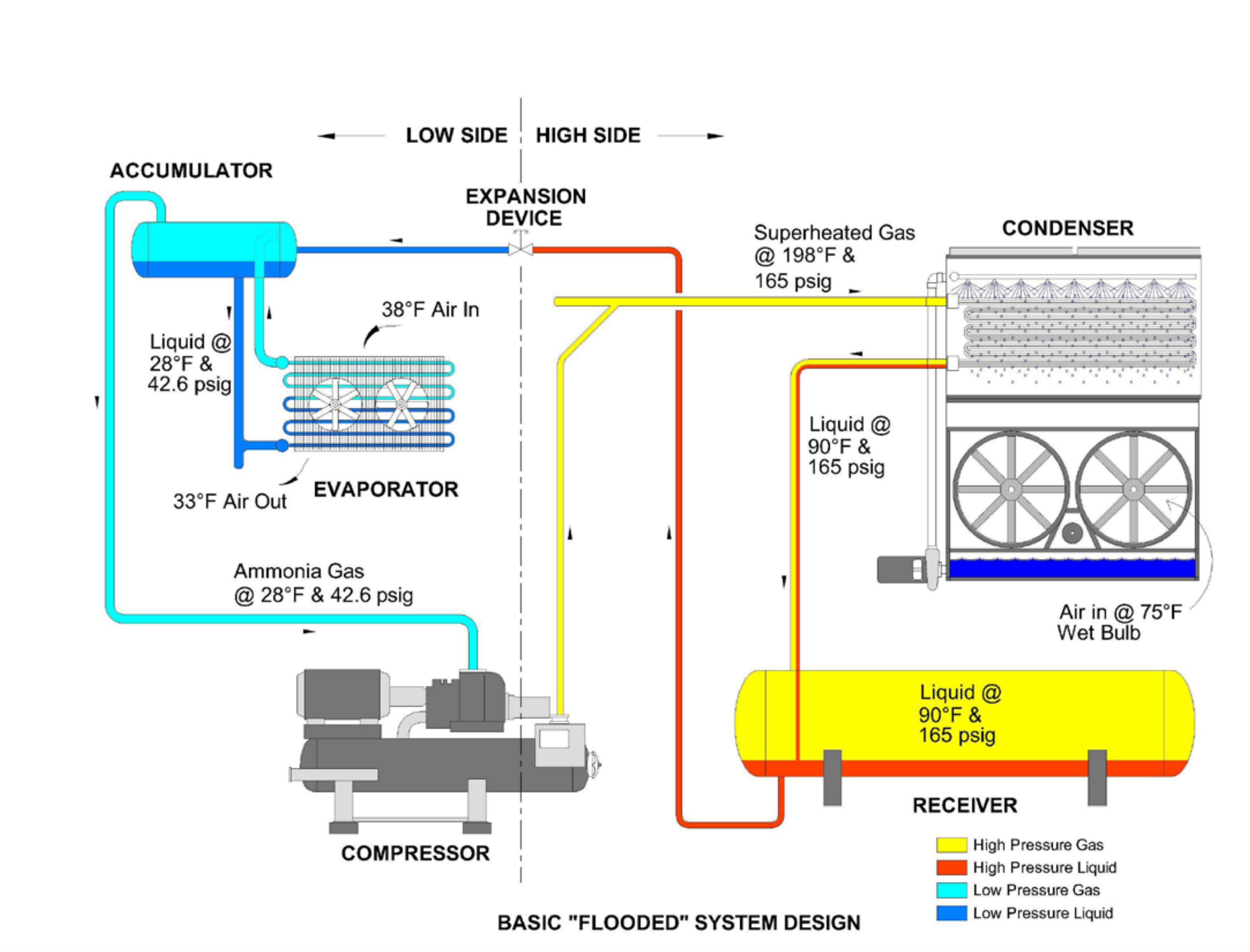


4. Evaporator Coil

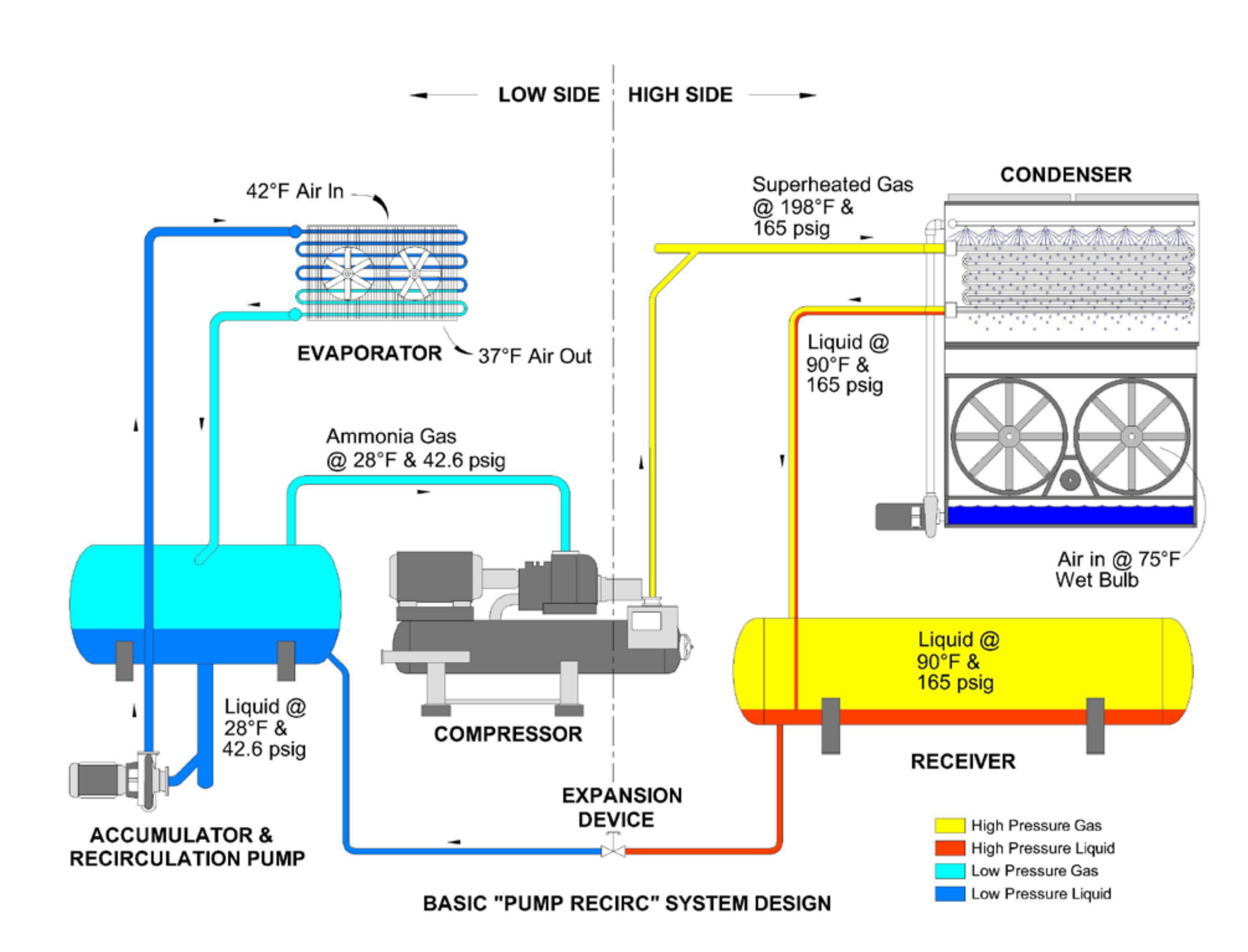
- Low temperature liquid refrigerant enters the evaporator and absorbs heat from the air, lowering the temperature of the product and room

Providing Solutions. Simplifying Regulation.

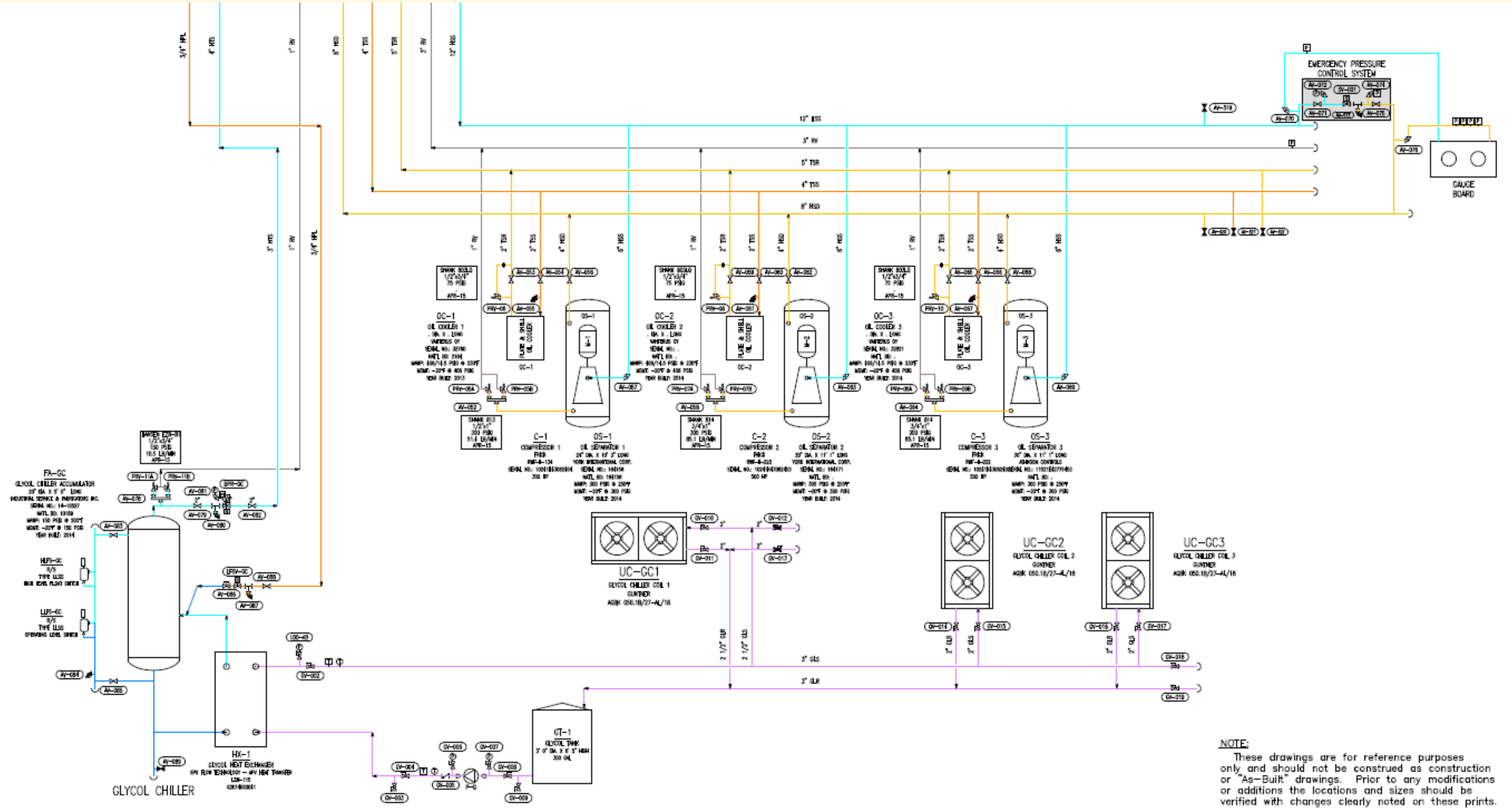
Flooded Configuration



Pump Overfeed (Recirc) Configuration

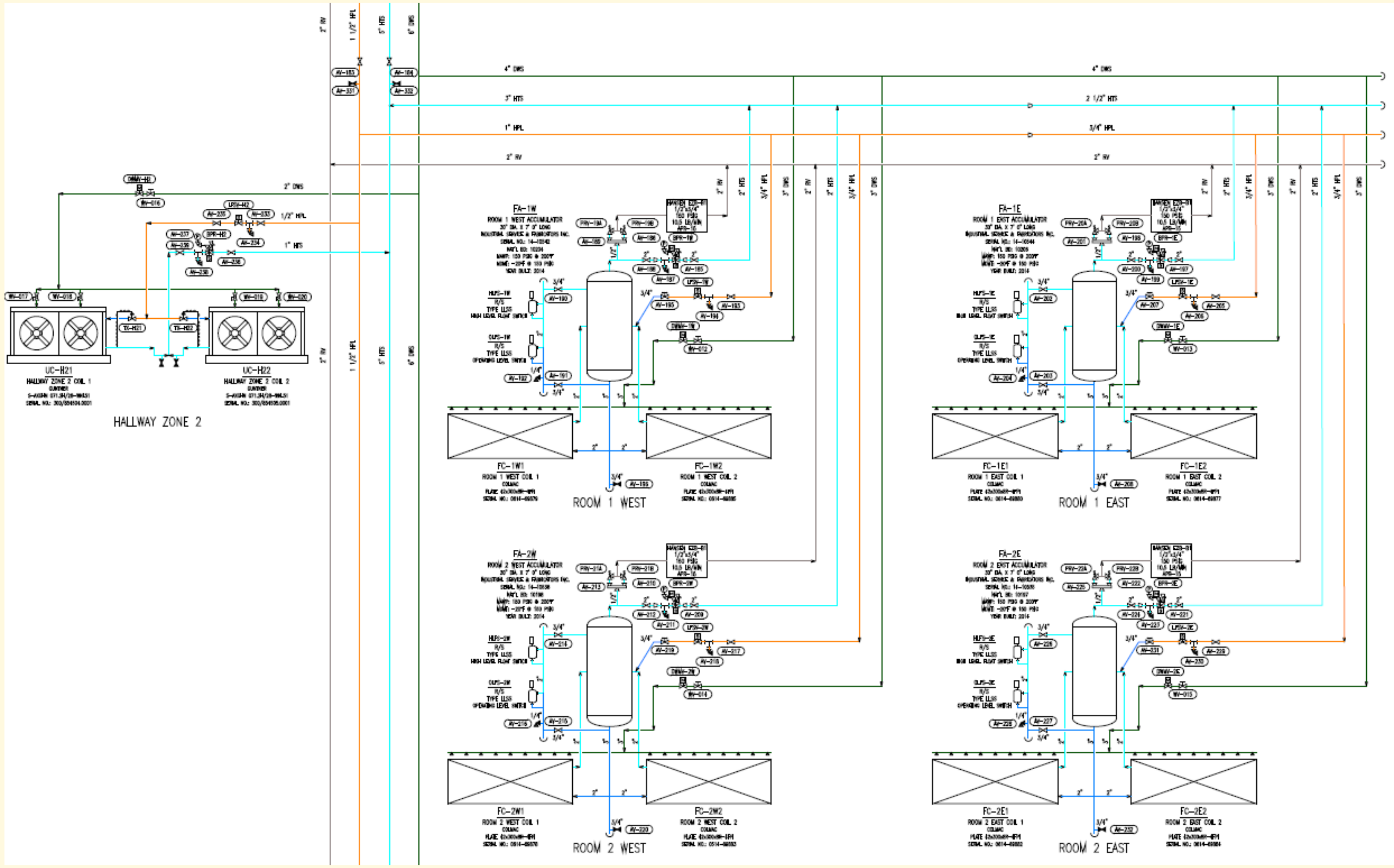


System Complexity



Providing Solutions. Simplifying Regulation.

System Complexity



Compressor

Compressor

Evaporative Condenser

RESOURCE COMPLIANCE

Providing Solutions. Simplifying Regulation.

Evaporative Condenser

Evaporative Condenser

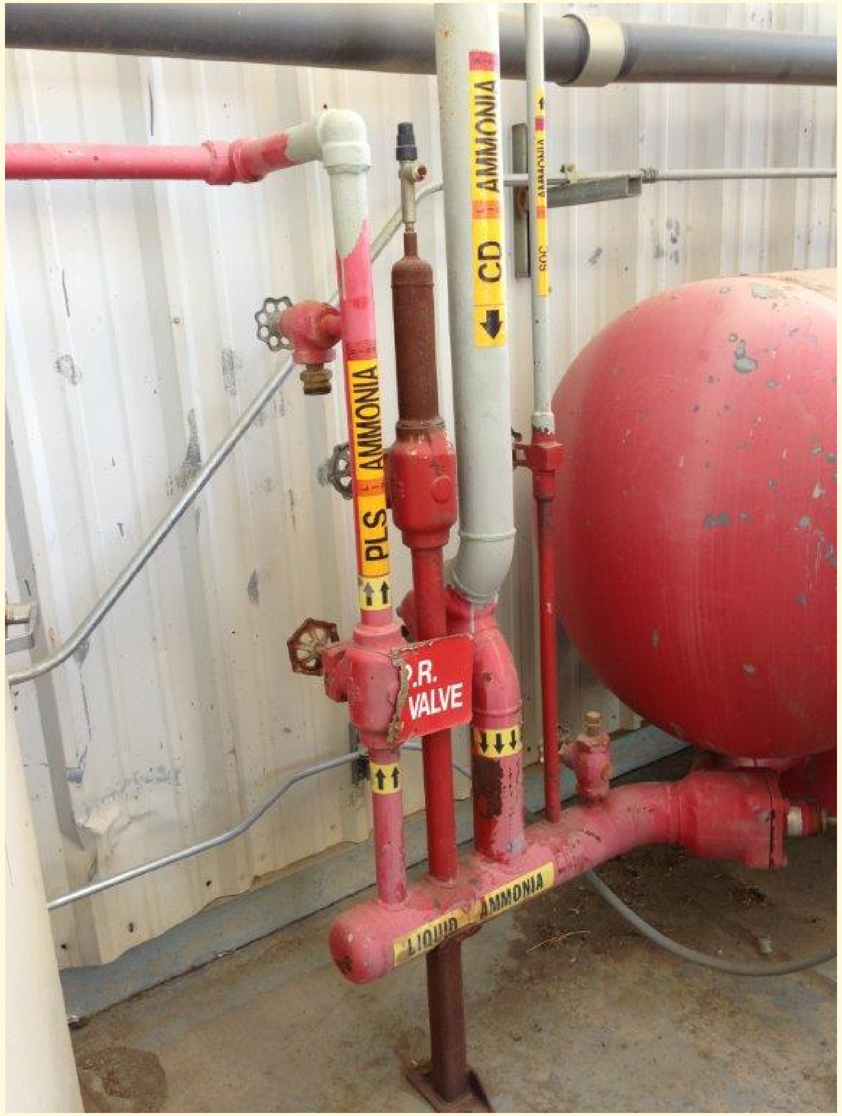
High Pressure Receiver

High Pressure Receiver

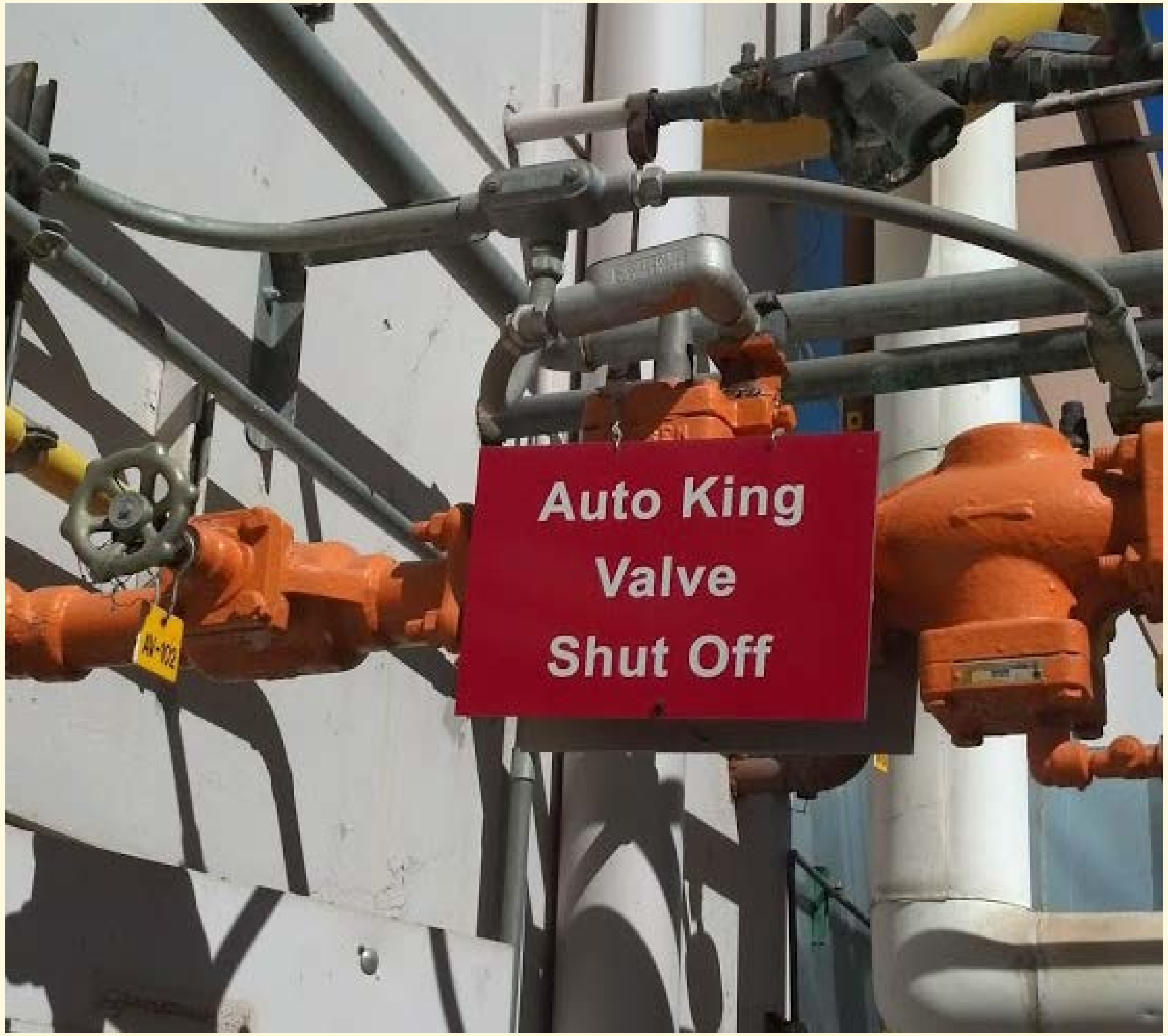
High Pressure Receiver

King Valve


AMMONIA
HPL
KING VALVE


AMMONIA
CD
AMMONIA
PLS
.R. VALVE
AMMONIA

King Valve



Recirculator

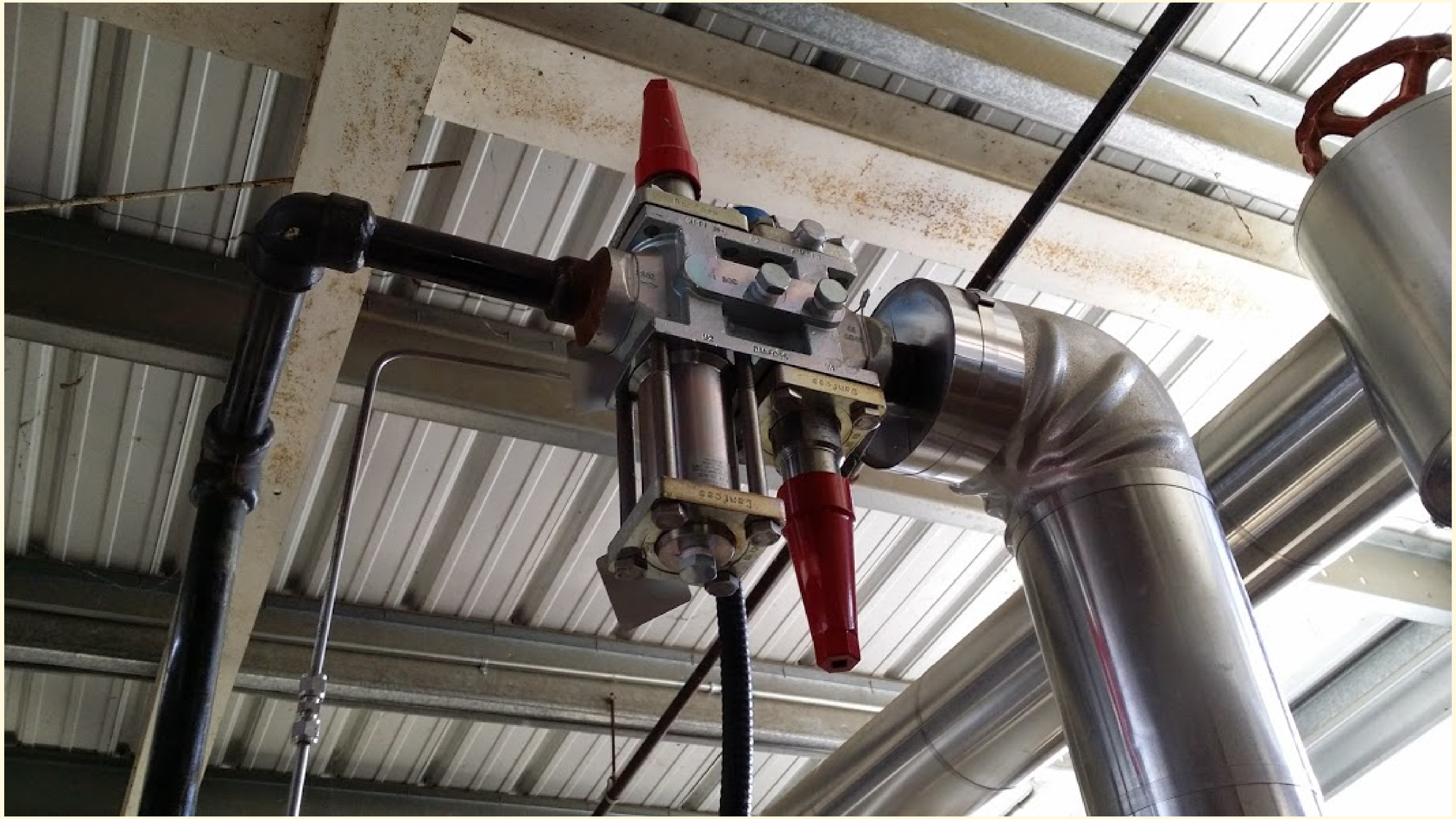
Ammonia Pump

Control Valves

Control Valves

Control Valves

Control Valves



Evaporators

Evaporators

Accumulators or Surge Drums

RESOURCE COMPLIANCE

Providing Solutions. Simplifying Regulation.

Accumulators or Surge Drums

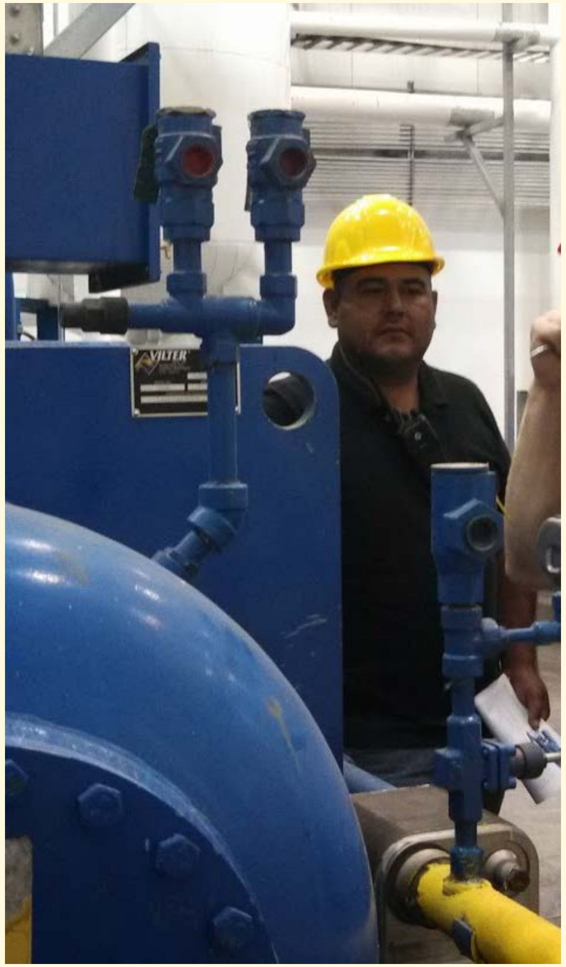
Plate and Frame Heat Exchangers

Shell and Tube Heat Exchangers

Shell and Tube Heat Exchangers

Jacketed Tanks (Silos)

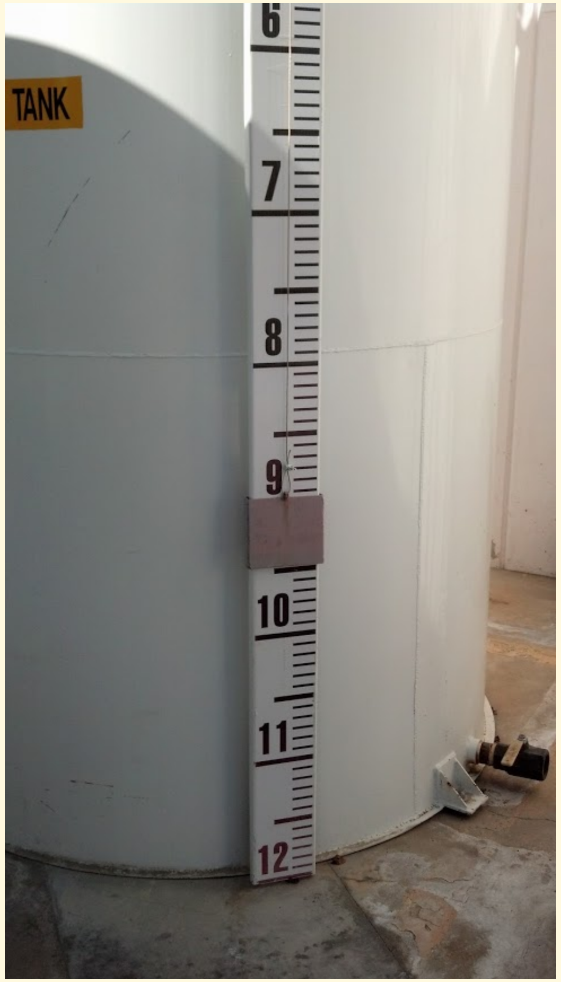
Relief Valves



Relief Valves

Relief Valves

Ammonia Diffusion Tank

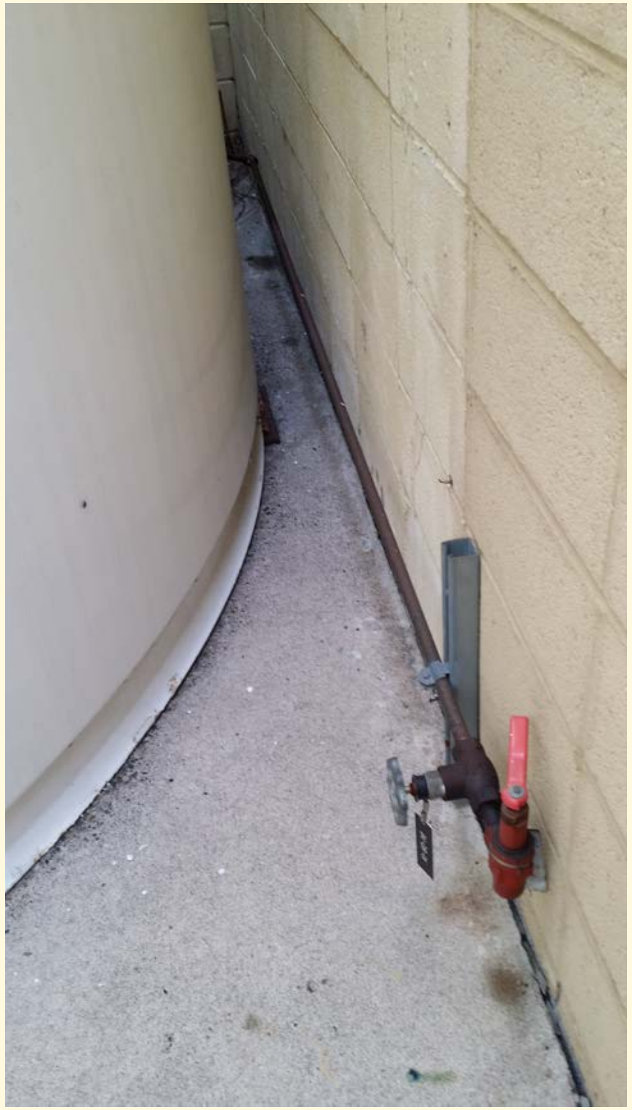


Ammonia Diffusion Tank

Ammonia Diffusion Tank

Oil Draining

Oil Draining

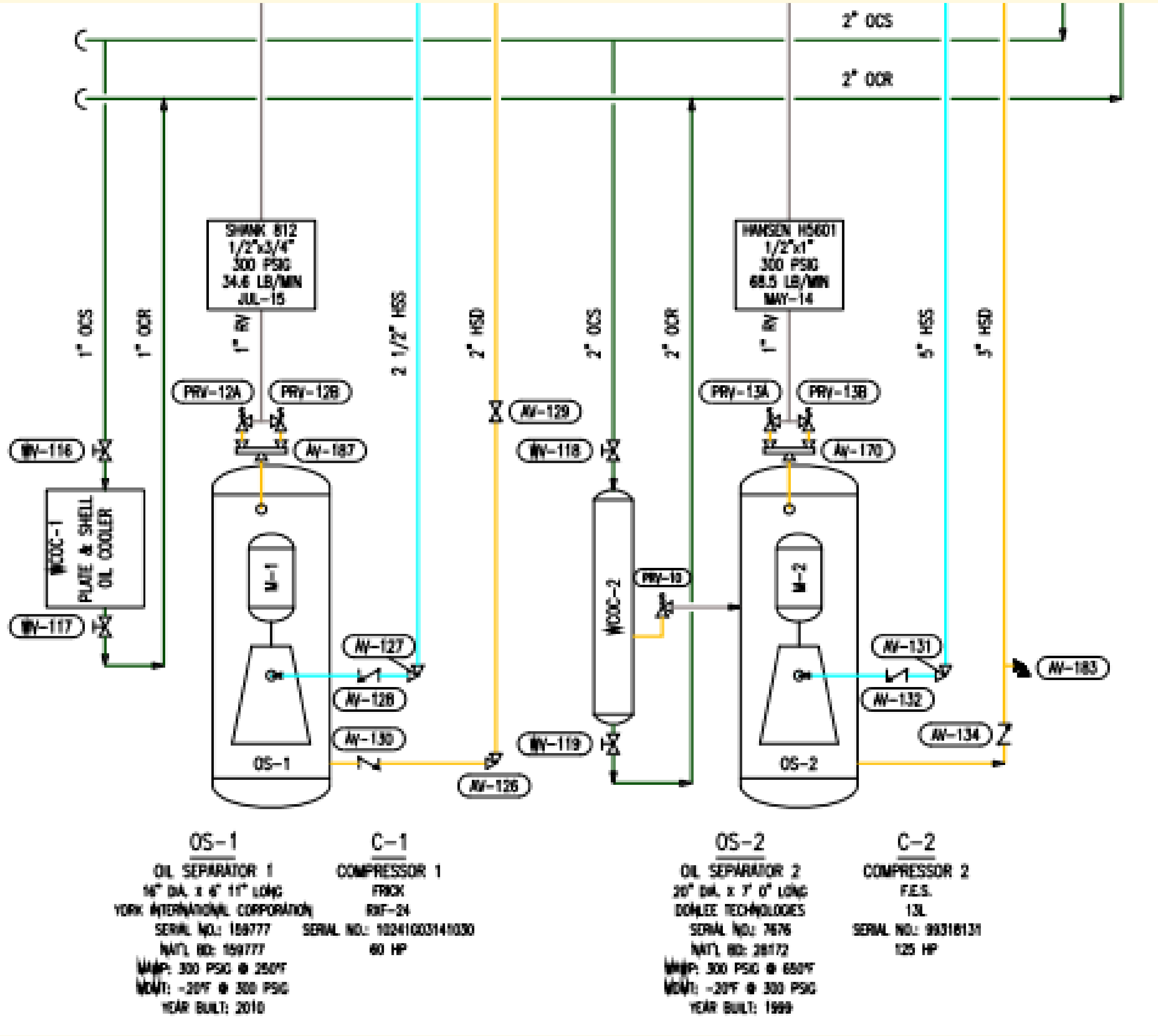


Oil Draining

Oil Cooling - Thermosyphon

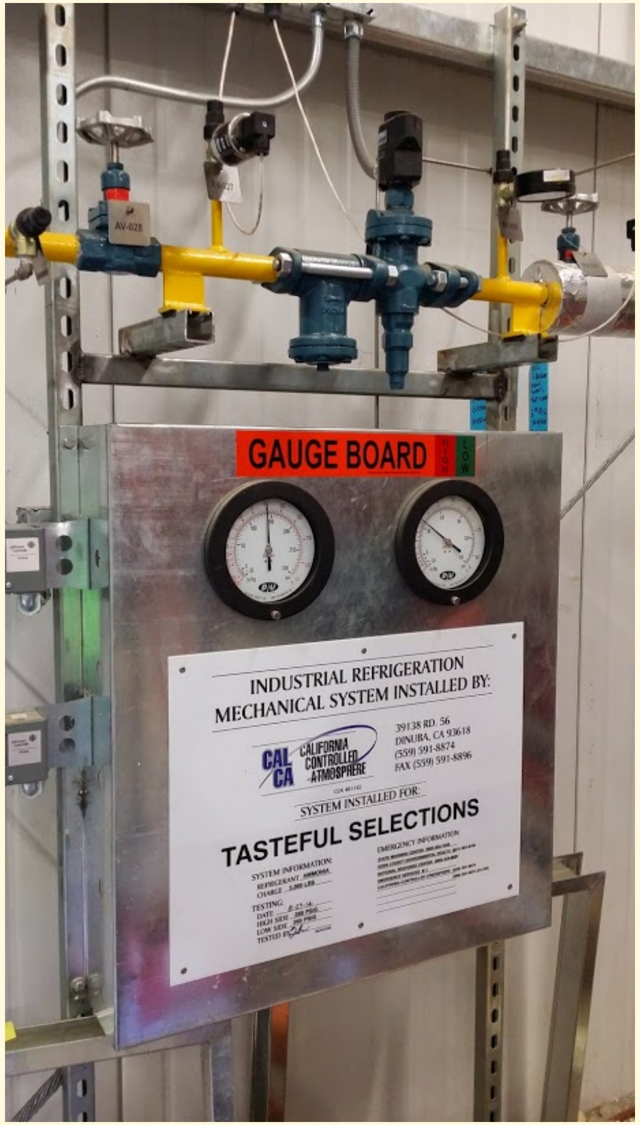
Oil Cooling – Liquid Injection

Oil Cooling – Water Cooled

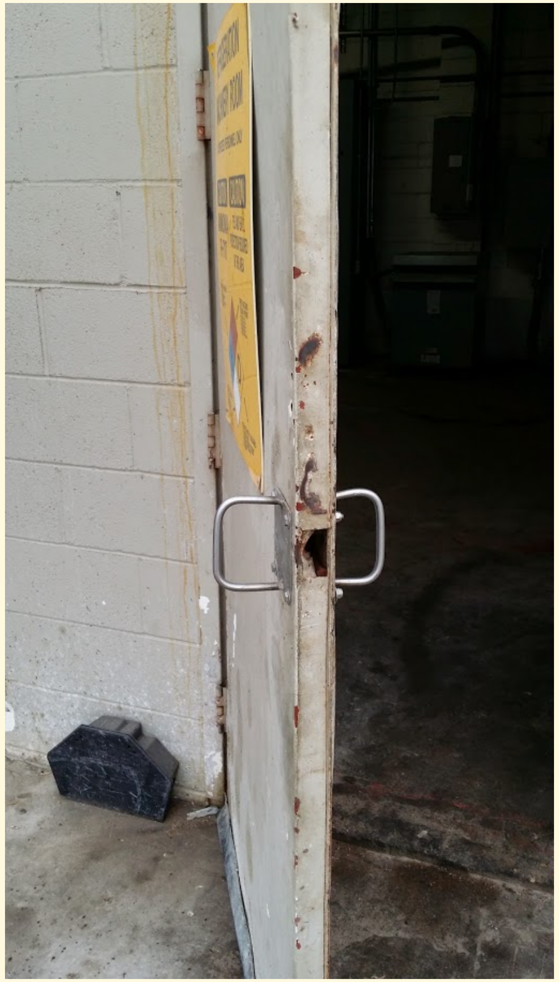


Machinery Rooms

Machinery Rooms



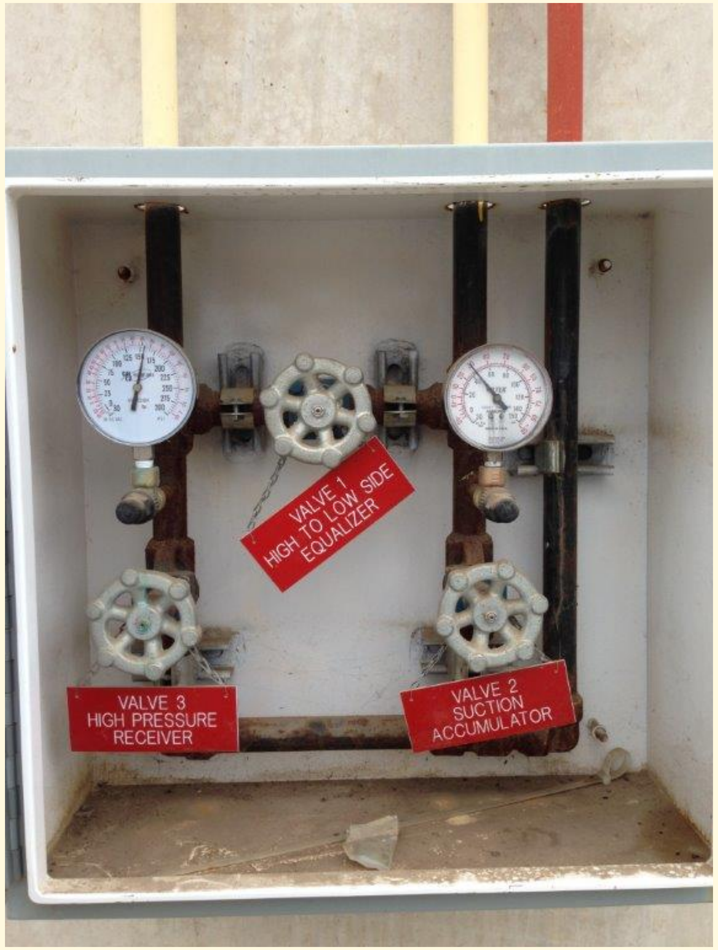
Machinery Rooms



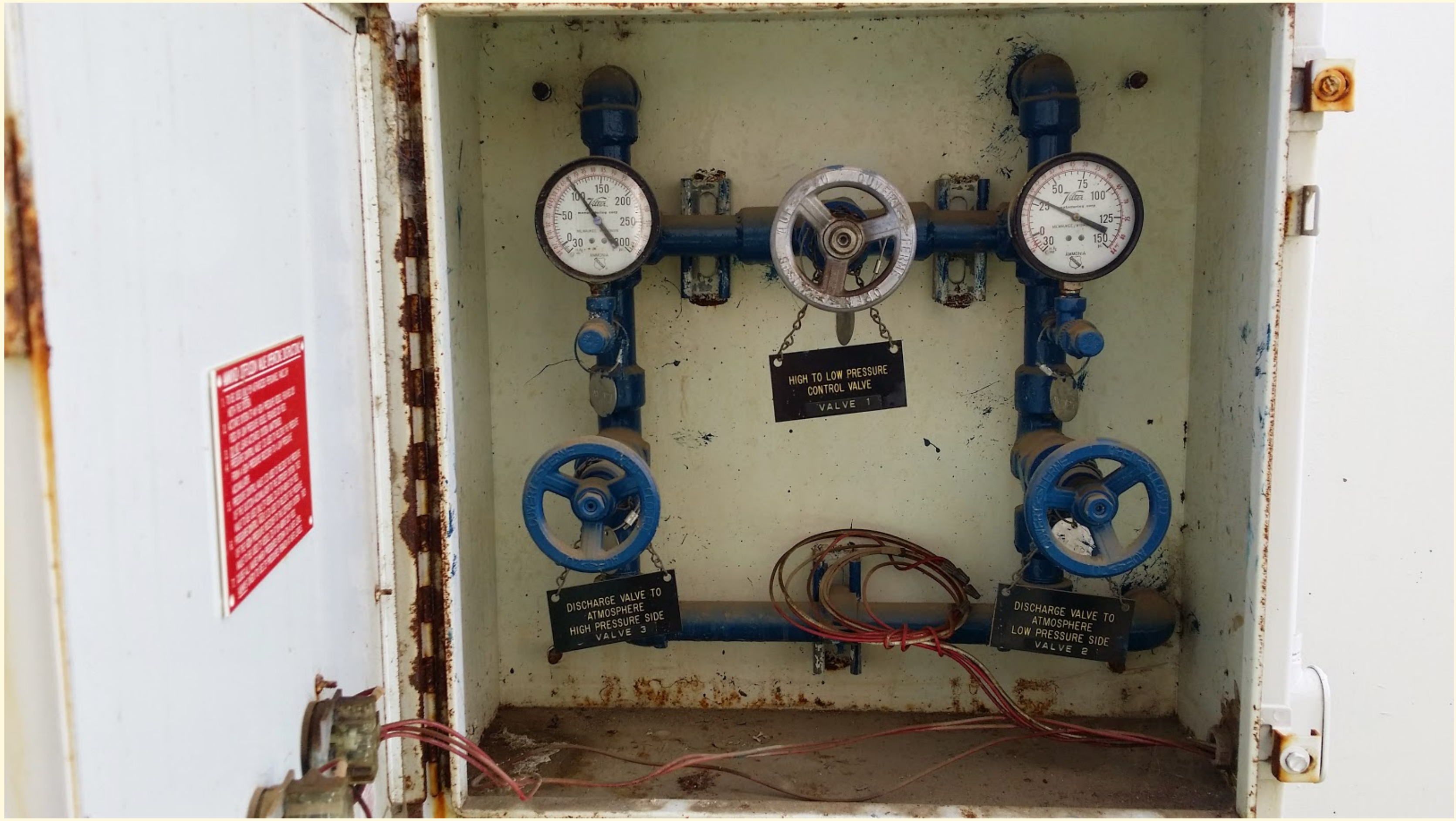
Emergency Control Box

Emergency Control Box

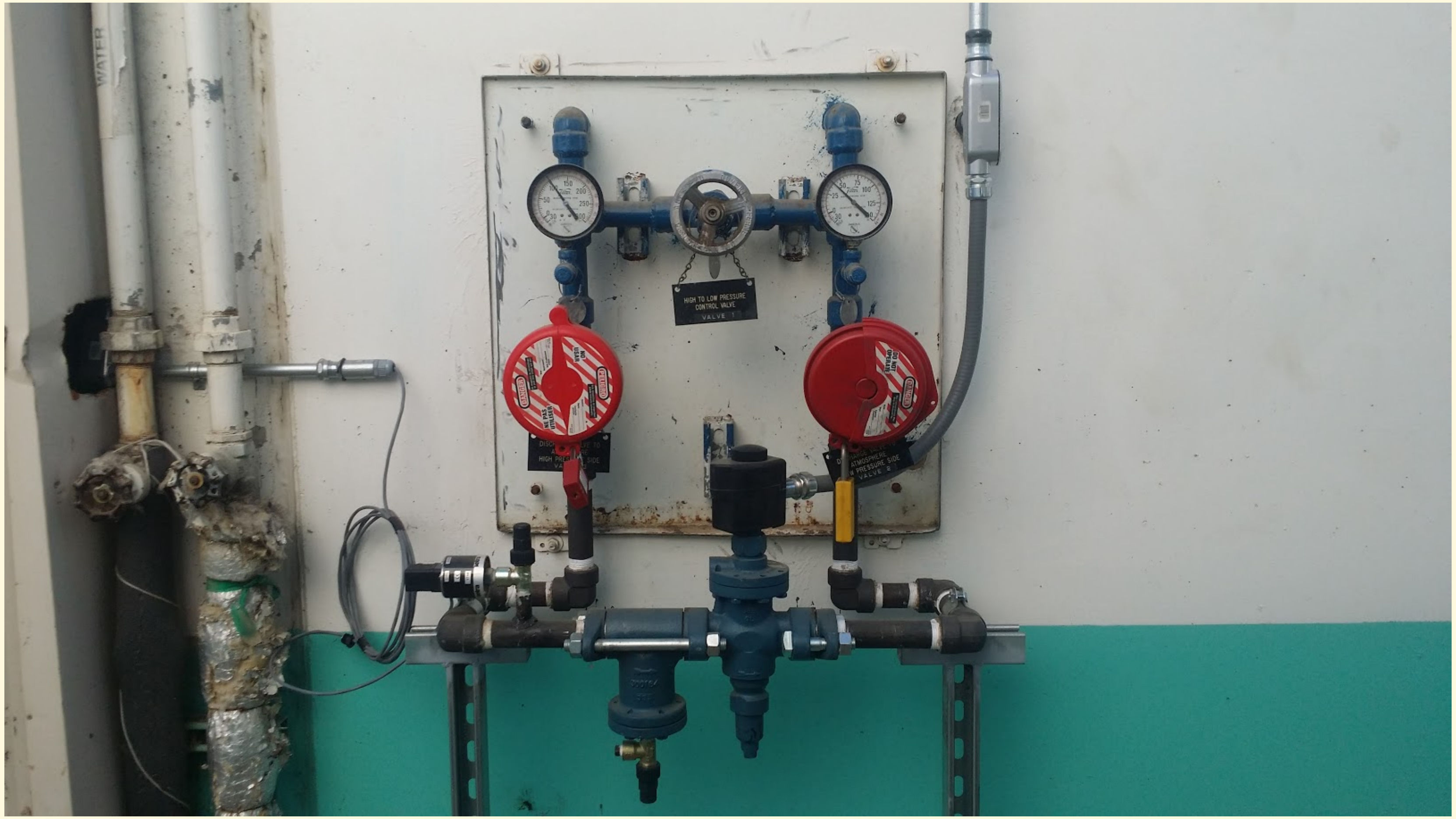
Emergency Control Box



Emergency Control Box



Emergency Pressure Control System



Emergency Pressure Control System

Ventilation

Ventilation

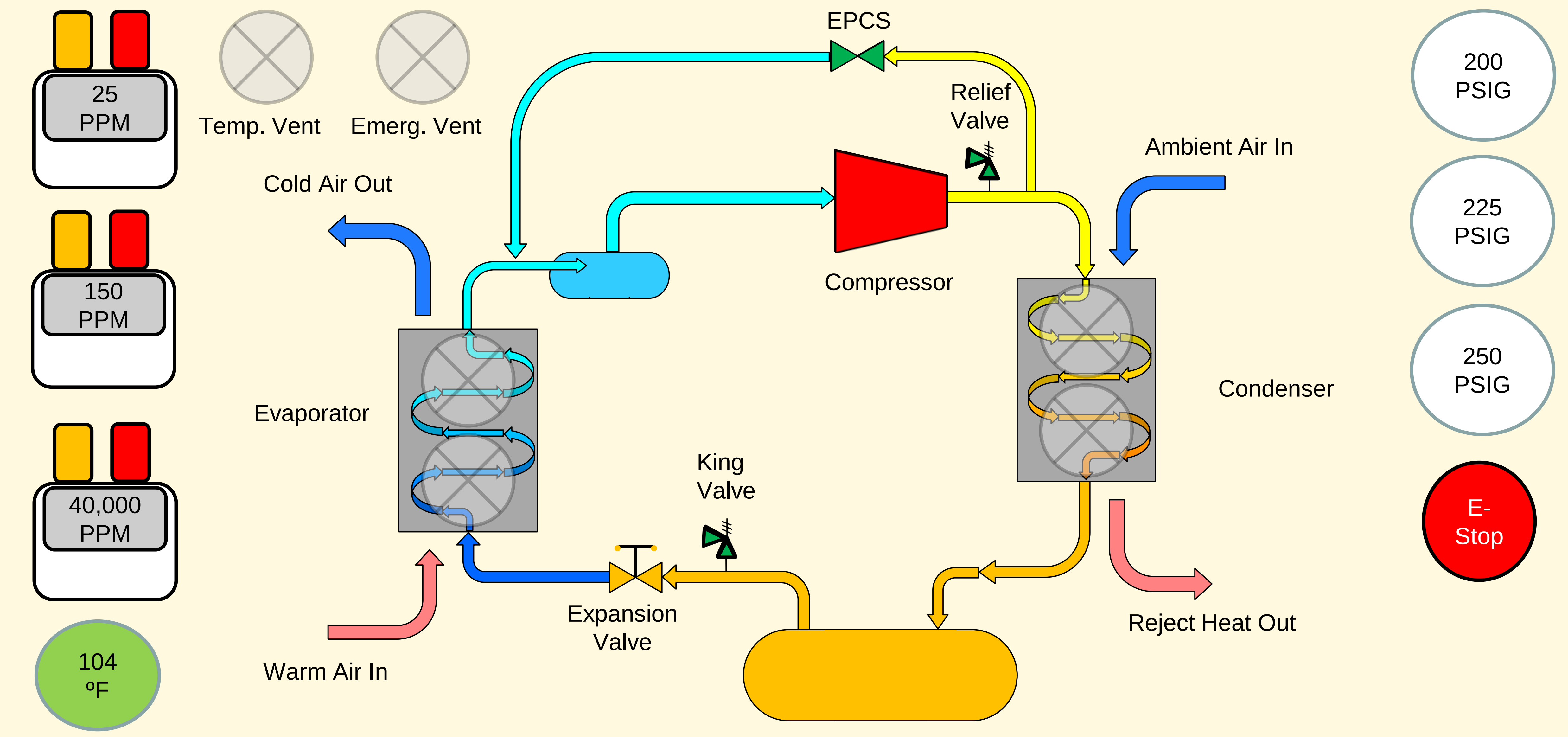
Ventilation

Ammonia Detection

Ammonia Detection

Emergency Controls

Emergency Controls


25
PPM
150
PPM
40,000
PPM
104
ºF
Temp. Vent
Emerg. Vent
EPCS
Relief
Valve
Cold Air Out
Ambient Air In
Compressor
Evaporator
Condenser
King
Valve
Expansion
Valve
Warm Air In
Reject Heat Out
200
PSIG
225
PSIG
250
PSIG
E-
Stop

Pipe


GR.B/ASME SA53/SA106 GR.B/API 5L B PSL1/NACE MR0175/
SCH 80 (0.200") x 21" H.5871H/2500 … NDE/B.BLG-892/3.53 LBS/FT/INDIA

Pipe

Insulation

Insulation

Insulation

RESOURCE COMPLIANCE

Providing Solutions. Simplifying Regulation.

Questions?

Peter Thomas, P.E.
Resource Compliance
www.resourcecompliance.com
(559) 591-8898
pthomas@resourcecompliance.com