Ammonia Refrigeration 101

DESIGN AND INDUSTRY

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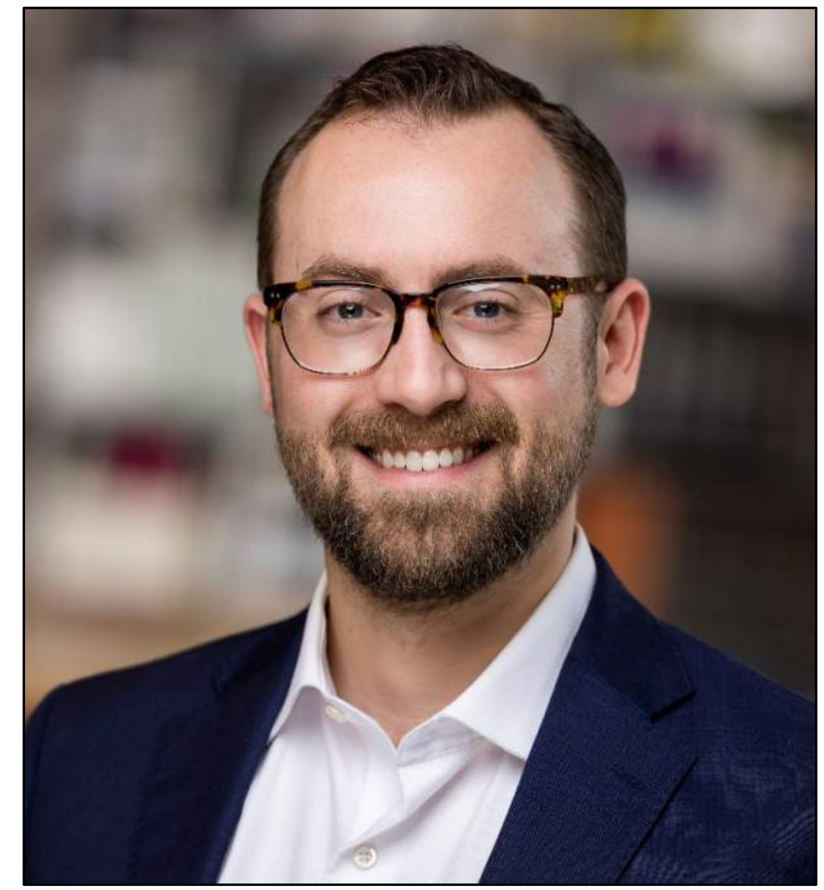
IMAGE COURTESY OF: STELLAR FOOD FOR THOUGHT

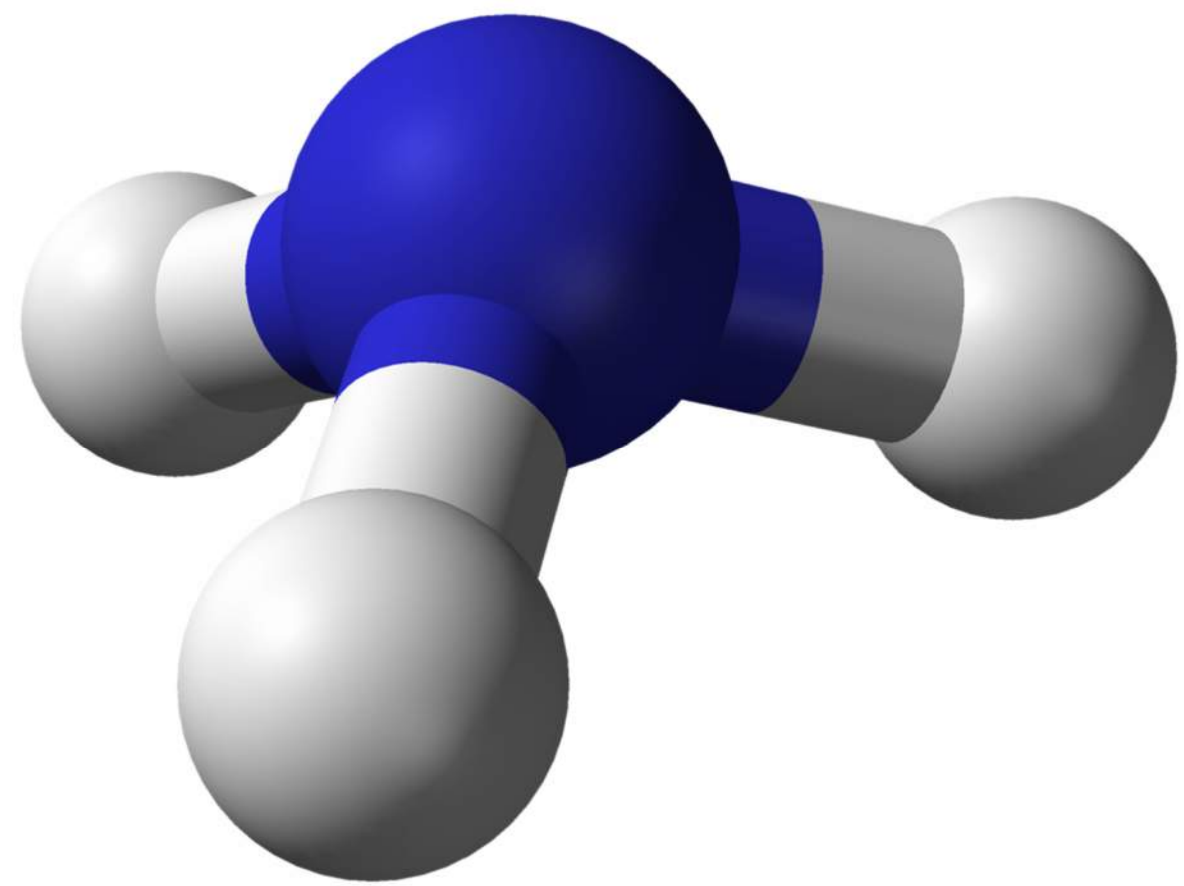
Background

- Joseph Gettemy, PE
  - Graduated ISU 2017
  - Worked for ~5 years as a refrigeration engineer
    - 1.5 years as a field engineer at a pork-processing construction site.
  - Now Mechanical Engineer here at Shive Hattery
    - Focused on Commercial and Industrial projects
    - Pursuing Passive-House certification



AGENDA

- Intro to Ammonia Refrigeration – Why and where?
- Ammonia Refrigeration as a Sub-Industry
- Design of Ammonia Systems
- Ammonia Safety – System and Personal
- Experience as a Refrigeration Engineer.



NH3 REFRIGERANT BY THE NUMBERS

		Halocarbons	Ammonia	CO2
SAFETY	Recommended Exposure Limit (REL)	1000+ ppm	35 ppm	5000 ppm
	Upper Operating Pressures	~150 psig	~200-300 psig	~1000 psig
OPERATION	COP *(Evap 20F, Cond 86F)*	5.6 - 6.1	6.3	3.5**
	Initial Cost*	Highest	Lowest	Middle
	GWP	7-2,500+	0	1

**Cost given as relative due to fluctuating market costs.*

***CO2 is typically most efficient at higher condensing temps*

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Ammonia (NH3) REFRIGERANT SUMMARY

- NH3 as a refrigerant:
  - Negative: Higher Harm Risk – Requires more *engineered* safety.
  - Positive: More efficient and less expensive

- Therefore, NH3 lends itself to larger-scale industrial, especially food production.
  - Greater net benefit from efficiency and cost allows for dedicated safety systems and staff.
  - Results in a **singular central system** for the whole plant.

- Other applications include:
  - Server farms
  - Ice Rinks
  - Sustainability applications (due to low GWP)

IMAGE COURTESY OF GOOGLE MAPS

NH3 REFRIG. AS A (SUB)INDUSTRY - CODE

- International Institute of Ammonia Refrigeration (IIAR) standards are typically the governing code.
  - IMC defers to IIAR.

- IIAR standards include:
  - IIAR 1, Definitions and Terminology.
  - IIAR 2, Design of Closed-Circuit Ammonia Refrigeration Systems.
  - IIAR 3, Ammonia Refrigeration Valves.
  - IIAR 4, Installation of Closed-Circuit Ammonia Refrigeration Systems.
  - IIAR 5, Start-up and Commissioning of Closed-Circuit Ammonia Refrigeration Systems.
  - IIAR 7, Developing Operating Procedures for Closed-Circuit Ammonia Mechanical Refrigerating Systems.
  - IIAR 8, Decommissioning of Closed-Circuit Ammonia Refrigeration Systems.
  - IIAR 9, Minimum System Safety Requirements for Existing Closed-circuit Ammonia Refrigeration Systems.

<u>FROM IMC 2021 - CH 11:</u>

1101.1.2 Ammonia refrigerant. P

Refrigeration systems using ammonia as the refrigerant shall comply with IIAR 2, IIAR 3, IIAR 4 and IIAR 5 and shall not be required to comply with this chapter.

IMAGE COURTESY OF: INTERNATIONAL INSTITUTE OF AMMONIA REFRIGERATION

NH3 REFRIG. AS A (SUB)INDUSTRY - CODE

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  - **IIAR 9, Minimum System Safety Requirements for Existing Closed-circuit Ammonia Refrigeration Systems.**
    - ***IIAR 9 Limited Grandfathering.***

IMAGE COURTESY OF: INTERNATIONAL INSTITUTE OF AMMONIA REFRIGERATION

OSHA®
Occupational Safety and Health Administration

NH3 REFRIG. AS A (SUB)INDUSTRY - CODE

- Systems containing more than 10,000 lbs need a Process Safety Management (PSM) system (per OSHA):
  - Maintained P&IDs
  - Regular documentation and calculation showing compliance
  - Typically, dedicated staff.

- Updates to these compliance calculations requires frequent engineering visits.

IMAGES COURTESY OF: OSHA AND FOODPLANTENGINEERING.COM

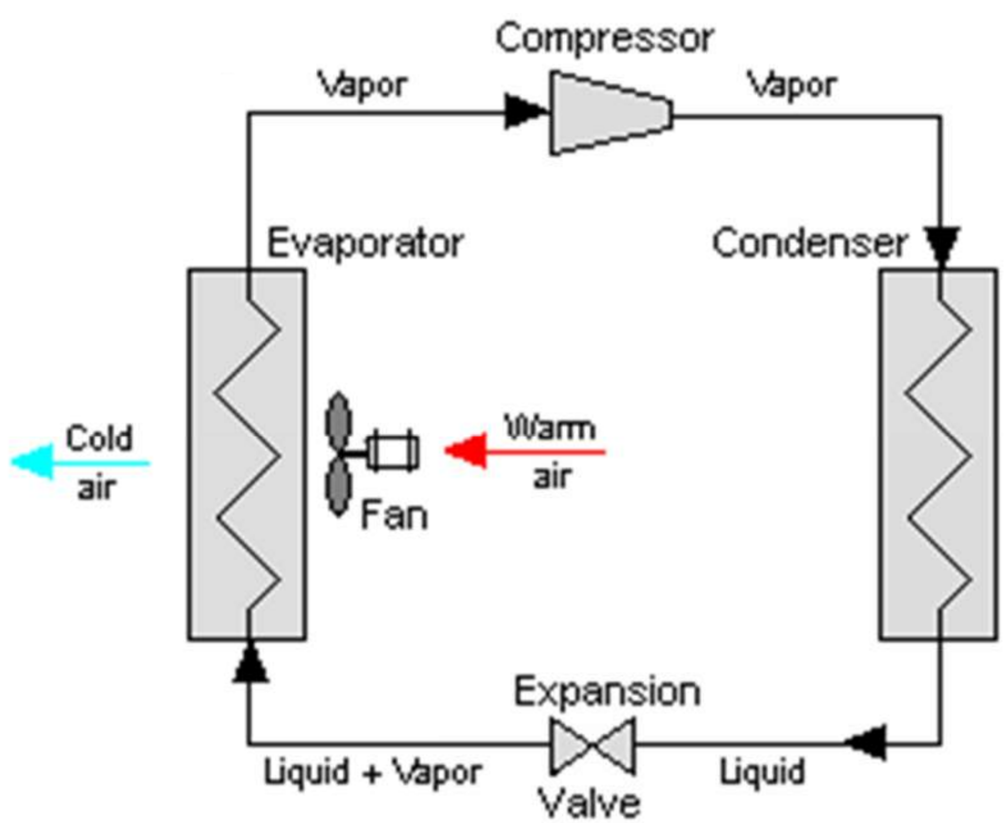
NH3 REFRIG. AS A (SUB)INDUSTRY - NUANCE

- For Engineers, these visits create frequent repeat customers and relationship building.

- Because the system is a singular central design, changes to a portion of the system require knowledge of the whole system.

IMAGE COURTESY OF: PROGRESSIVE AE

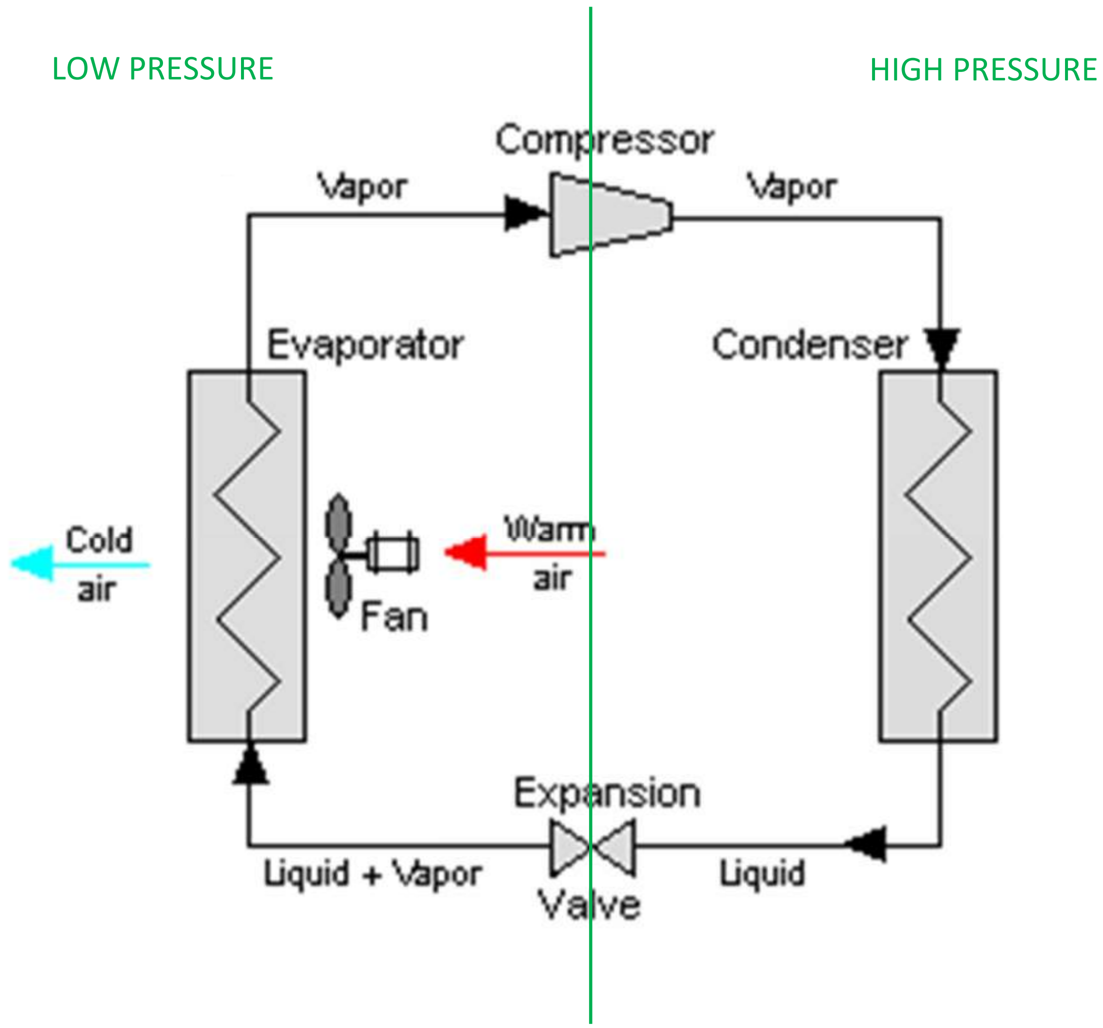
SYSTEM DESIGN



SYSTEM DESIGN - BASICS

- Ammonia refrigeration operates using the refrigeration cycle.

IMAGE COURTESY OF: WIKIPEDIA.ORG



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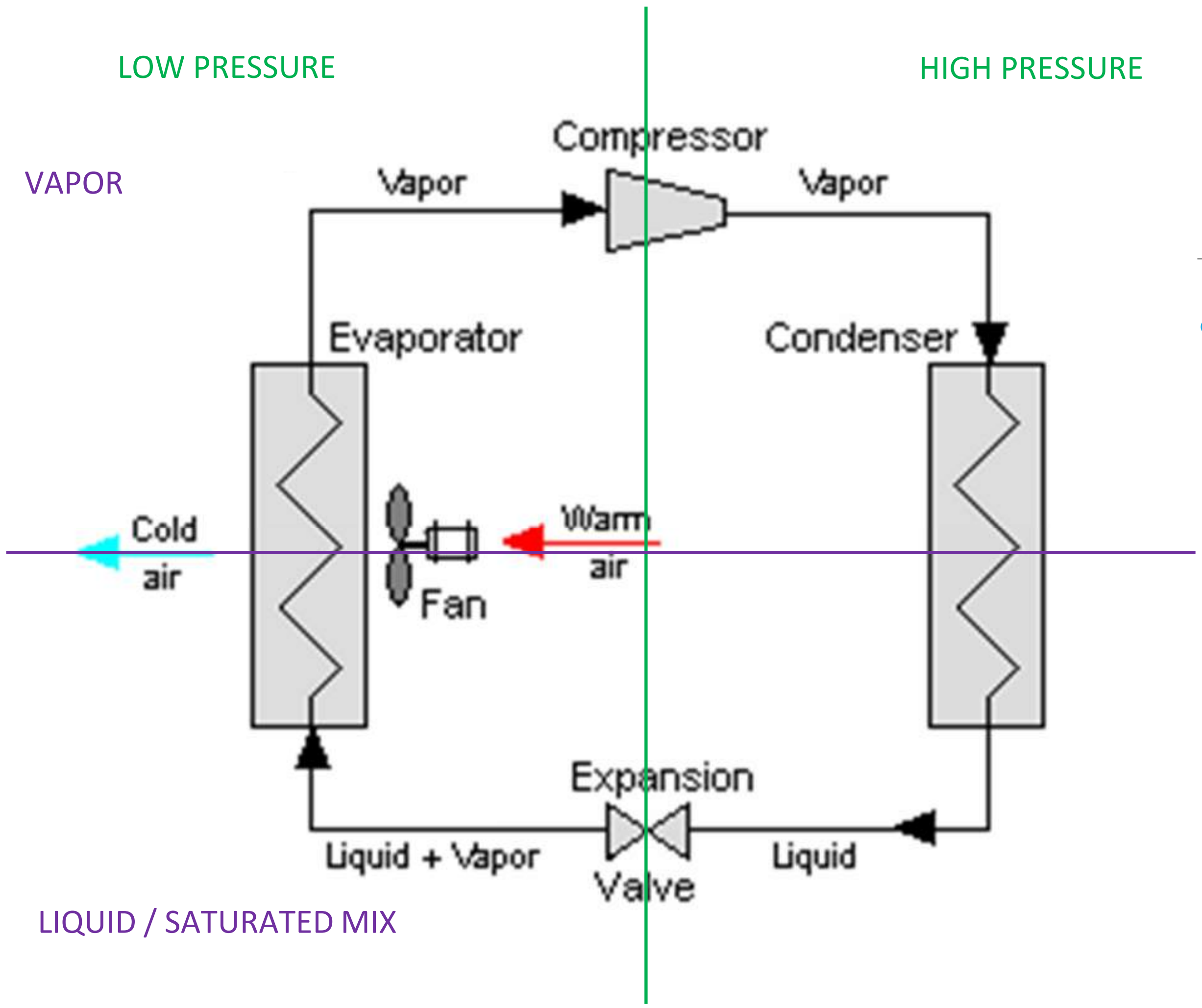

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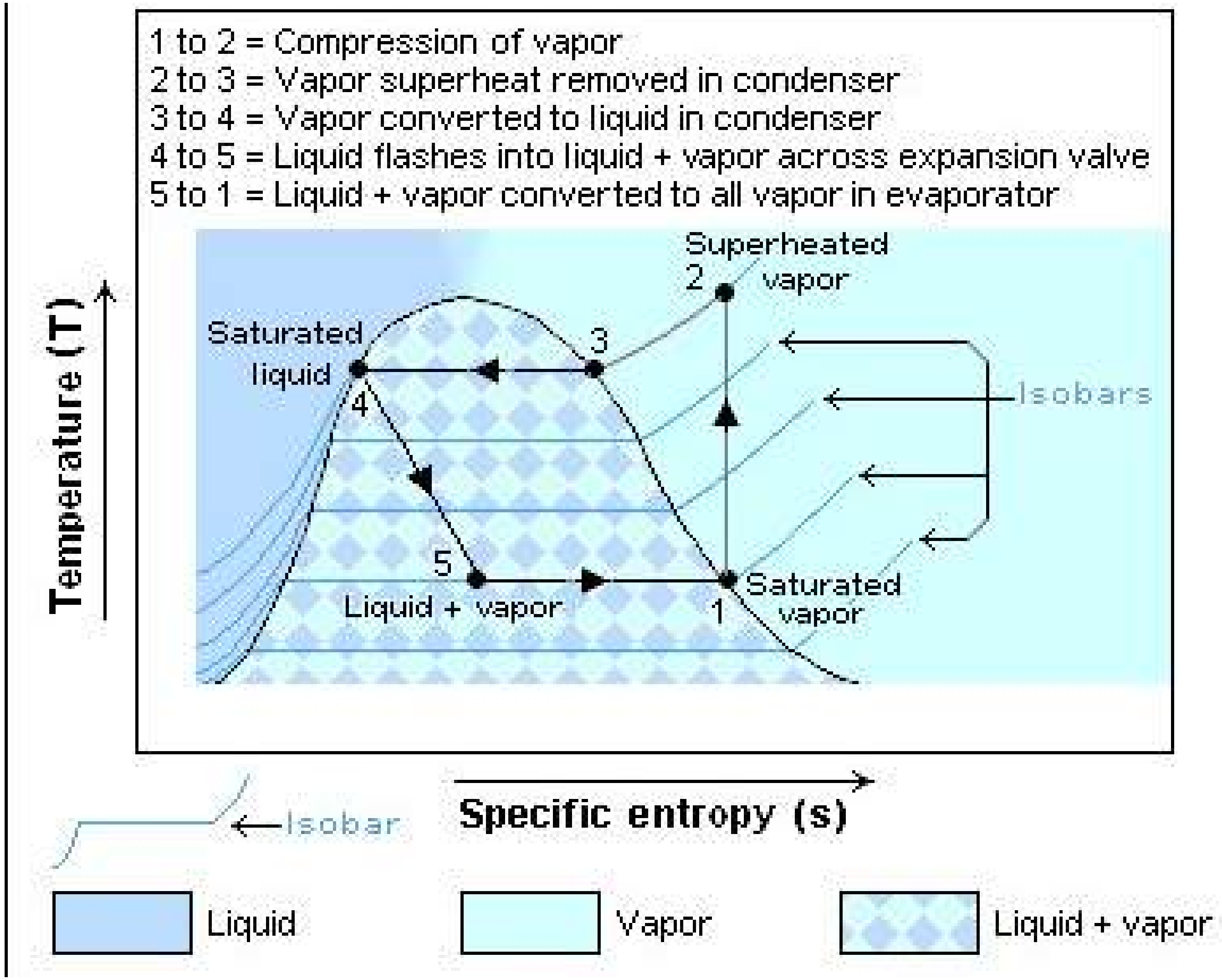
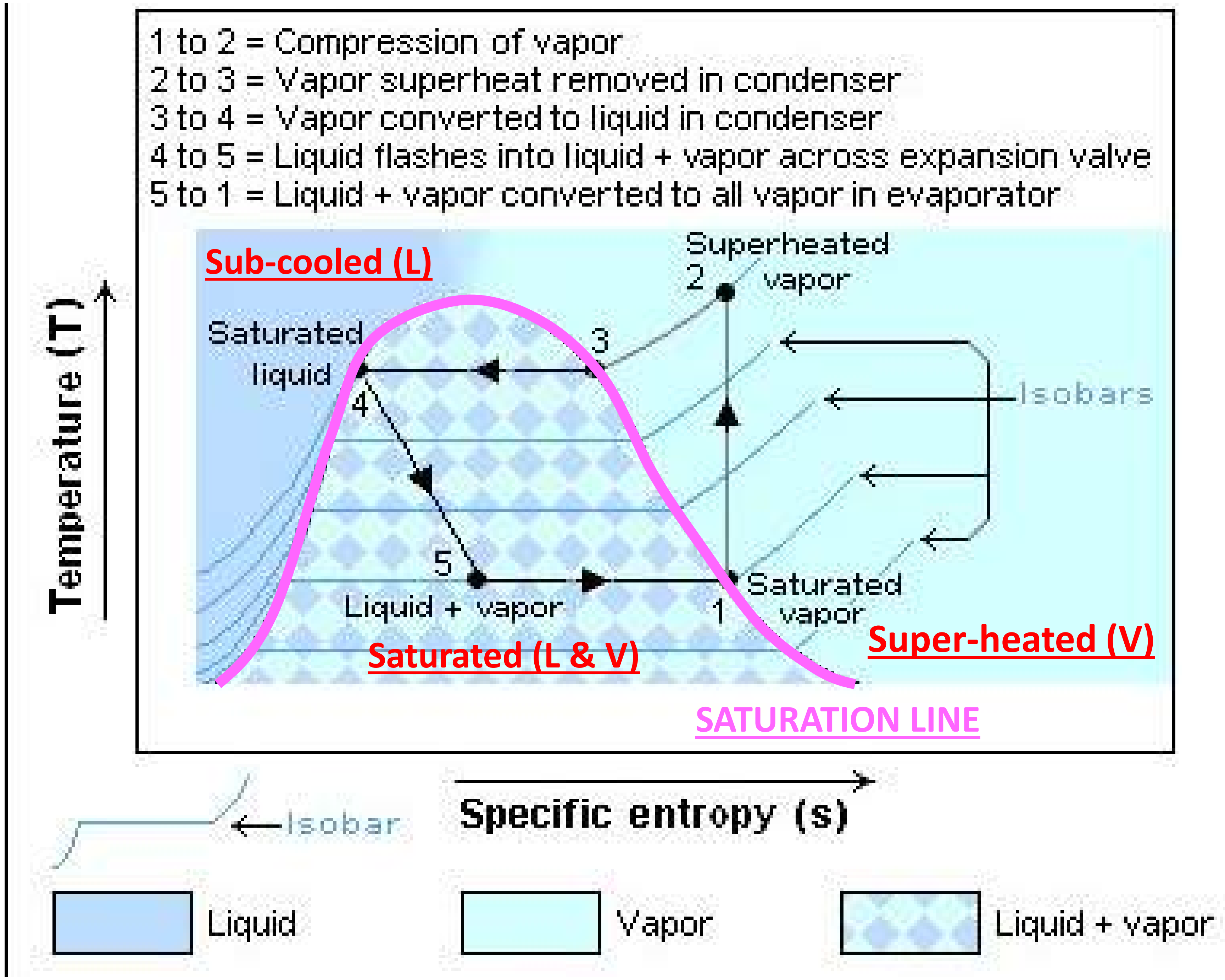


FLUID SATURATION

- Refresher: *at a given pressure and temperature*: fluid transitions between **liquid and vapor**
  - At temp: **saturated**
  - Above temp: **super-heated**
  - Below temp: **sub-cooled**

IMAGE COURTESY OF: WIKIPEDIA.ORG



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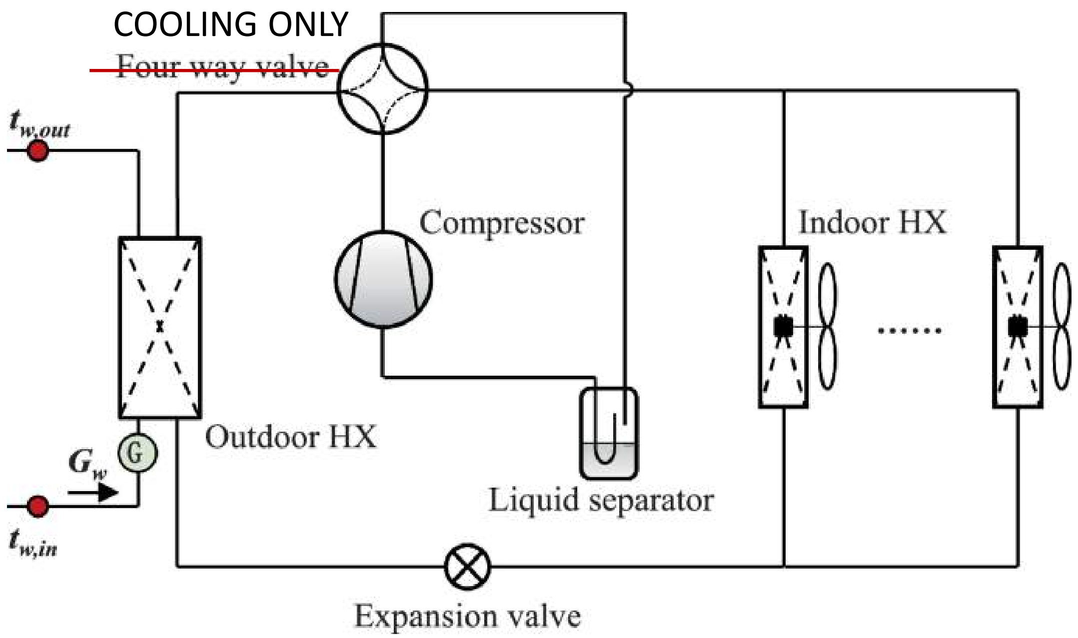
FLUID SATURATION

EVAP

COND

Refrigerant 717 (Ammonia) Properties of Saturated Liquid and Saturated Vapor

Temp.,* °F	Pressure, psia	Density, lb/ft³	Volume, ft³/lb	Enthalpy, Btu/lb-°F		Entropy, Btu/lb-°F		Specific Heat c_p Btu/lb-°F		C_p/C_v	Thermal Conductivity Btu/hr-ft-°F		Temp.,* °F
		Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Vapor	Liquid	Vapor	
25.00	53.720	40.20	5.3307	70.072	618.974	0.1547	1.28726	1.0983	0.6271	1.3894	0.3302	0.01331	25.00
30.00	59.730	39.96	4.8213	75.585	620.305	0.1660	1.27842	1.1019	0.6366	1.3951	0.3253	0.01345	30.00
35.00	66.255	39.72	4.3695	81.116	621.582	0.1772	1.26975	1.1056	0.6465	1.4012	0.3204	0.01360	35.00
40.00	73.322	39.48	3.9680	86.666	622.803	0.1883	1.26125	1.1094	0.6569	1.4078	0.3155	0.01376	40.00
45.00	80.962	39.24	3.6102	92.237	623.967	0.1993	1.25291	1.1134	0.6678	1.4147	0.3107	0.01392	45.00
75.00	140.590	37.73	2.1217	126.126	629.647	0.2640	1.20570	1.1410	0.7440	1.4670	0.2825	0.01504	75.00
80.00	153.130	37.47	1.9521	131.861	630.359	0.2745	1.19823	1.1470	0.7580	1.4780	0.2780	0.01525	80.00
85.00	166.510	37.21	1.7983	137.624	630.999	0.2850	1.19085	1.1530	0.7740	1.4900	0.2734	0.01548	85.00
90.00	180.760	36.94	1.6588	143.417	631.564	0.2955	1.18356	1.1590	0.7900	1.5020	0.2689	0.01571	90.00
95.00	195.910	36.67	1.5319	149.241	632.052	0.3059	1.17634	1.1660	0.8070	1.5150	0.2644	0.01595	95.00

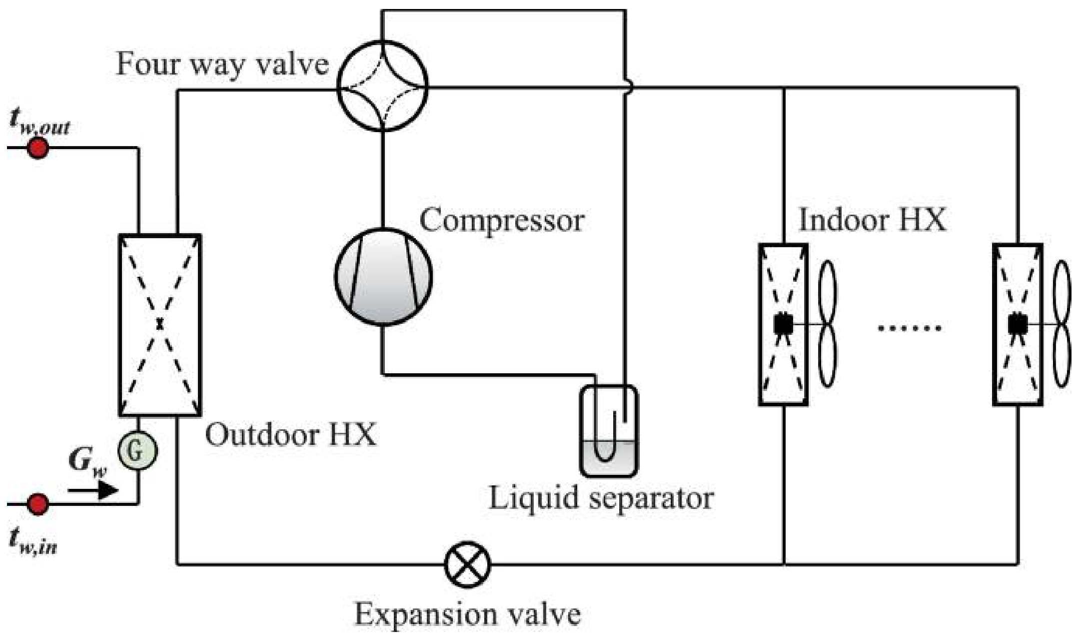


SYSTEM DESIGN

- Ammonia refrigeration operates using the refrigeration cycle.
- Comparable to a VRF system (cooling only)

IMAGES COURTESY OF: SPRINGER.COM AND TRANE

SYSTEM DESIGN - SCALE



IMAGES COURTESY OF: SPRINGER.COM, TRANE, EPA, EVAPCO, STELLAR FOOD FOR THOUGHT, AND EDG

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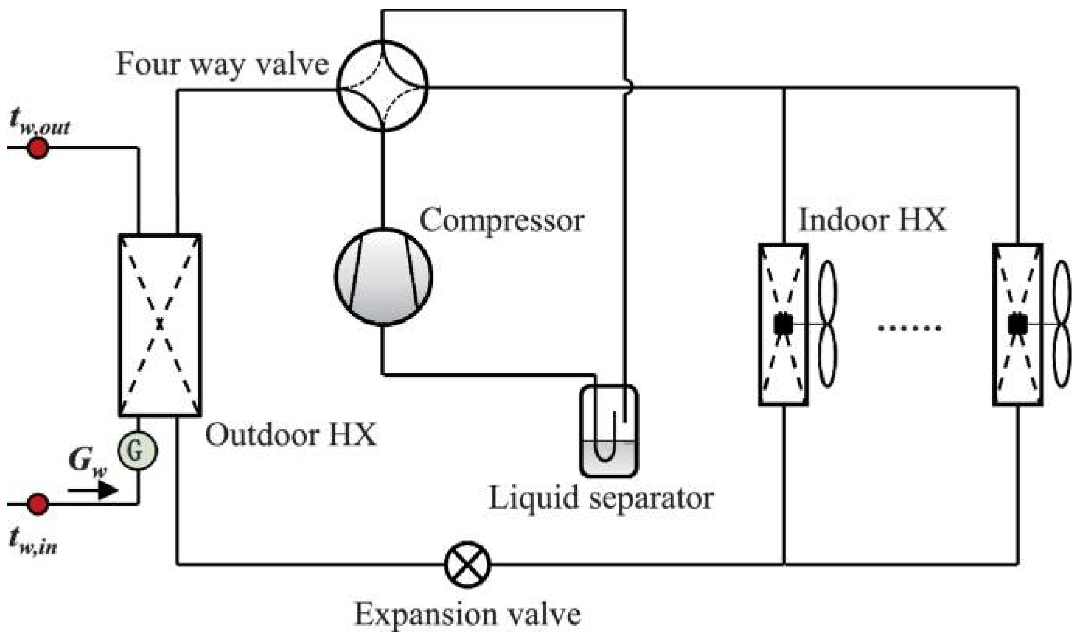



CONDENSER

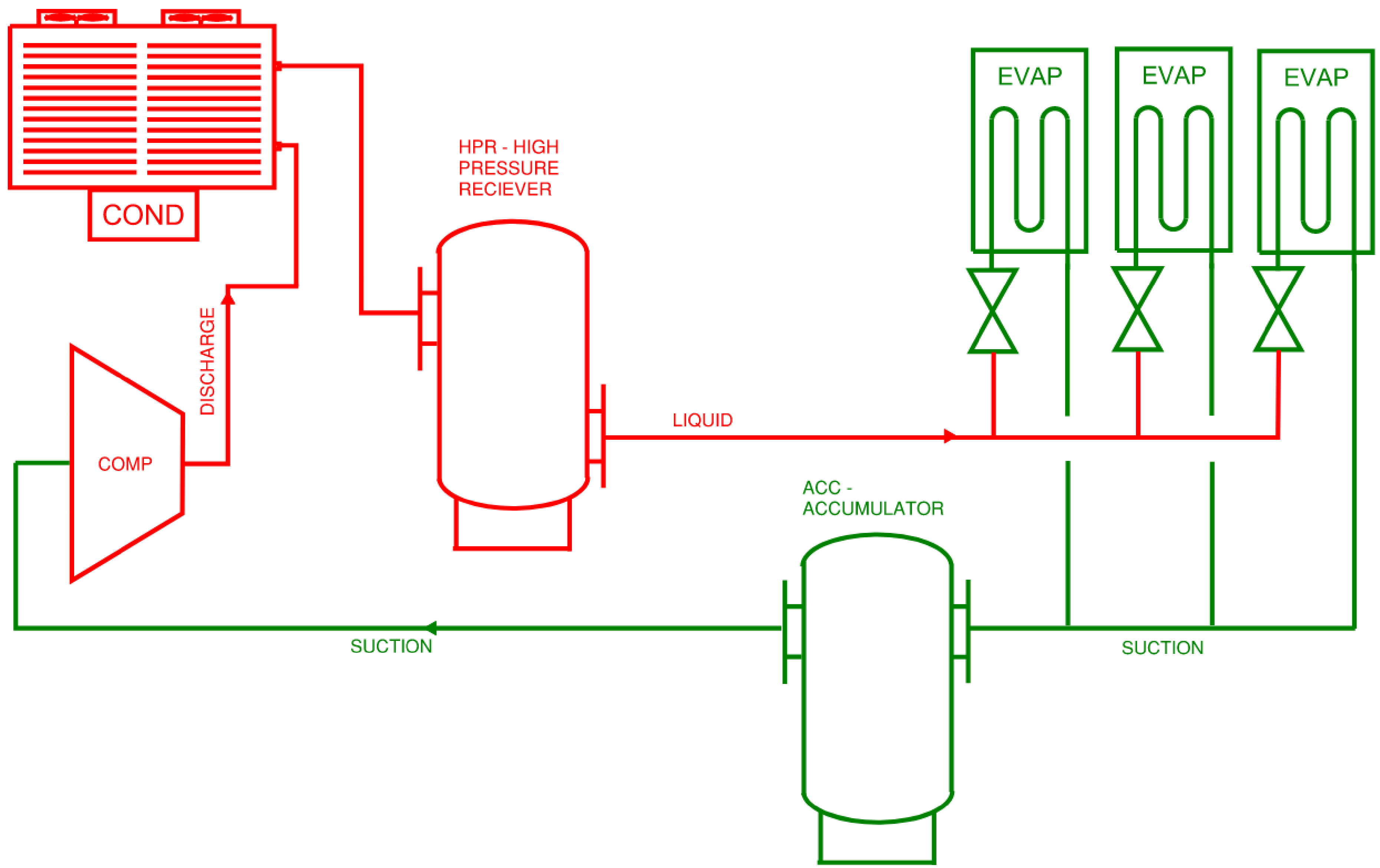

COMPRESSOR


EVAPORATOR


VESSELS

IMAGES COURTESY OF: SPRINGER.COM, TRANE, EPA, EVAPCO, STELLAR FOOD FOR THOUGHT, AND EDG

SYSTEM DESIGN – DX – ONE STAGE



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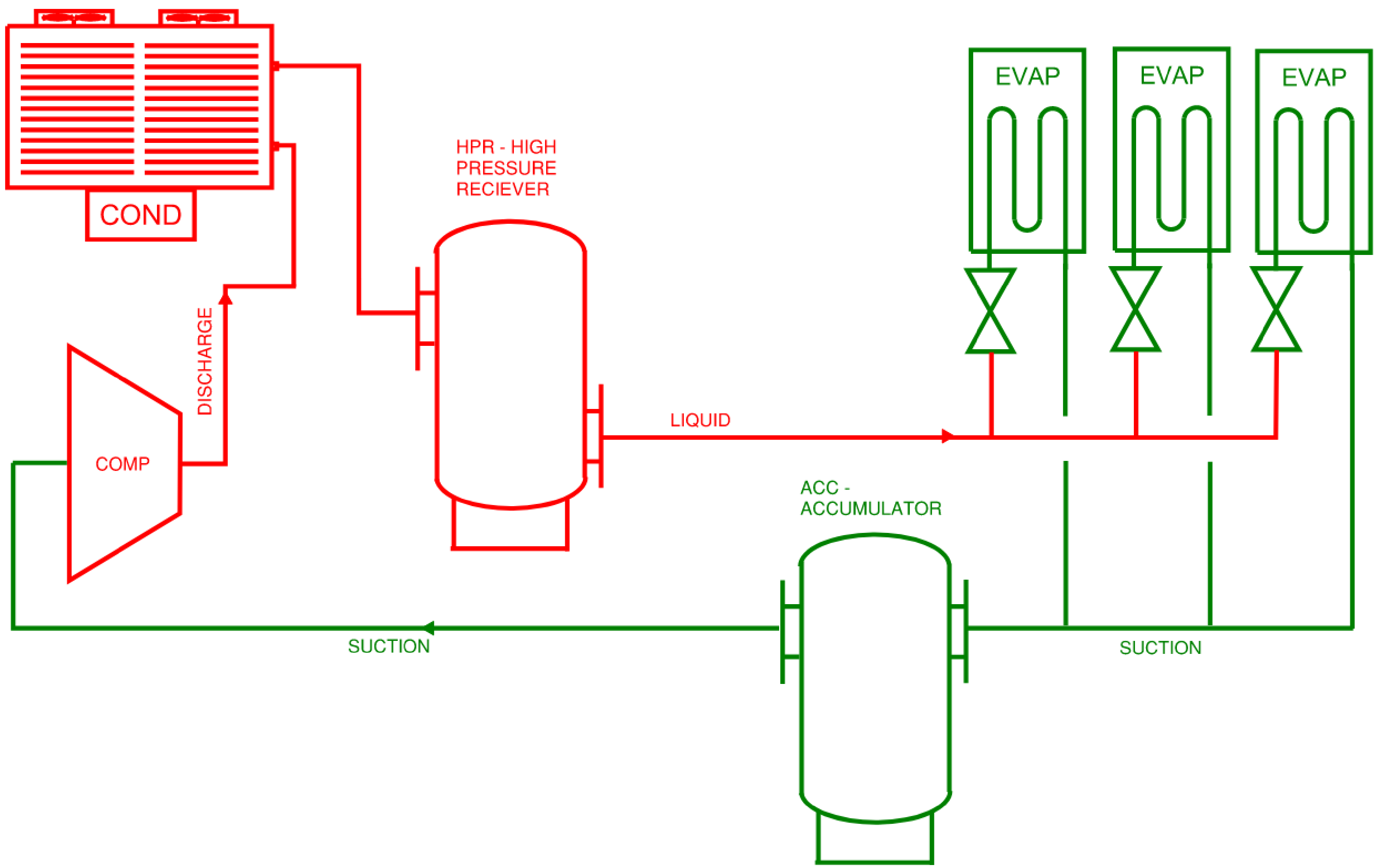
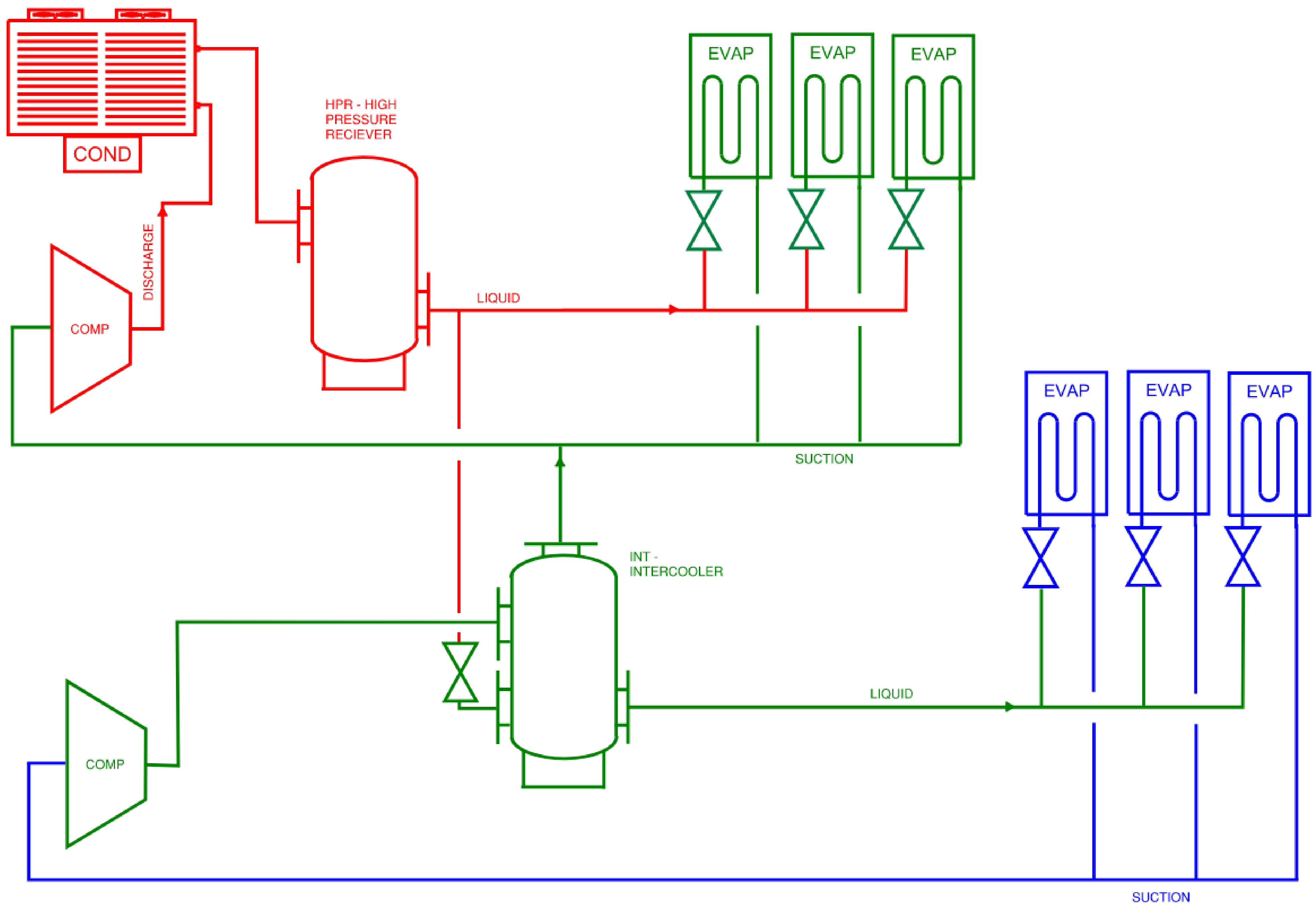


- Most basic system.
- Functions when required temperatures are similar.

SYSTEM DESIGN – DX – TWO STAGE



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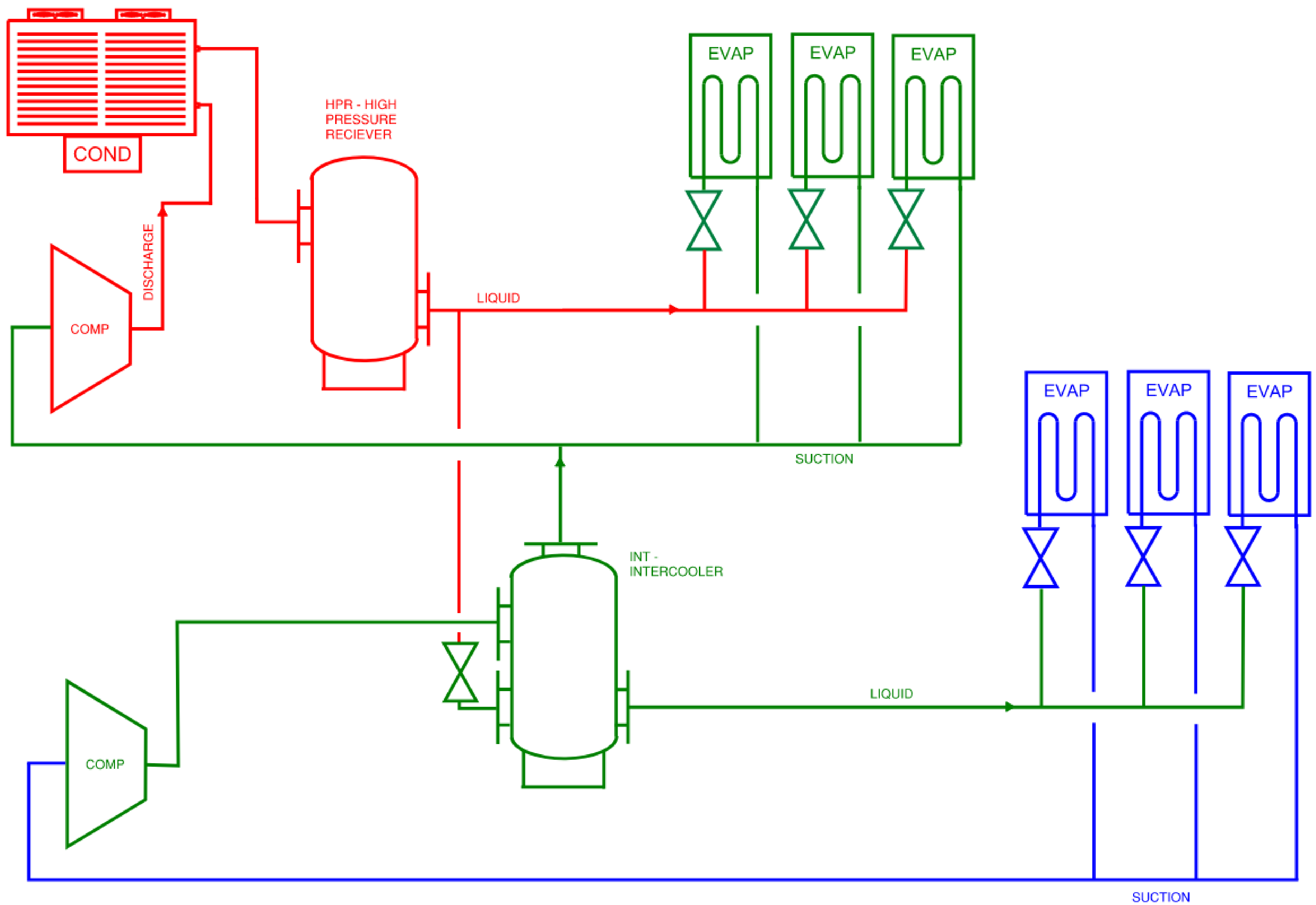
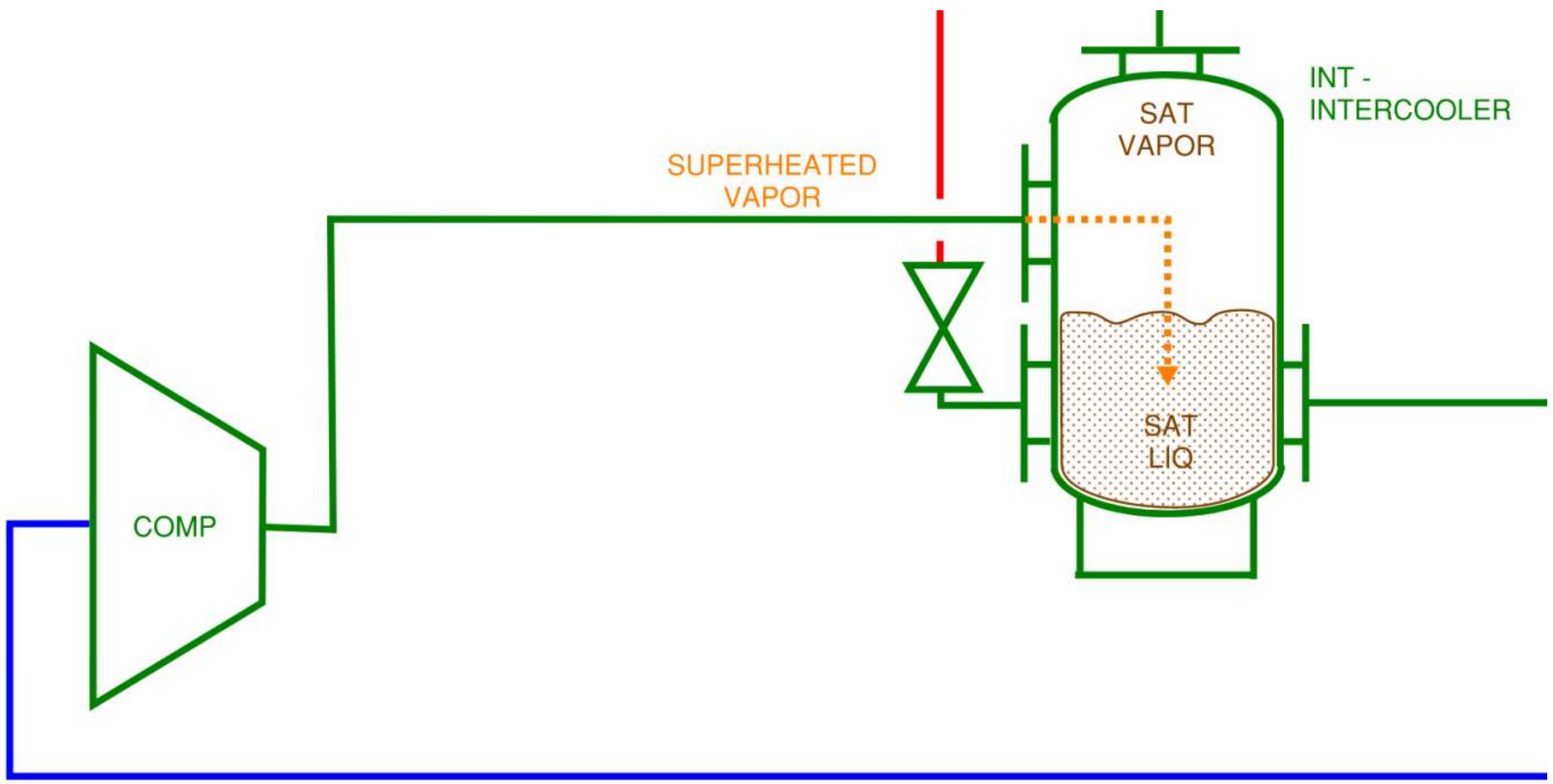


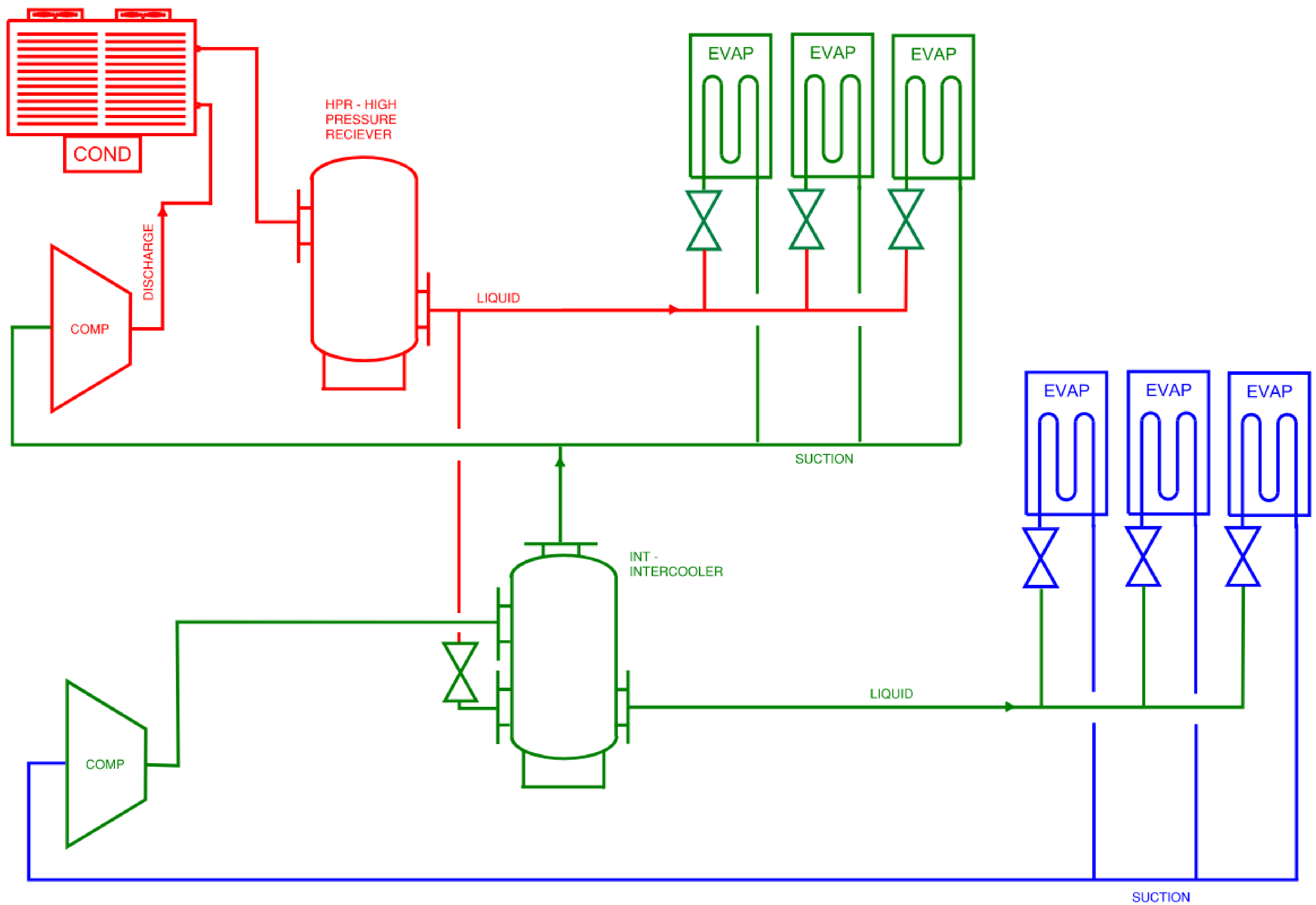
- Allows for two temperature ranges:
  - Usually refrigerated and below-freezing.
- Adds to system:
  - Booster compressor
  - Intercooler.
  - 3rd pressure/temperature.

SYSTEM DESIGN – DX – TWO STAGE



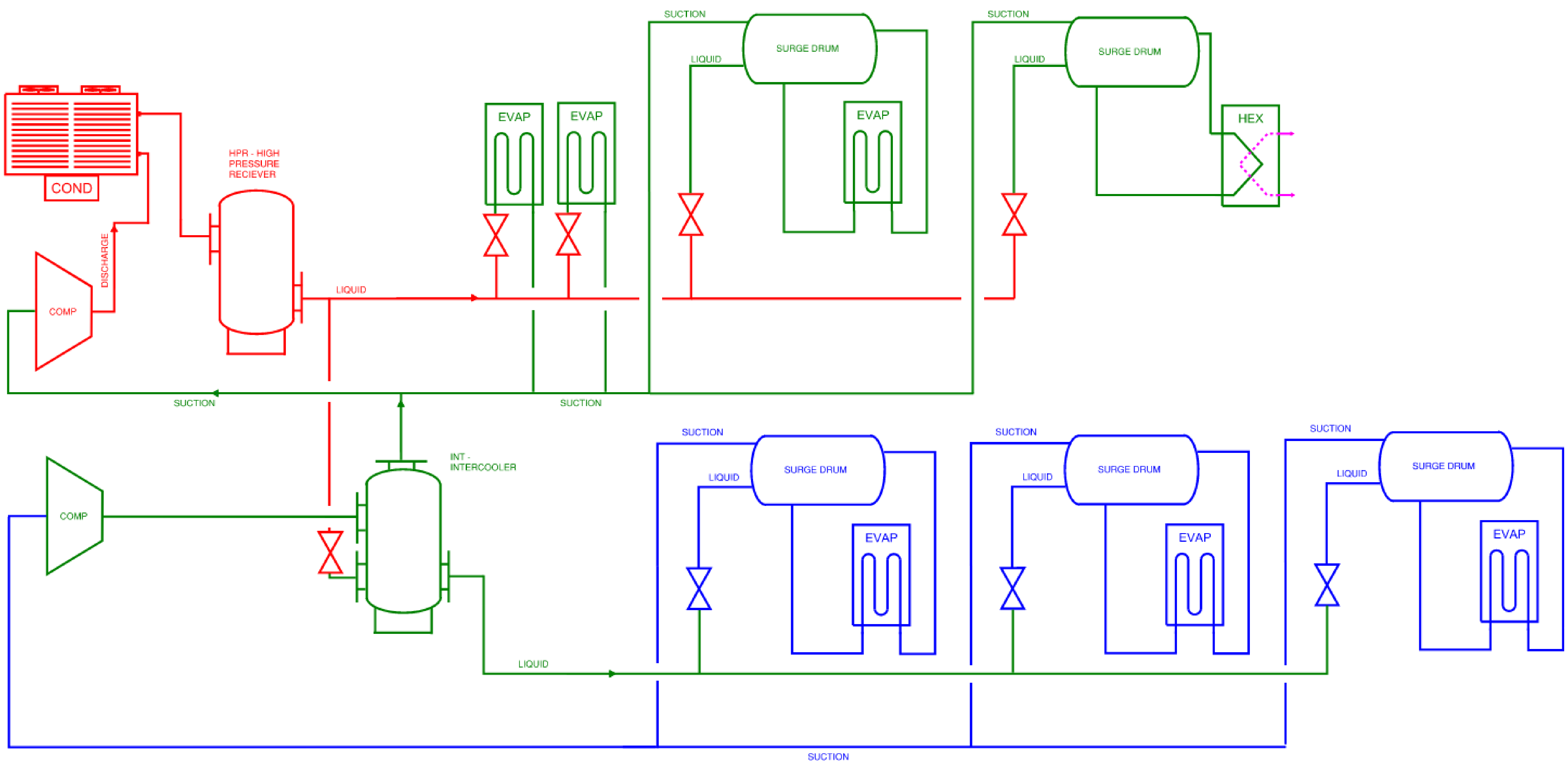
- In intercooler:
  1. Superheated vapor from compressor enters vessel.
  2. Vessel is at saturation with both liquid and vapor.
  3. Superheated vapor cools to saturation and converts some of the sat liquid to vapor also.
  4. Vessel is maintained with sufficient liquid to keep temp and pressure at saturation.

SYSTEM DESIGN – DX – TWO STAGE

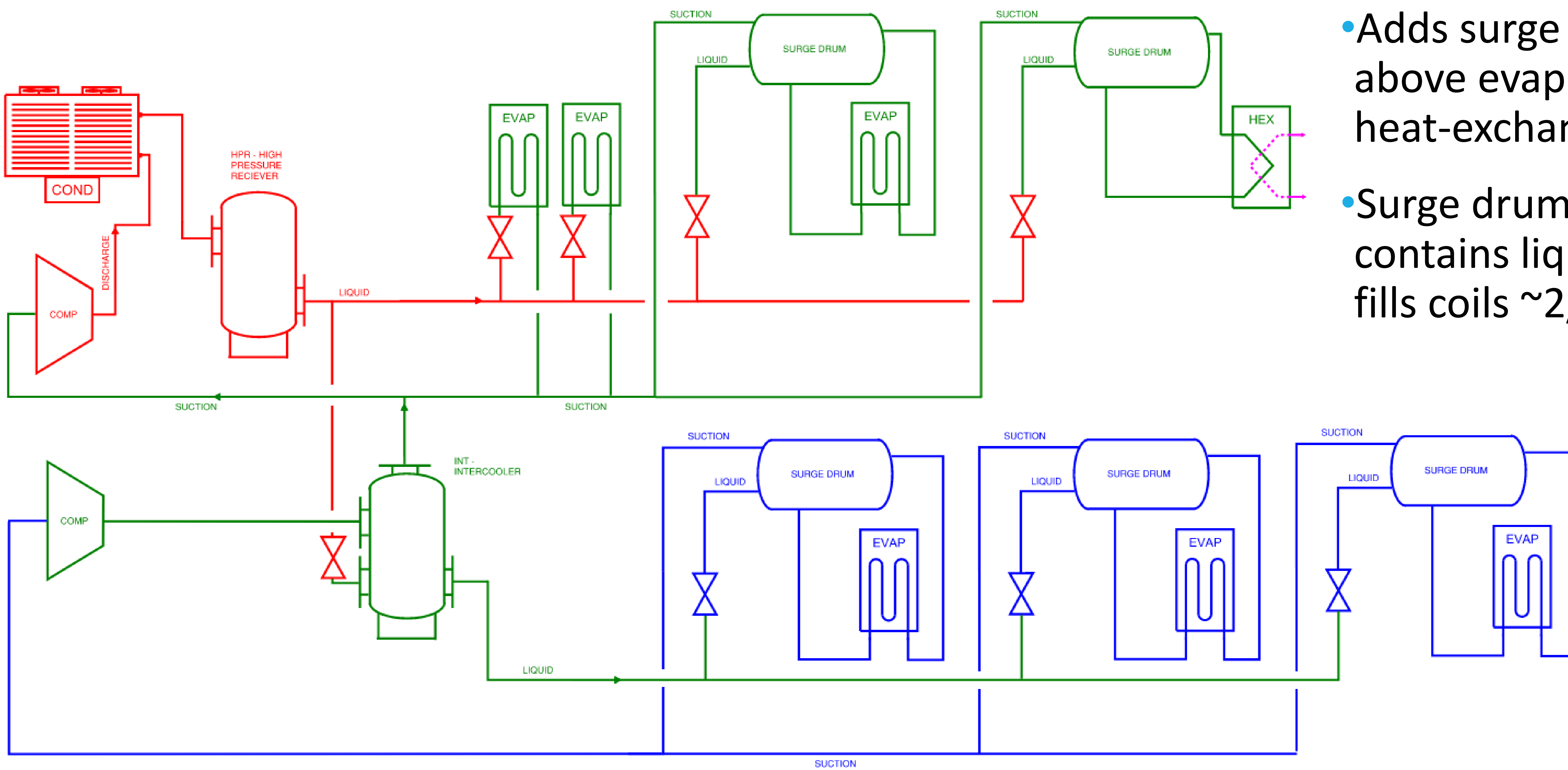


- DX limitation:
  - Evaporator coil size limited.
  - If too large, liquid may evaporate before filling coil.
- Frequent issue with lower temps and heat-exchangers.

SYSTEM DESIGN – FLOODED – TWO STAGE

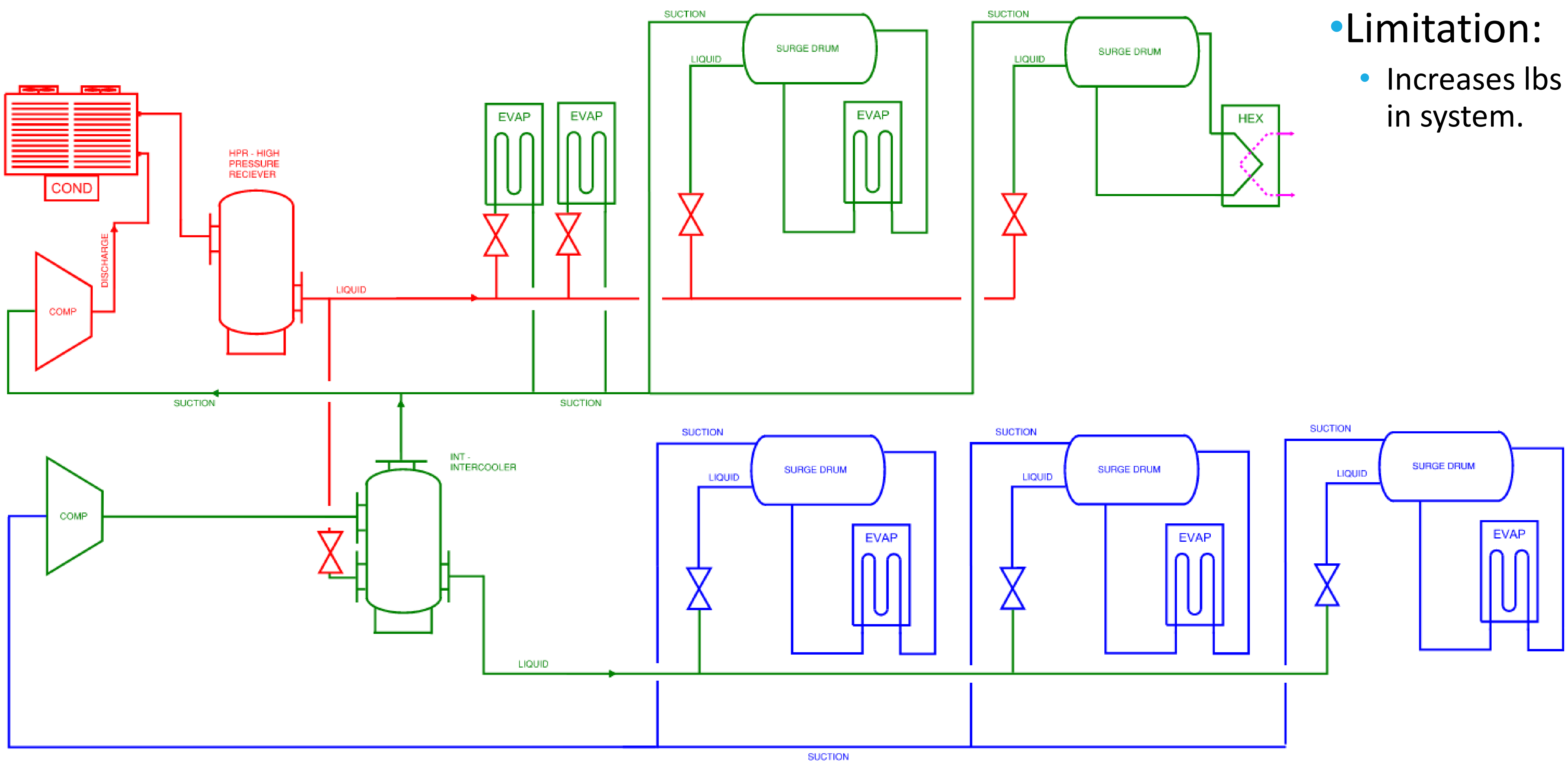


SYSTEM DESIGN – FLOODED – TWO STAGE



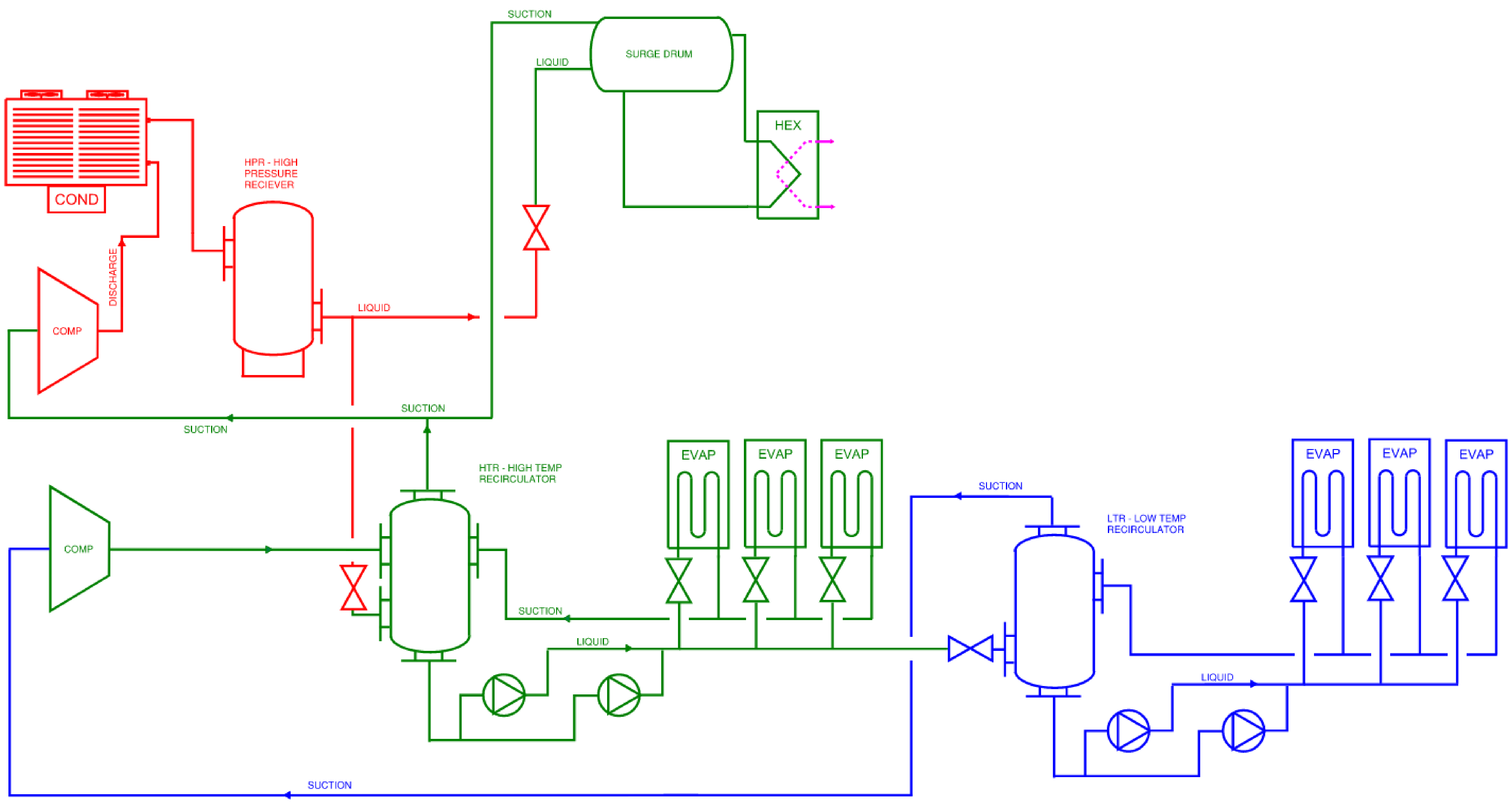
- Adds surge drums above evaporator/ heat-exchanger.
- Surge drum contains liquid and fills coils ~2/3 full.

SYSTEM DESIGN – FLOODED – TWO STAGE

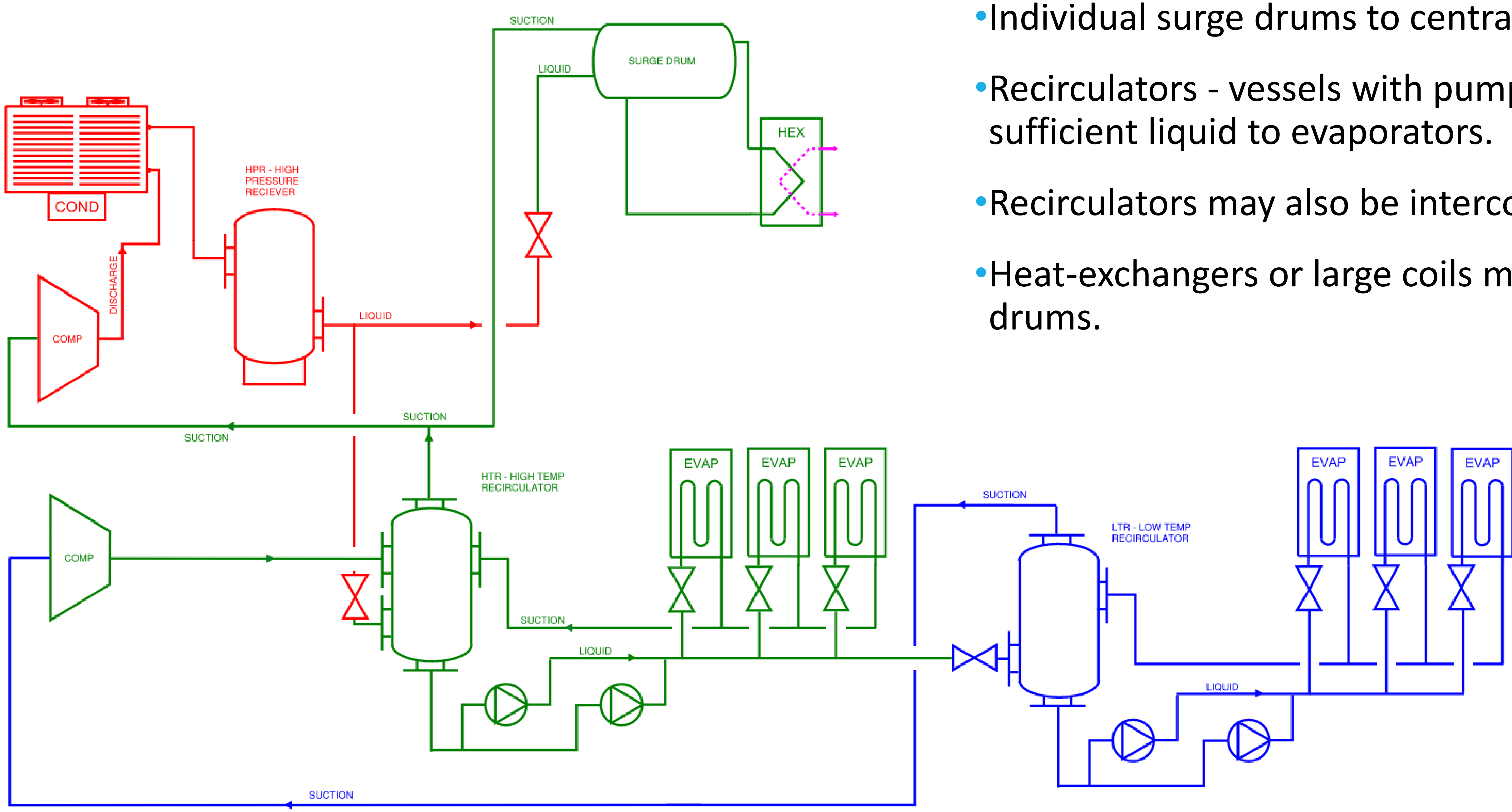


- Limitation:
  - Increases lbs ammonia in system.

SYSTEM DESIGN – RECIRCULATED – TWO STAGE

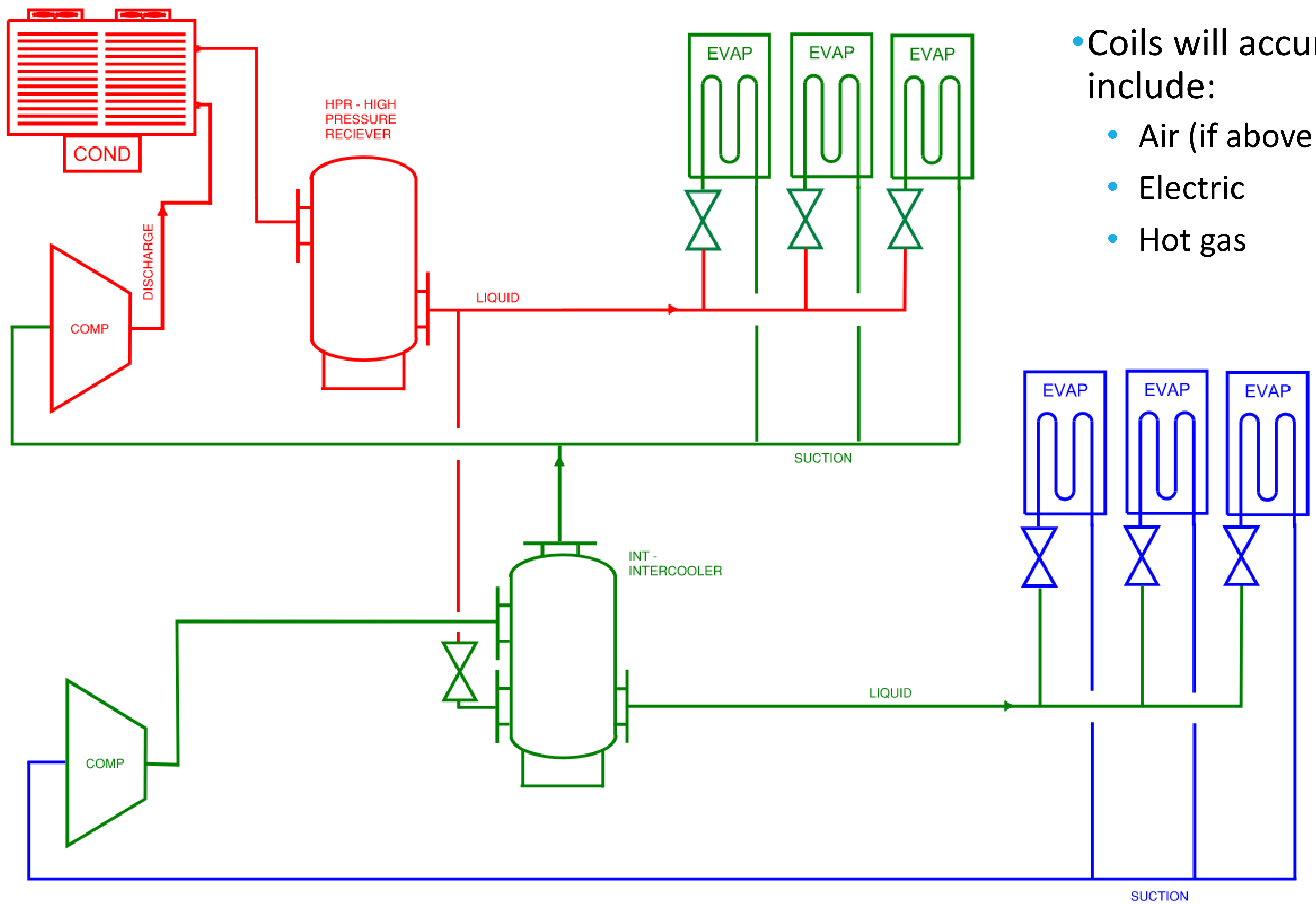


SYSTEM DESIGN – RECIRCULATED – TWO STAGE



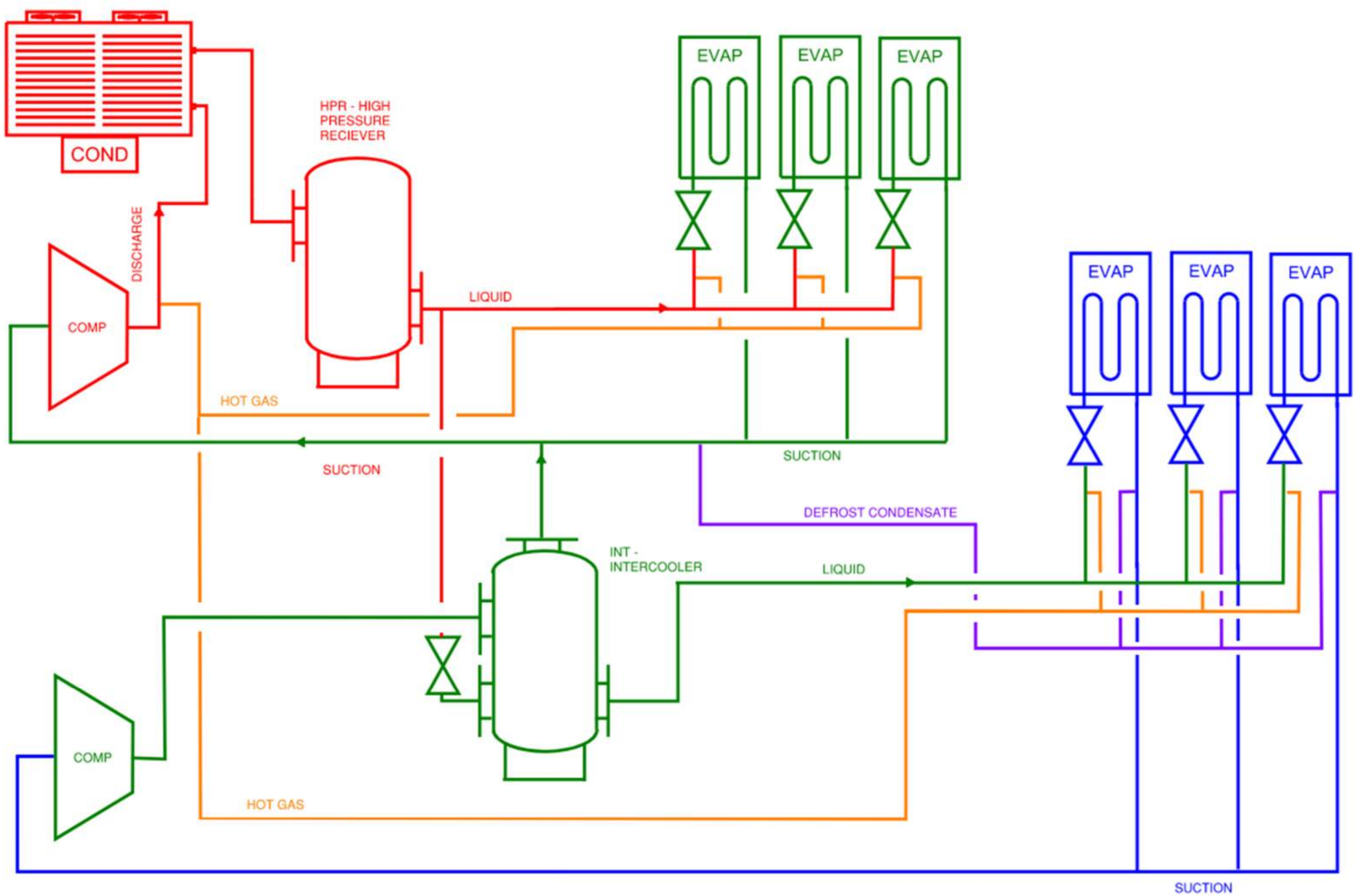
- Individual surge drums to central Recirculators.
- Recirculators - vessels with pumps - provide sufficient liquid to evaporators.
- Recirculators may also be intercoolers.
- Heat-exchangers or large coils may still use surge drums.

SYSTEM DESIGN – DEFROST



- Coils will accumulate ice and require defrost. Methods include:
  - Air (if above freezing)
  - Electric
  - Hot gas

SYSTEM DESIGN – DEFROST – HOT GAS



- Most common defrost.
- Hot gas from compressor discharge heat coils:
- Higher temp: three-pipe
  - Defrost gas returns through suction.
- Lower temp: four-pipe.
  - Defrost liq/gas returns through separate line to high-stage suction.

OTHER DESIGN – THERMOSYPHON OIL COOLING

- Screw compressors inject oil (lubricant) with ammonia before compression.
- Oil is then separated in vessel below.
- To cool oil:
  - Vessel is suspended above compressors.
  - Liquid ammonia gravity-fed to ammonia-oil HEX at compressor.
  - Liquid converts to vapor as it cools oil.
  - Vapor returns to vessel.

IMAGE COURTESY OF: GENERAL REFRIGERATION COMPANY

OTHER DESIGN – UNDERFLOOR WARMING AND MOISTURE MANAGEMENT

- Hot gas from compressors exchanges heat with glycol.
- Glycol runs under slab to prevent ice.
- Insulation and pipe integrity is (ideally) regularly inspected.
- As needed, additional moisture-management practices are used:
  - Local exhaust
  - Localized fans
  - Dehumidification

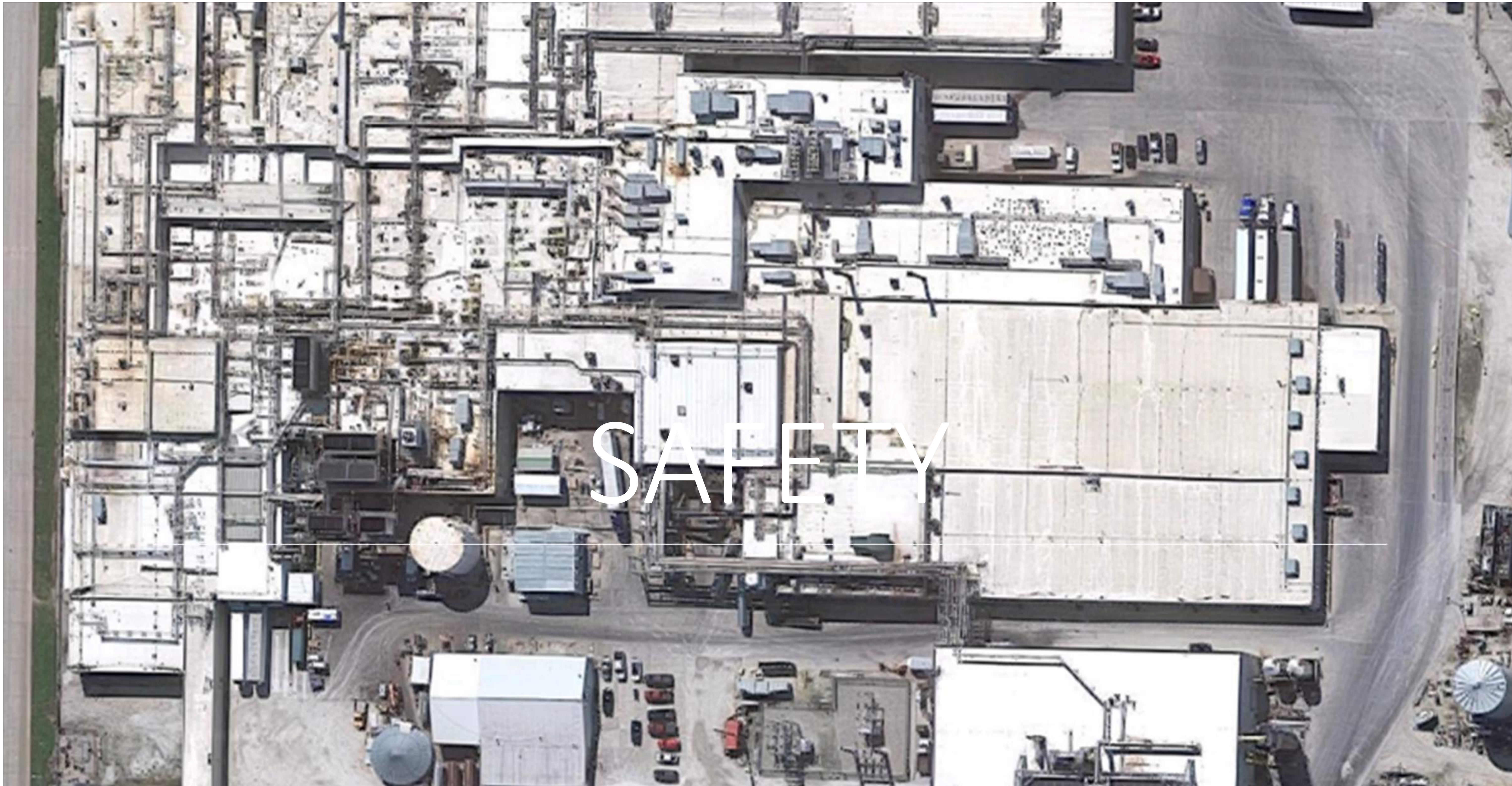
IMAGES COURTESY OF: WIKIPEDIA.ORG, BERG CHILLING SYSTEMS

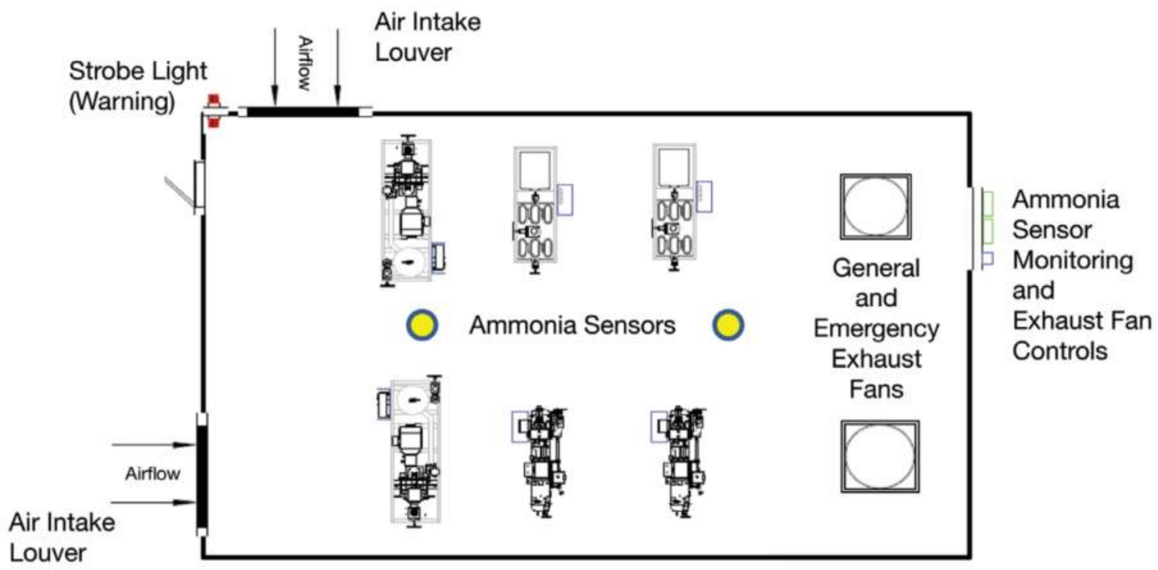
OTHER DESIGN – SKIDS

- Shop made skids - for quick install and cost savings.
  - Either as a central machine room OR
  - Distributed system (mini-machine rooms)
- Mini-machine-room skids serve separate parts of facility:
  - Refrigerant reduction.
  - Quick install.
  - Loss of redundancy.

IMAGE COURTESY OF: CLAUGER

SAFETY

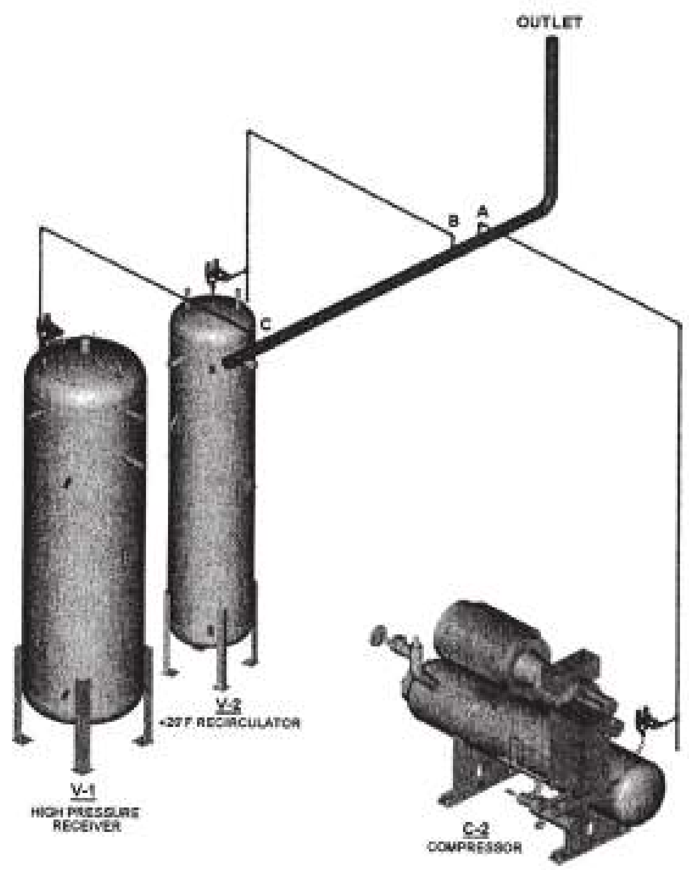




SYSTEM DESIGN - SAFETY

- Detection and Alarm – PPM Limits:
  - 25 ppm – Alarms
  - 150 ppm - Emergency Ventilation
    - Often Emergency Ventilation will start sooner
  - 40,000 ppm – System shutdown
    - For flamability
- Emergency ventilation – Low Louvers to High Upblast Exhaust Fans
  - Sweep the room

IMAGES COURTESY OF: ASHRAE REFRIGERATION HANDBOOK, GOOGLE MAPS



SYSTEM DESIGN - SAFETY

- EPCS – Emergency Pressure Control System releases pressure from higher-pressure to lower.
- Pressure Relief System – Releases pressure to the atmosphere at max vessel pressure.
  - These relief valves are tied together in a relief tree, which must be engineered for compliance.
  - Requires iterative calculation and typically software or a spreadsheet macro.

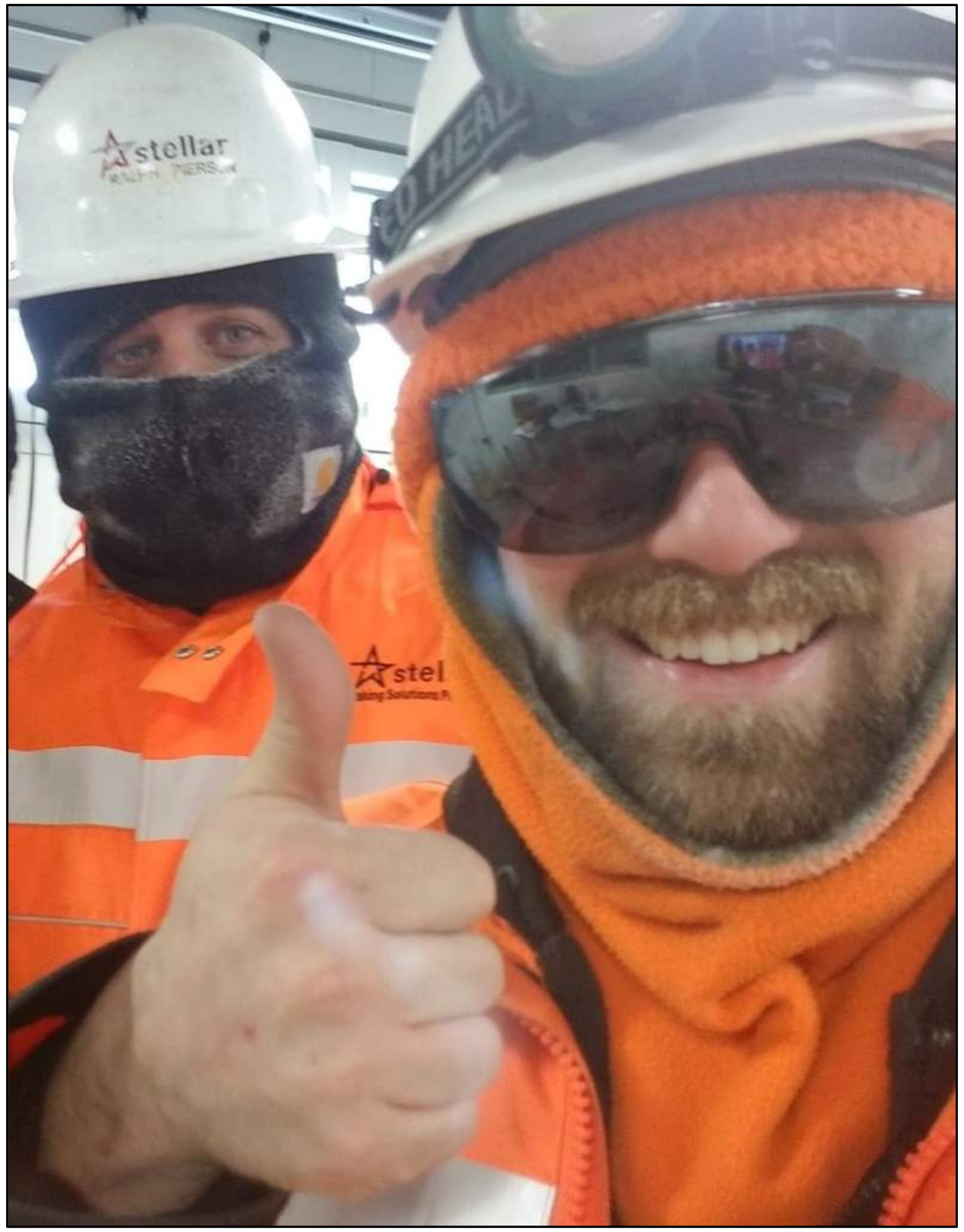
IMAGE COURTESY OF HANSEN

Personal Safety

- Use your nose – Ammonia detectable as low as ~5ppm.
- Ammonia is invisible but will create a cloud during a larger leak.
- When encountering a leak:
  - Stay calm and walk
  - Get low – Ammonia rises
  - When outside – Look for wind direction.
    - Windsocks are required at an ammonia site.
- Buddy-system when entering a cooler, freezer, or other unoccupied territory.

IMAGES COURTESY OF: WIKIMEDIA.ORG

REFRIG. ENG. EXPERIENCE



Being a Refrigeration Engineer

- My own experience:
  - 15 months as a field engineer – Pork plant start to finish.
  - Remaining time as safety-systems engineer.

- Pros and Cons often the same:
  - Multi-day site visits ~1-3 times/month coast to coast.
  - Deep knowledge of a specific field – subject matter expert fast.
  - Very engineering-focused, minimal interaction with other disciplines.

Questions?

Thank you