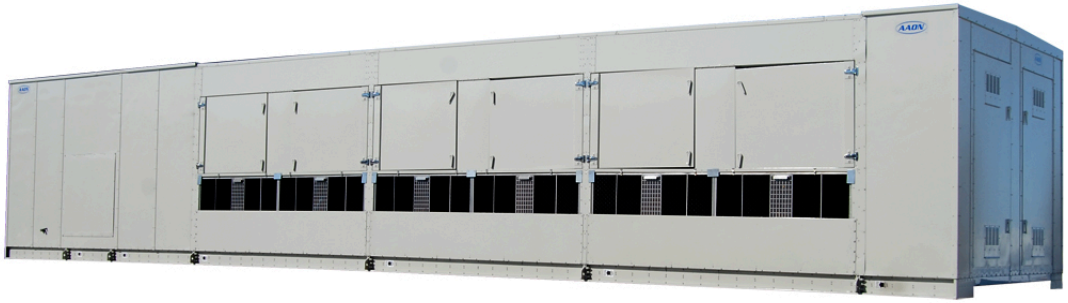
The Refrigeration Cycle

Jerry Cohen
President
Jacco & Assoc.

Agenda

- Basic Refrigerant Cycle
- P/h Chart
- Compressor Options
- Condenser Options
- Head Pressure Control
- Thermal Expansion
- Evaporator Options
- Lift
- Evaporative Condensing
- Water Treatment
- A Word From Our Sponsor



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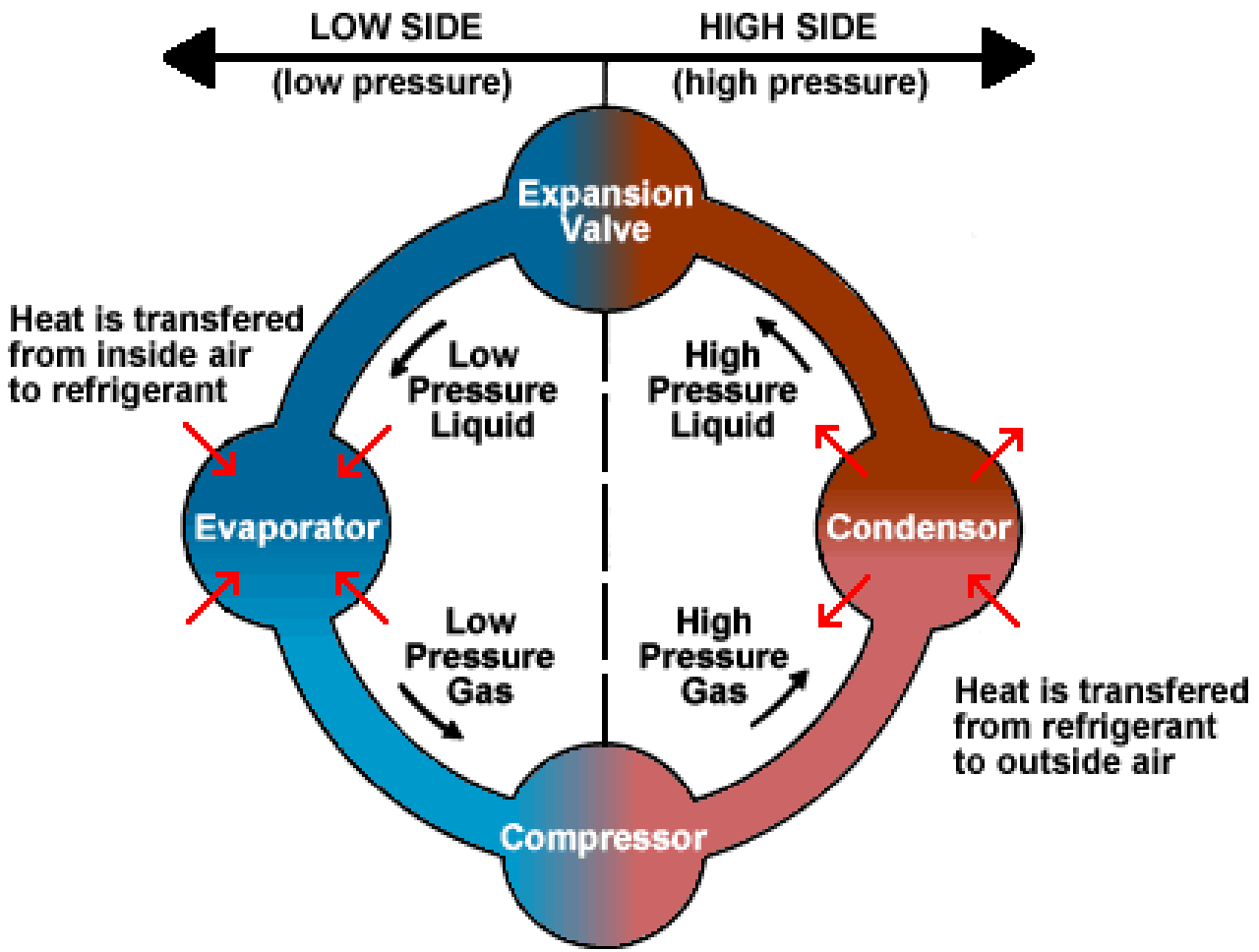
LOW SIDE
(low pressure)
HIGH SIDE
(high pressure)
Expansion Valve
Heat is transfered from inside air to refrigerant
Low Pressure Liquid
High Pressure Liquid
Evaporator
Condensor
Low Pressure Gas
High Pressure Gas
Heat is transfered from refrigerant to outside air
Compressor

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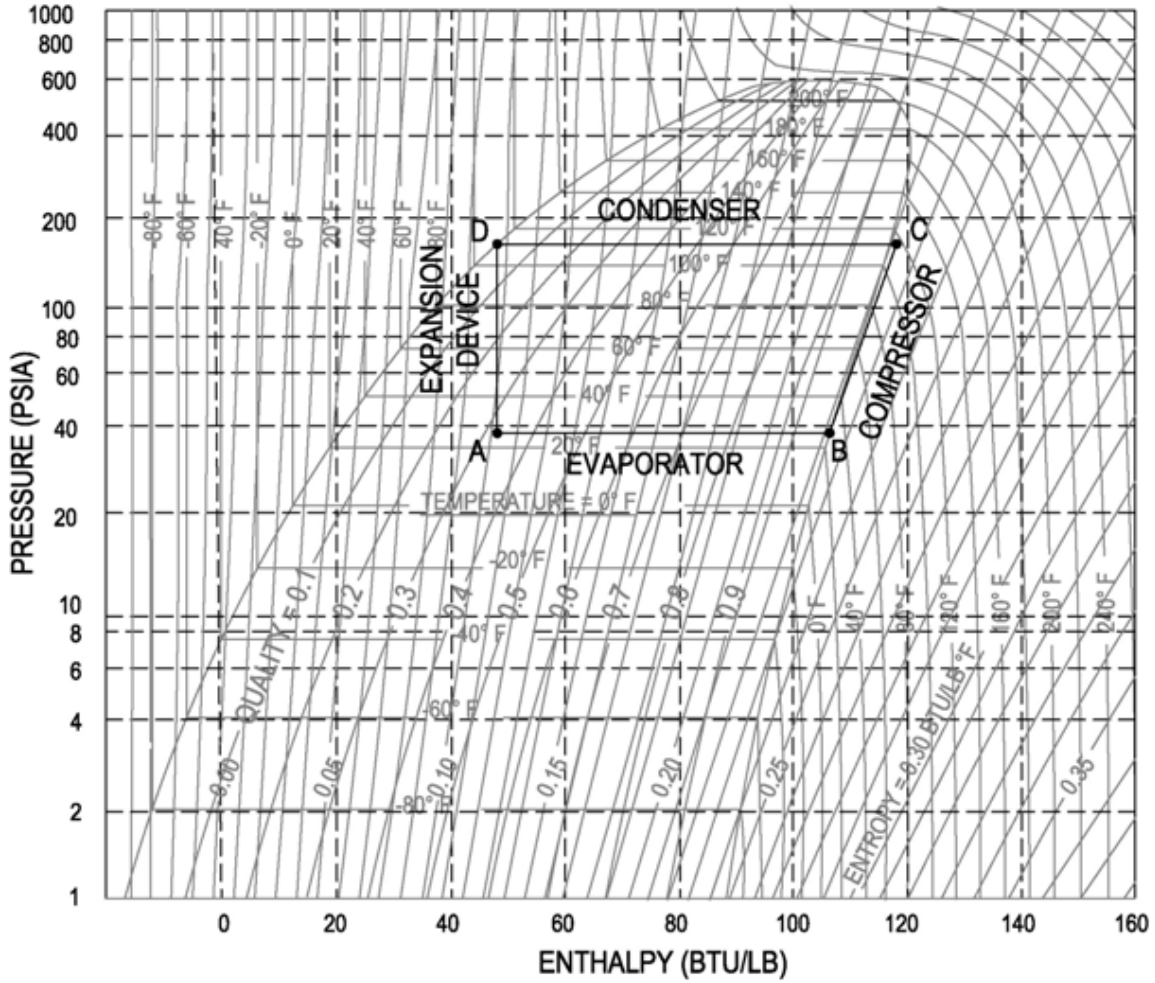
P/h Chart - Isotherm



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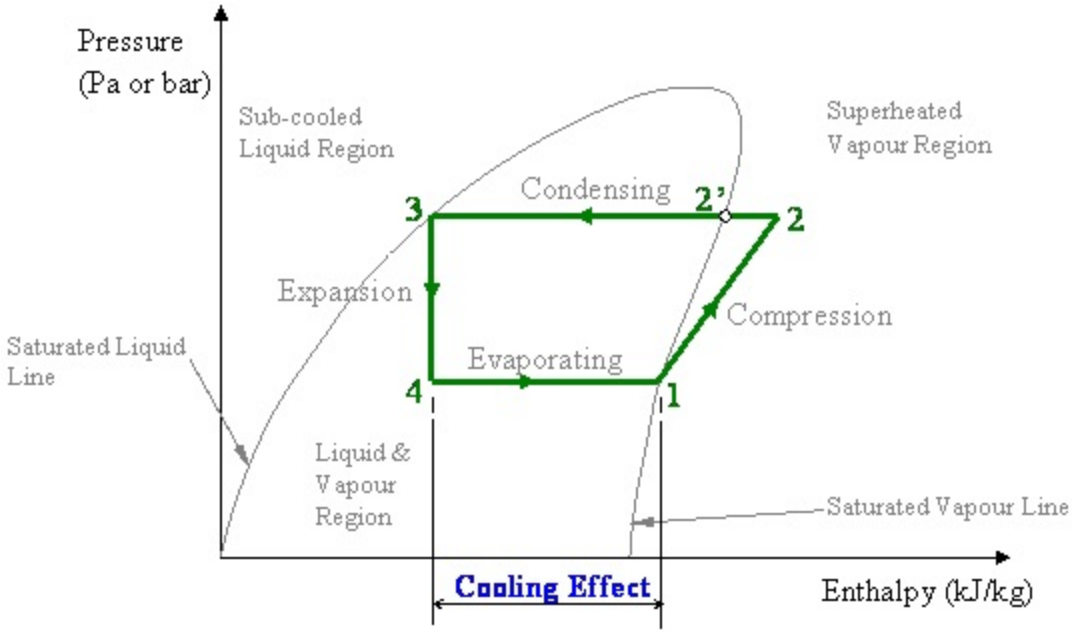
P/h Chart



p-H Diagram of Refrigeration Cycle

Superheat & Subcooling

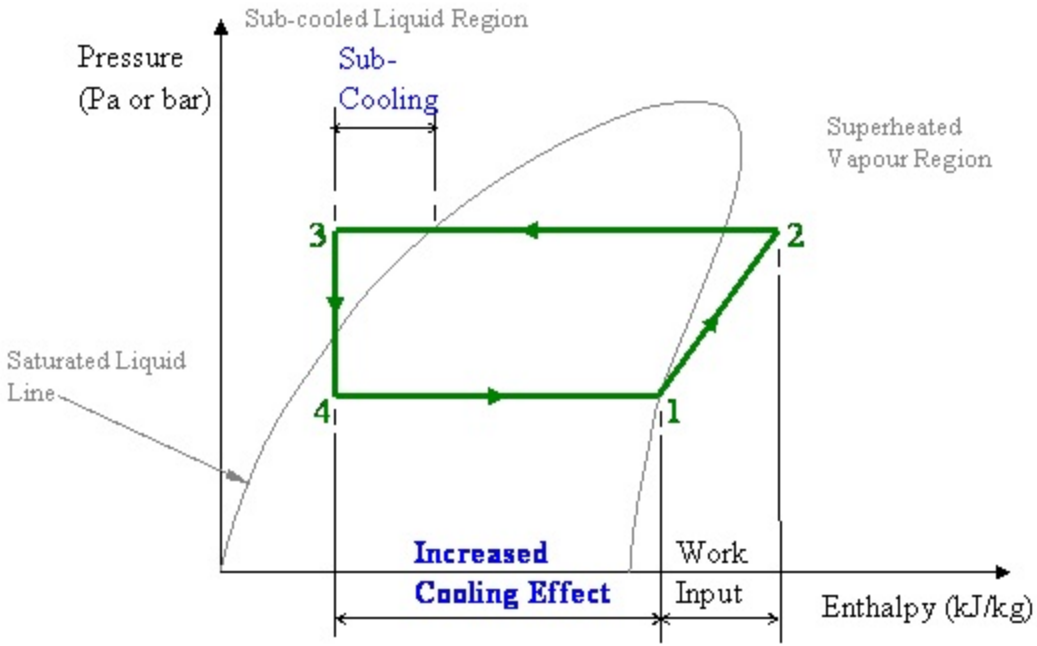
Defining Superheat
Superheat is defined as the difference between the temperature at which the refrigerant boils at the given pressure in the evaporator, and the temperature of the refrigerant gas as it leaves the evaporator. In essence, it's how much extra temperature the refrigerant picks up after it has boiled

Heating of a gas, at a constant pressure, above the point at which it has boiled.

Defining Sub-Cooling
Sub-Cooling is defined as the difference between the temperature at which the refrigerant condenses at the given pressure in the condenser, and the temperature of the liquid refrigerant gas as it leaves the condenser. In essence, it's how much extra temperature the refrigerant cools after it has condensed.

Cooling of a liquid, at a constant pressure, below the point at which it was condensed.

P/h Chart



p-H Diagram of Refrigeration Cycle with Sub-Cooling

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What is a Compressor?

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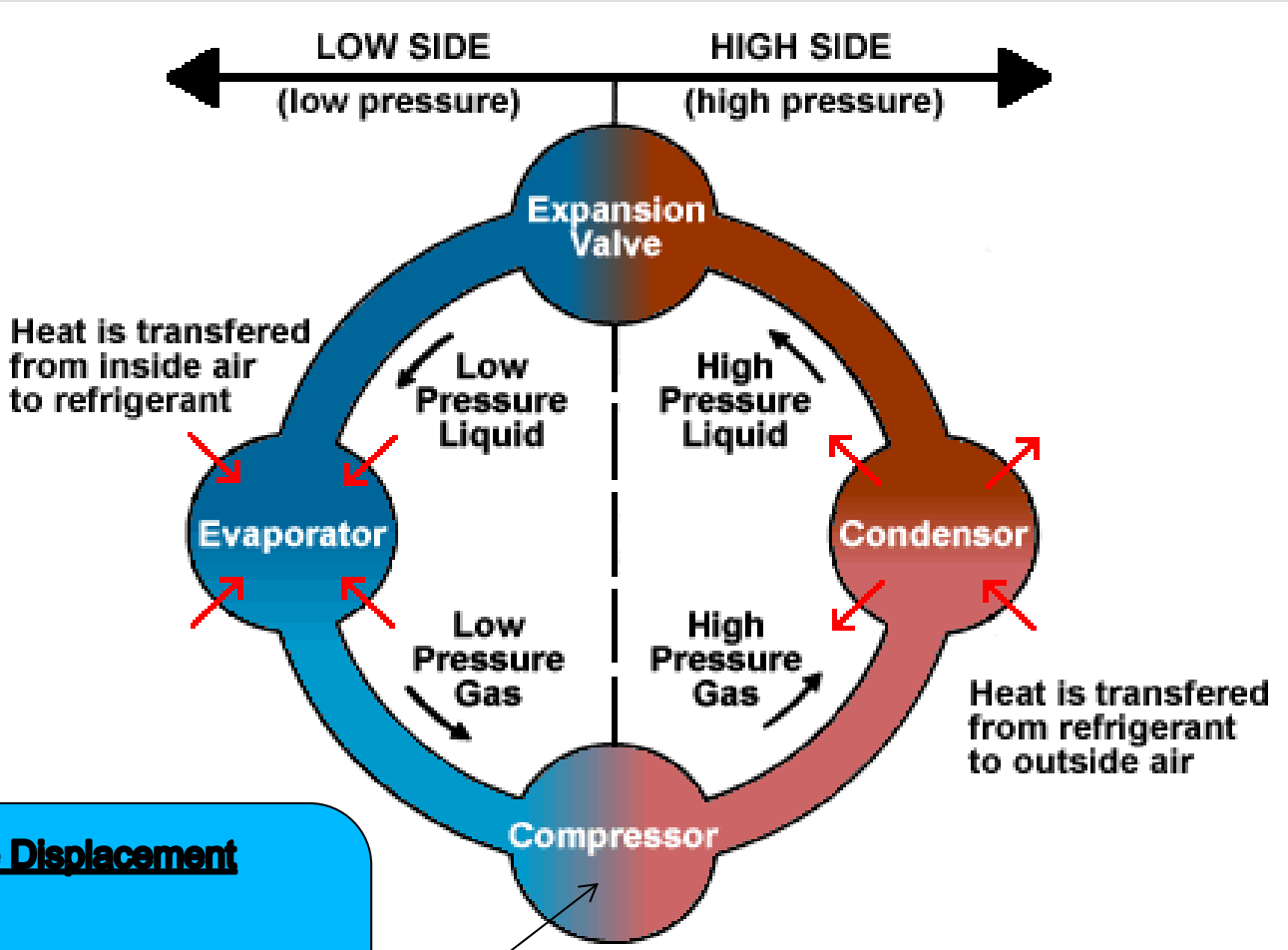

Positive Displacement
- Scroll
- Screw
- Reciprocating

Non Positive Displacement
-Centrifugal

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Scroll Compressor

- Limited to ~ 25 HP
- Tandem Compressor Options
- With or Without VFD

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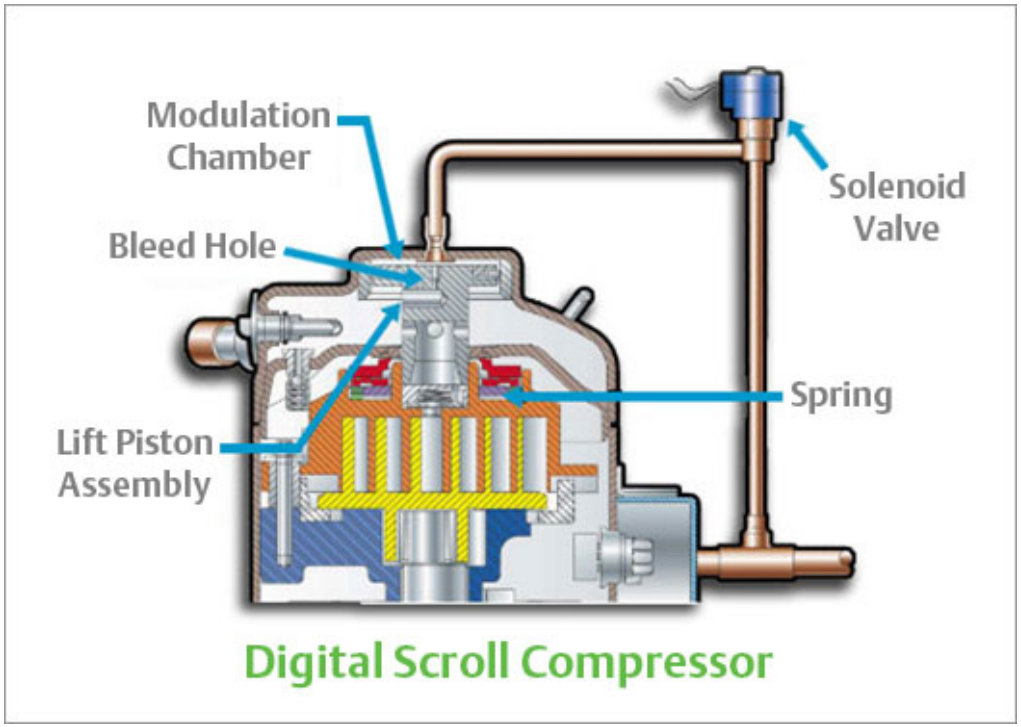
Digital Scroll Compressor

- Digital Scroll



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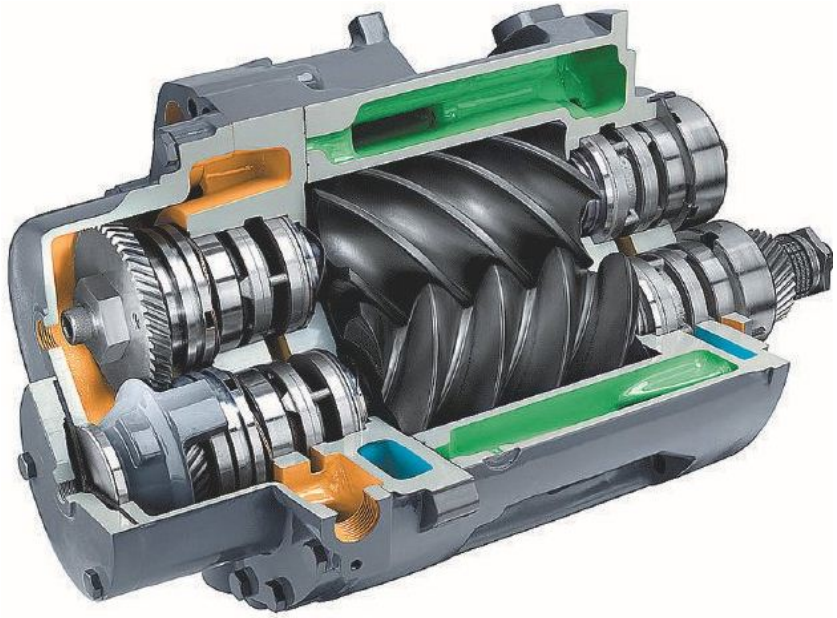
Screw Compressor

- Limited to ~ 500 HP
- With or Without VFD



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Reciprocating Compressor

- Limited to ~ 100 HP

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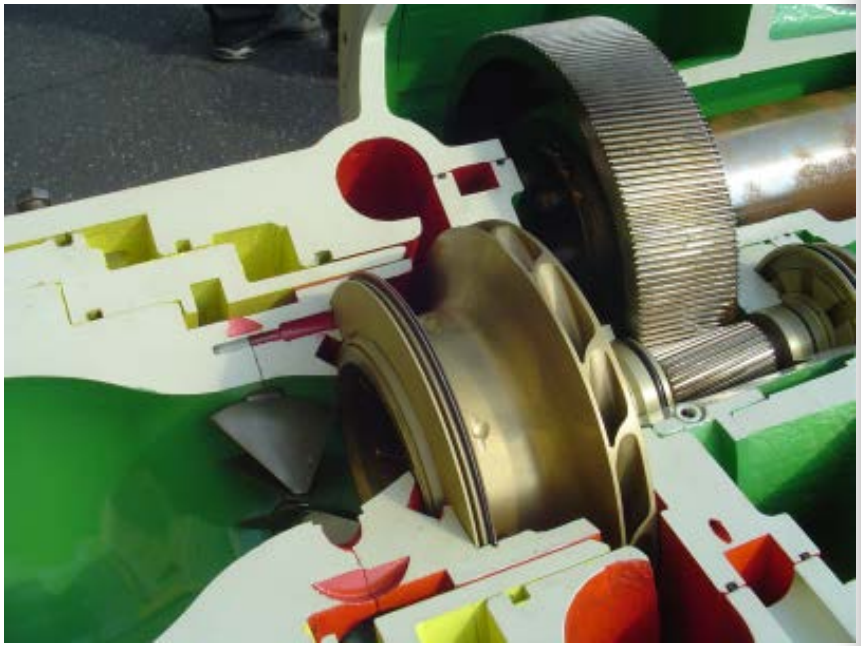
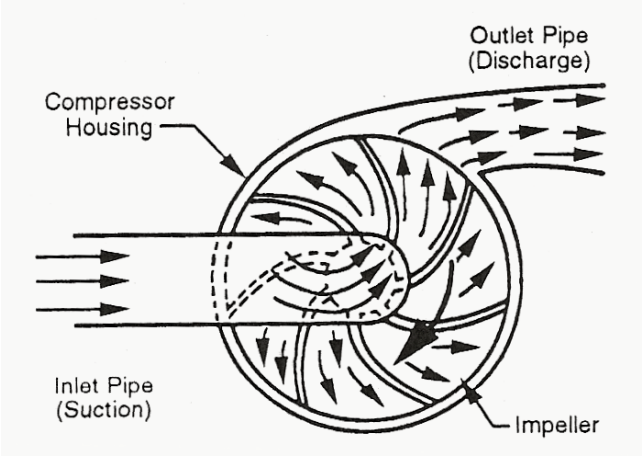
Centrifugal Compressor

- Virtually Unlimited
- With or Without VFD





Non Positive Displacement compressors raise the pressure and temperature of the refrigerant by converting kinetic energy into pressure.

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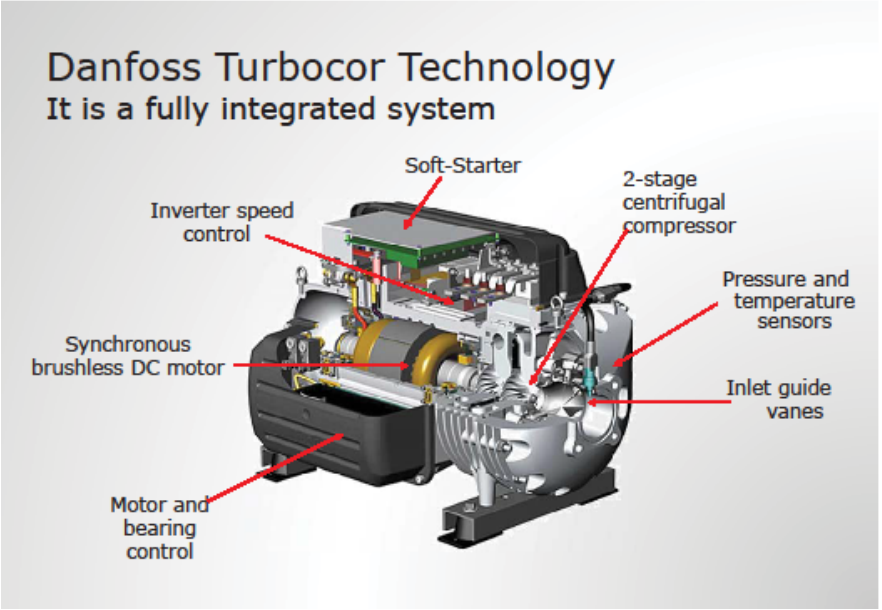
Centrifugal Compressor

- Oil Free Magnetic Bearing Centrifugal
- With VFD
- Limited to 75 & 150 HP



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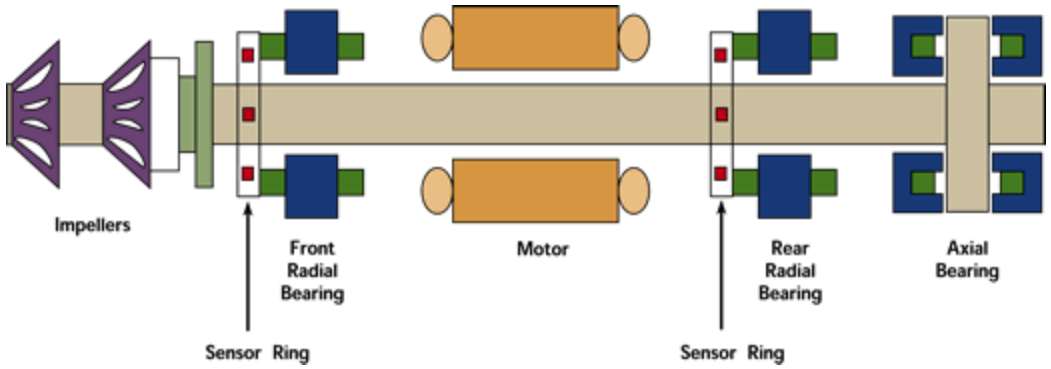
Magnetic Bearings

- Oil Free Magnetic Bearing Centrifugal
- Limited to 75 & 150 HP



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Hot Gas Bypass

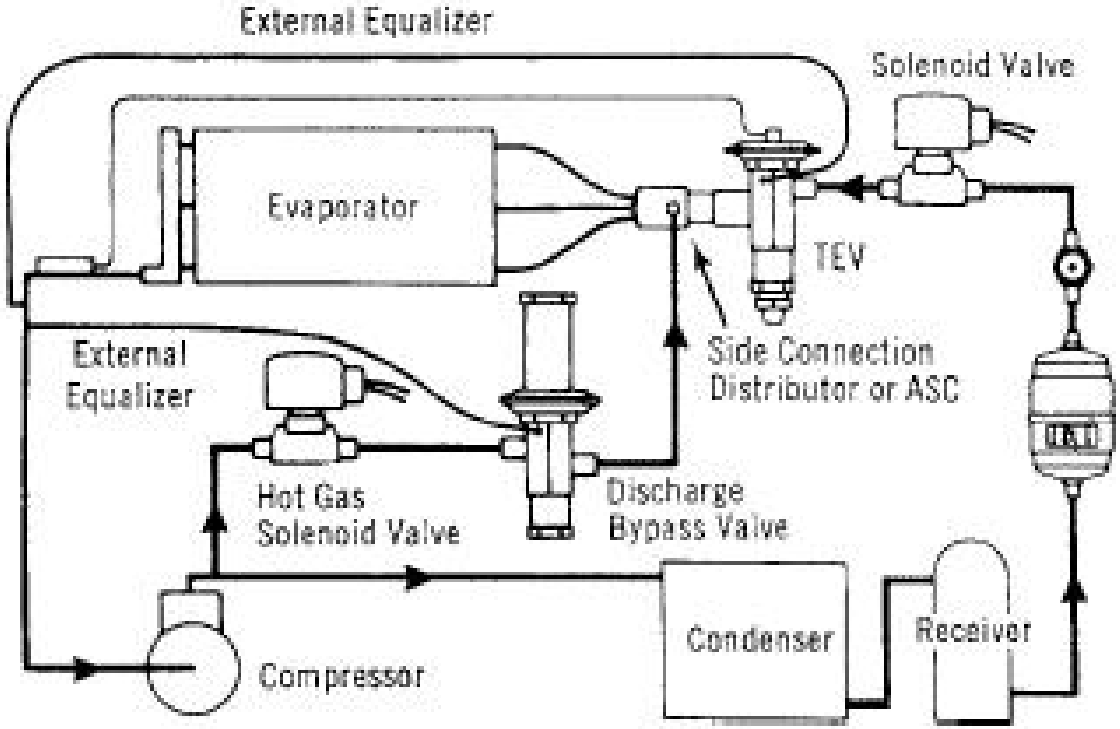
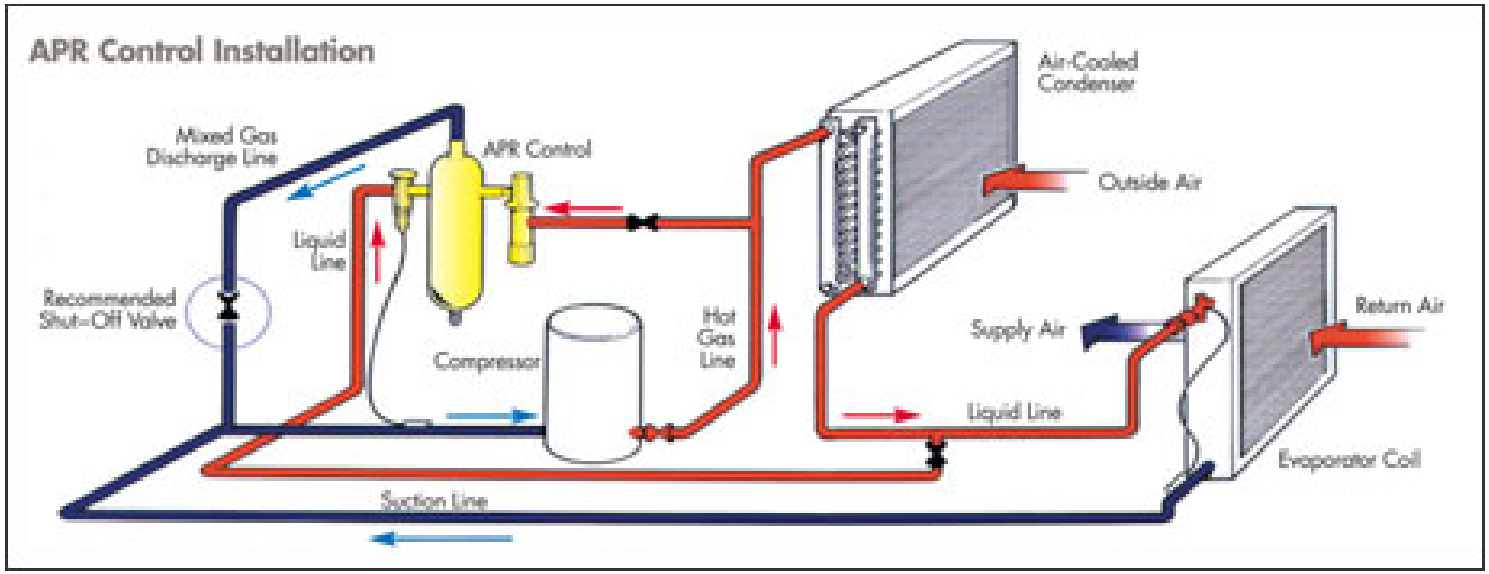
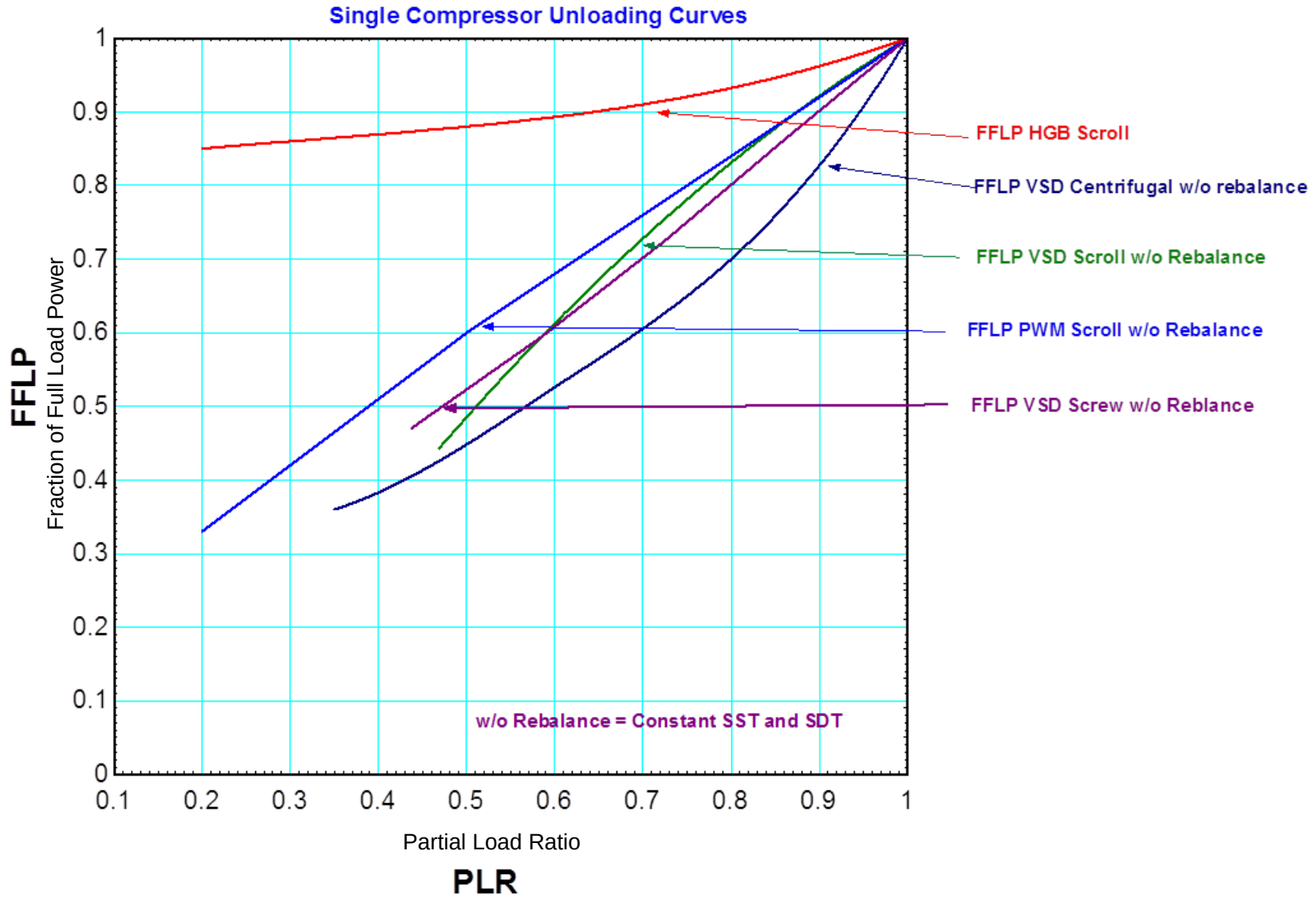


Figure 11-38 Connection arrangement for a discharge-bypass valve. (*Courtesy of Sporlan Valve.*)

Hot Gas Bypass




Single Compressor Unloading Curves
FFLP
Fraction of Full Load Power
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Partial Load Ratio
PLR
FFLP HGB Scroll
FFLP VSD Centrifugal w/o rebalance
FFLP VSD Scroll w/o Rebalance
FFLP PWM Scroll w/o Rebalance
FFLP VSD Screw w/o Reblance
w/o Rebalance = Constant SST and SDT

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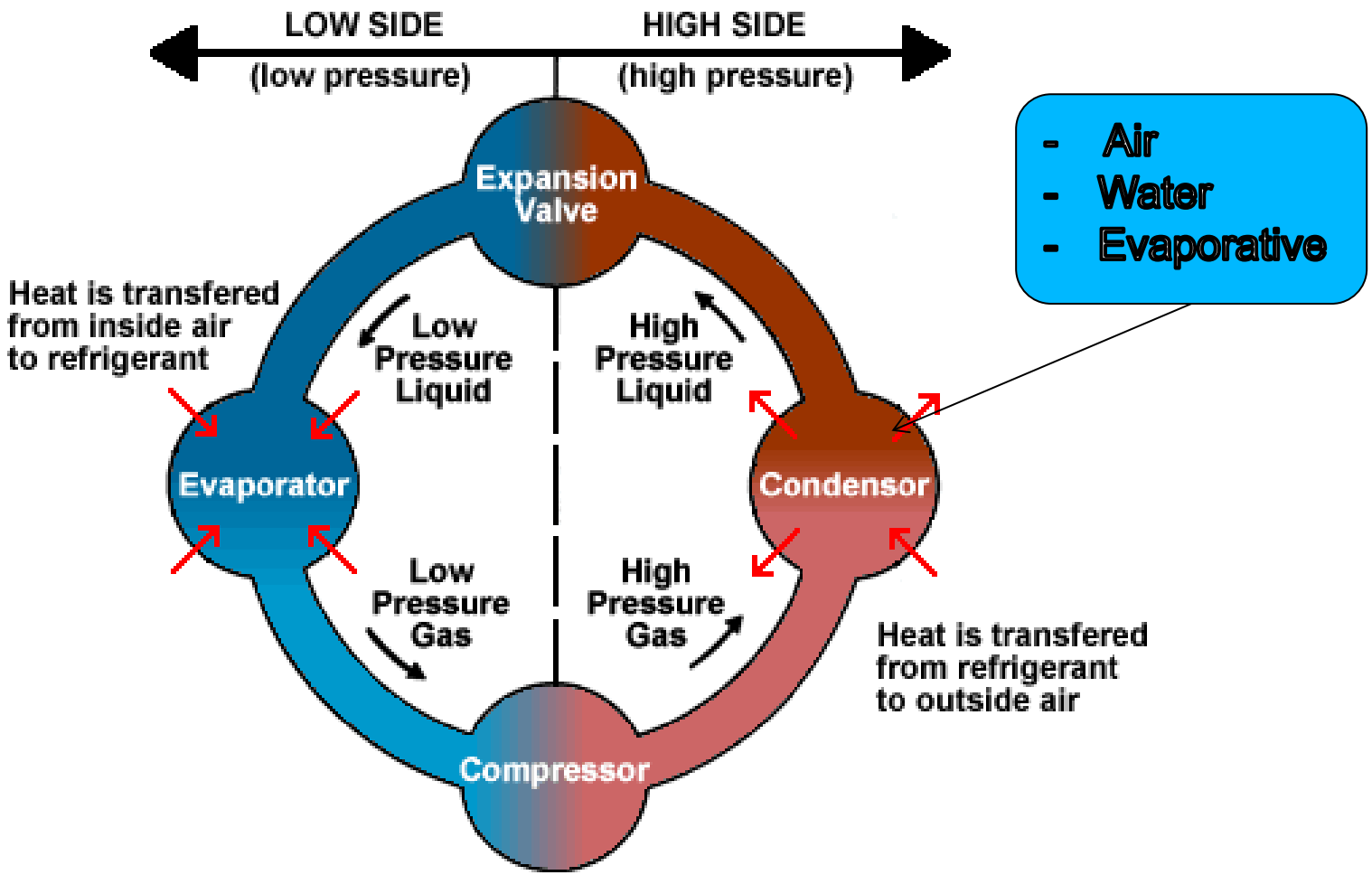
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(low pressure)
HIGH SIDE
(high pressure)
Expansion Valve
Heat is transfered from inside air to refrigerant
Low Pressure Liquid
High Pressure Liquid
Evaporator
Condensor
Low Pressure Gas
High Pressure Gas
Compressor
Heat is transfered from refrigerant to outside air
- Air
- Water
- Evaporative

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Condenser – Air Cooled

- Given 95 db/75 wb
- 125 Condensing Temperature

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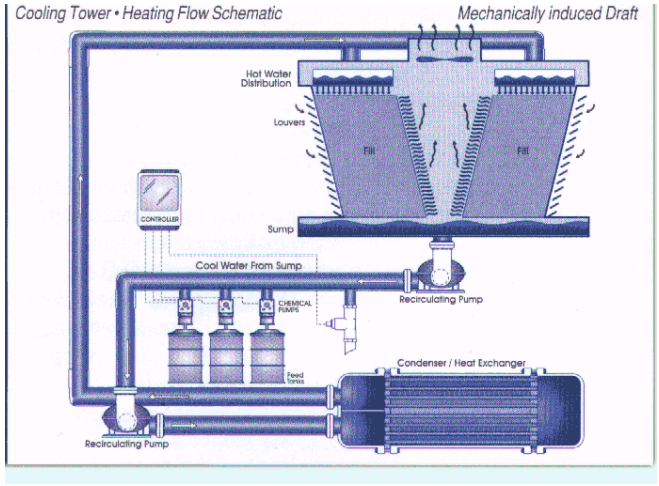
Condenser – Water Cooled

- Given 95 db/75 wb
- 105 Condensing Temperature



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Condenser – Evaporative Cooled

- Given 95 db/75 wb
- 105 Condensing Temperature

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Why Head Pressure Control

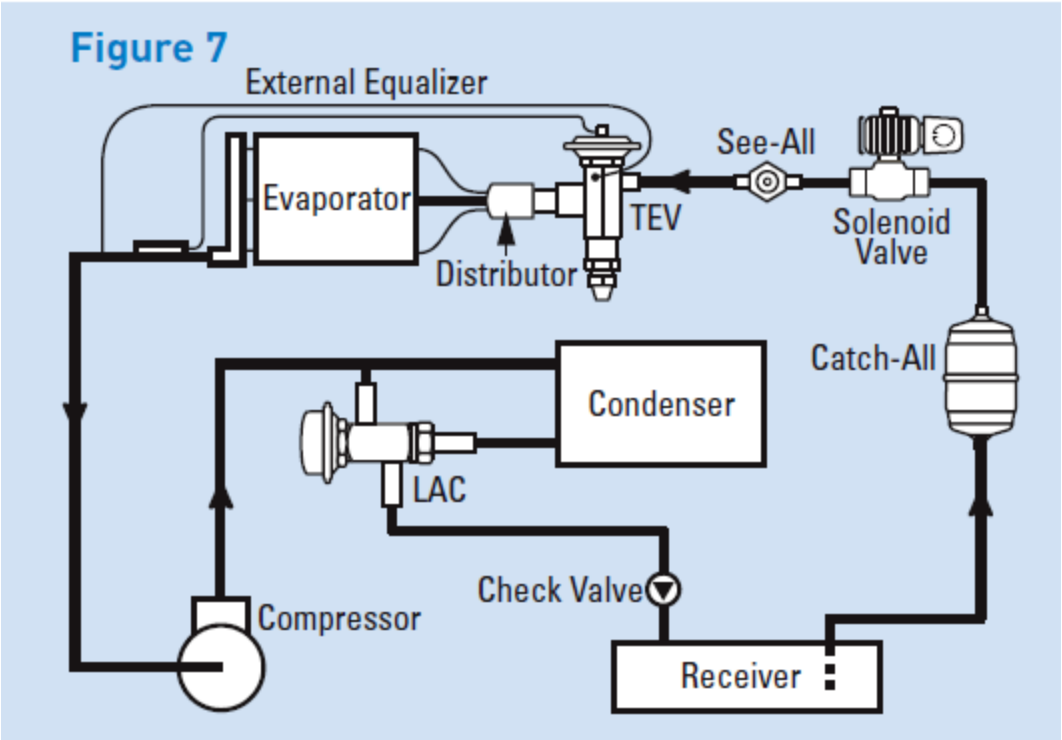
- Variable Speed Compressors
- Fluctuating Ambient Conditions
- Energy Savings
- Assure Proper TXV Operation

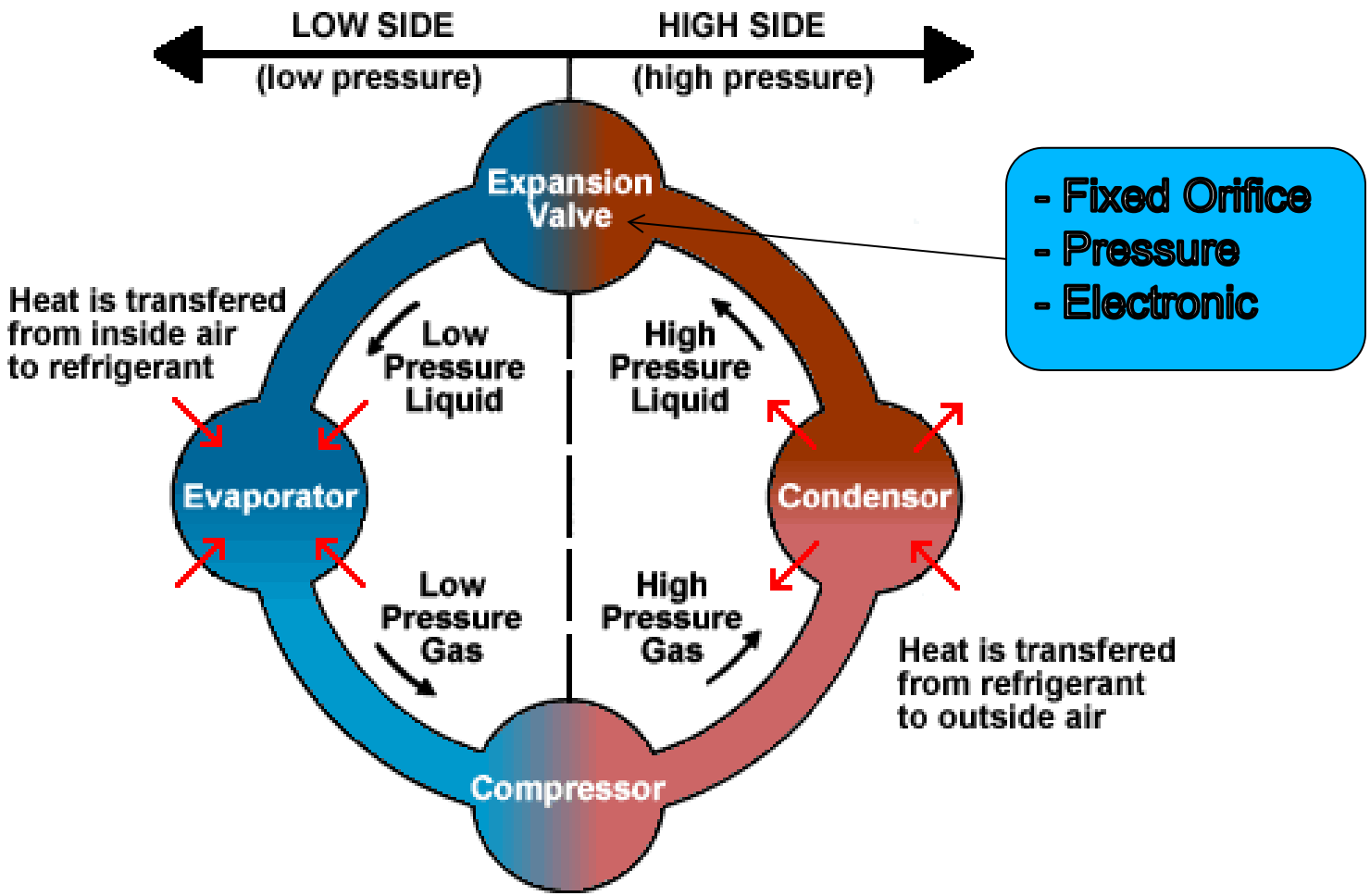
Common Head Pressure Control

- Condenser Fan Cycling
- Variable Speed Condenser Fan
  - Picture Cooling Tower w/ VFD

Low Ambient Head Pressure Control

- Flooded Condenser




LOW SIDE
(low pressure)
HIGH SIDE
(high pressure)
Expansion Valve
- Fixed Orifice
- Pressure
- Electronic
Heat is transfered from inside air to refrigerant
Low Pressure Liquid
High Pressure Liquid
Evaporator
Condensor
Low Pressure Gas
High Pressure Gas
Heat is transfered from refrigerant to outside air
Compressor

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Capillary Tube, Fixed Orifice, Thermal Expansion

- Cheap but Effective

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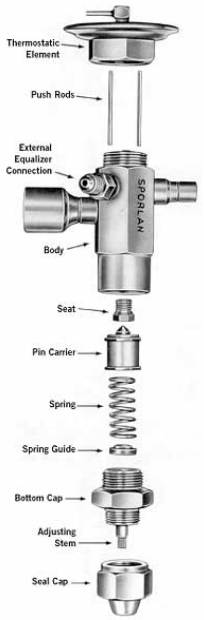
Pressure Thermal Expansion

- Old and Stable Technology



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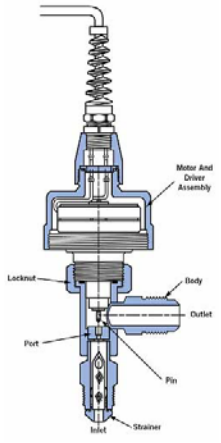
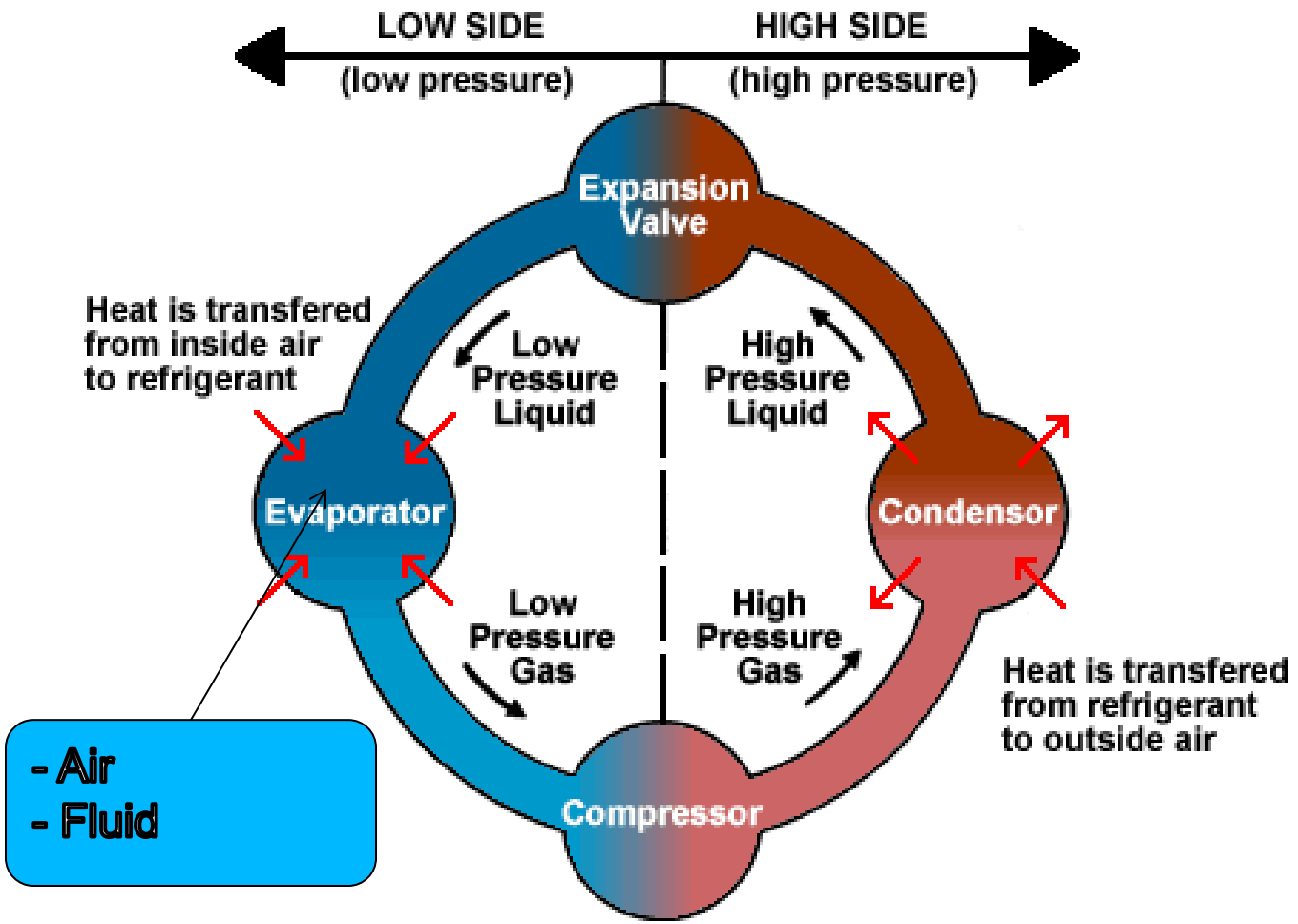
Electronic Thermal Expansion

- Very Controllable

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Low Pressure Liquid
High Pressure Liquid
Evaporator
Condensor
Low Pressure Gas
High Pressure Gas
Heat is transfered from refrigerant to outside air
Compressor
- Air
- Fluid

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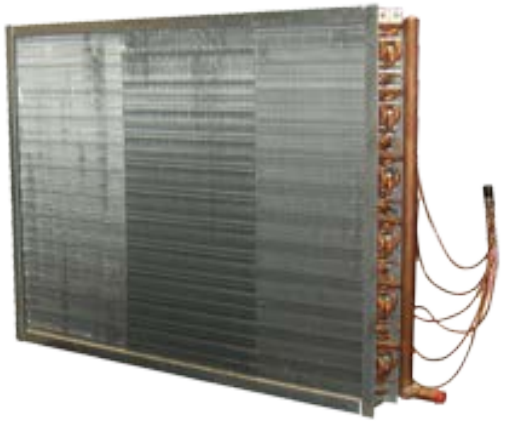
Evaporator – Air Cooled

- Given 55 Degree LAT
- 45 Degree Suction Temperature



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Evaporator – Chilled Water

- Given 55 Degree LAT
- 45 Degree Chilled Water/Glycol
- 35 Degree Suction Temperature

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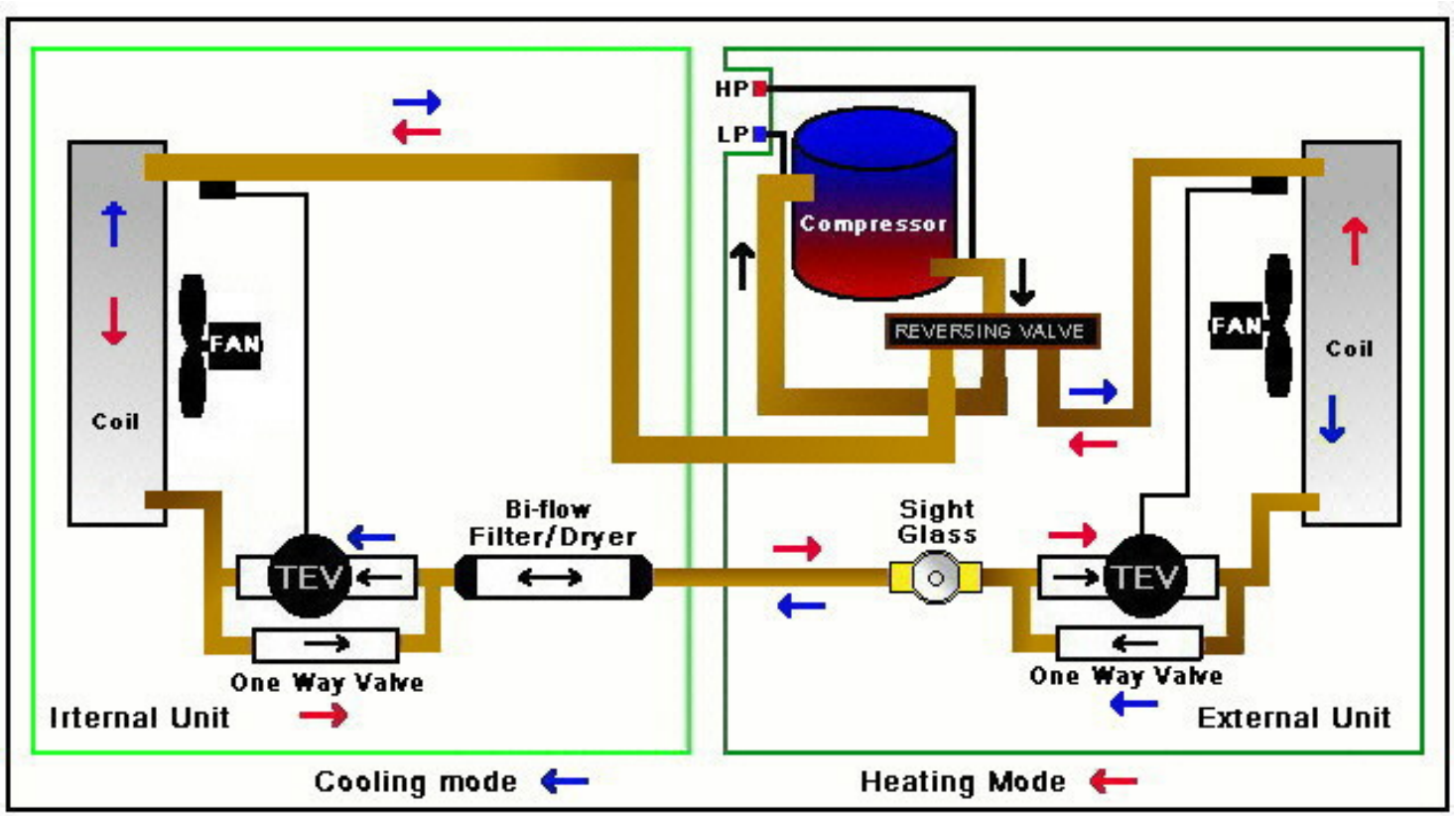
Heat Pump Refrigeration Cycle



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Pump Out vs. Pump Down

- The purpose of Pump Down and Pump Out is to minimize the effects of migration, which can result in a flooded start on the next startup.

Pump Out

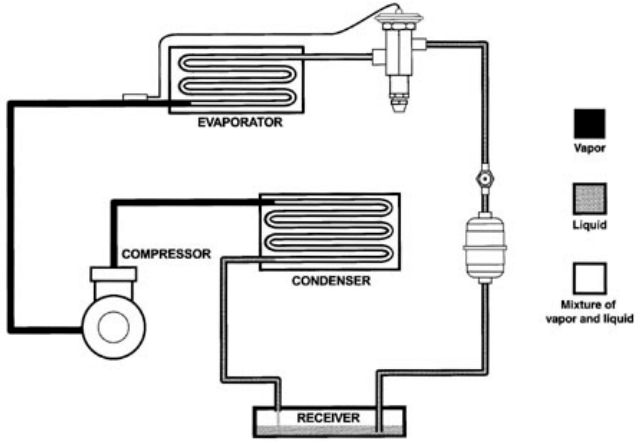
- Also known as a "one time pump out", is conducted by closing a solenoid in the liquid line while the compressor is still running, all of the refrigerant in the system downstream of the solenoid is removed. The compressor is shutdown by a low pressure control, and remains off until the next call for cooling which opens the solenoid valve and closes the contacts for the compressor. Thus the compressor pumps out the system after each running cycle, then remains off until the next call for cooling.

Pump Down

- Also known as "continuous pump down", is conducted exactly the same way as pump-out with the exception that the call for cooling ONLY controls the solenoid. Thus, during a normal running cycle, when demand is met, the solenoid is closed. The compressor pumps out all of the refrigerant downstream of the solenoid then shuts of on a low pressure control. The difference being that the compressor is allowed to restart any time the low pressure control makes, thus keeping the suction side of the system pumped down continuously. This usually comes into play if there is a leaking pump down solenoid.

Accumulators and Receivers

- A Receiver is a vessel for holding refrigerant liquefied by the condenser.
- An Accumulator is a vessel for preventing liquid slugging of the compressor.



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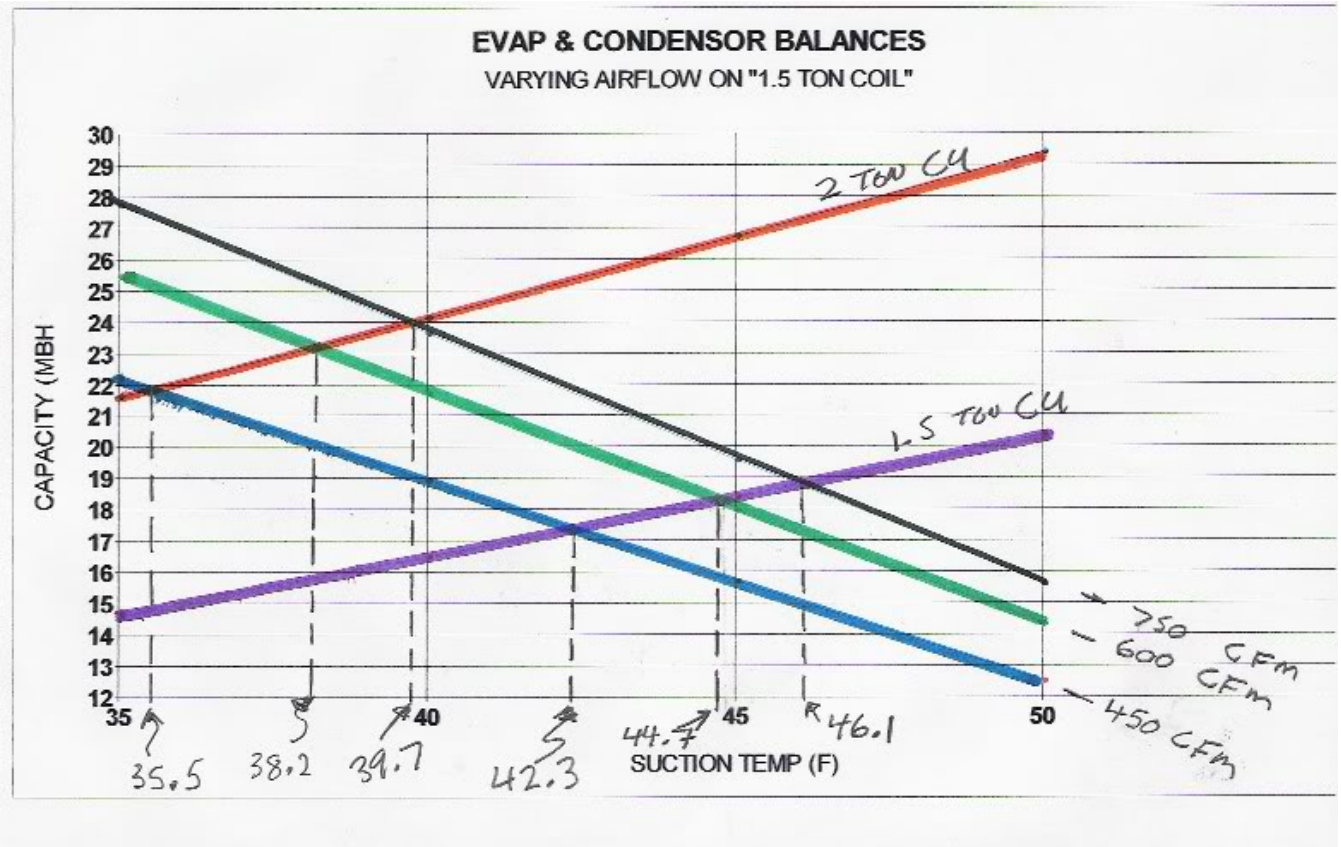
Condenser/Evaporator Balance



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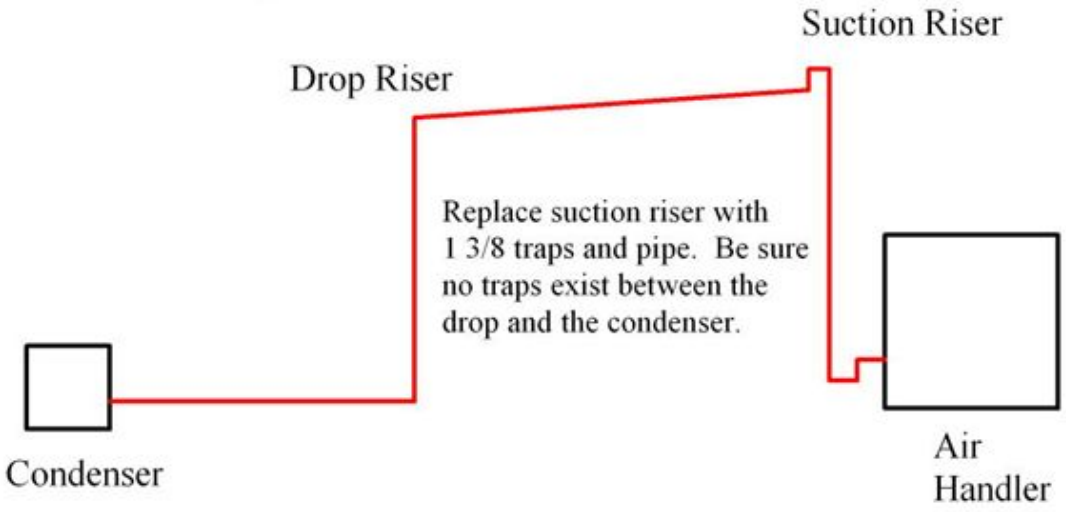
Refrigerant Field Piping

All piping must pitch from the top of the suction riser down to the condenser without any additional lifts or traps. The fall needs to be 1/8th per foot. The suction riser must be straight up with no 45's or elbows. Suction line should be 1 5/8OD. Elbows to be long radius. All existing system traps other than suction riser should be eliminated from the suction line. Liquid line can be left alone.



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Evaporative Condensing

- Water Cooled WITHOUT the Condenser Pump

The Compressor is a Pump

- Air Cooled
- 35 Suction & 125 Condensing

- Water & Evaporative Cooled
- 35 Suction & 105 Condensing

Refrigerant Pressure/Temperature Chart

HFC-134a

105 Condensing Temperature = 134.9 PSIG

HFC-410a

105 Condensing Temperature = 339.9 PSIG

HFC-134a

125 Condensing Temperature = 184.5 PSIG

HFC-410a

125 Condensing Temperature = 444.5 PSIG

Refrigerant Pressure Temperature Chart

Temperature		Refrigerant				
°F	°C	R-22	R-410a	R-407c	R-134a	R-404a
-60	-51.1	*11.9*	*0.9*	*16.0*	*21.6*	-
-55	-48.3	*9.2*	1.8	*13.7*	*20.2*	-
-50	-45.6	*6.1*	4.3	*11.1*	*18.6*	-
-45	-42.8	*2.7*	7.0	*8.1*	*16.7*	-
-40	-40.0	0.6	10.1	*4.8*	*14.7*	4.9
-35	-37.2	2.6	13.5	*1.1*	*12.3*	7.5
-30	-34.4	4.9	17.2	1.5	*9.7*	10.3
-25	-31.7	7.5	21.4	3.7	*6.8*	13.5
-20	-28.9	10.2	25.9	6.2	*3.6*	16.8
-18	-27.8	11.4	27.8	7.2	*2.2*	18.3
-16	-26.7	12.6	29.7	8.4	*0.7*	19.8
-14	-25.6	13.9	31.8	9.5	0.4	21.3
-12	-24.4	15.2	33.9	10.7	1.2	22.9
-10	-23.3	16.5	36.1	11.9	2.0	24.6
-8	-22.2	17.9	38.4	13.2	2.8	26.3
-6	-21.1	19.4	40.7	14.6	3.7	28.0
-4	-20.0	20.9	43.1	15.9	4.6	29.8
-2	-18.9	22.4	45.6	17.4	5.5	31.7
0	-17.8	24.0	48.2	18.9	6.5	33.7
1	-17.2	24.8	49.5	19.6	7.0	34.7
2	-16.7	25.7	50.9	20.4	7.5	35.7
3	-16.1	26.5	52.2	21.2	8.0	36.7
4	-15.6	27.4	53.6	22.0	8.6	37.7
5	-15.0	28.3	55.0	22.8	9.1	38.8
6	-14.4	29.1	56.4	23.7	9.7	39.8
7	-13.9	30.0	57.9	24.5	10.2	40.9
8	-13.3	31.0	59.3	25.4	10.8	42.0
9	-12.8	31.9	60.8	26.2	11.4	43.1
10	-12.2	32.8	62.3	27.1	12.0	44.3
11	-11.7	33.8	63.9	28.0	12.6	45.4
12	-11.1	34.8	65.4	29.0	13.2	46.6
13	-10.6	35.8	67.0	29.9	13.8	47.8
14	-10.0	36.8	68.6	30.9	14.4	49.0
15	-9.4	37.8	70.2	31.8	15.1	50.2
16	-8.9	38.8	71.9	32.8	15.7	51.5
17	-8.3	39.9	73.5	33.8	16.4	52.7
18	-7.8	40.9	75.2	34.8	17.1	54.0
19	-7.2	42.0	77.0	35.9	17.7	55.3
20	-6.7	43.1	78.7	36.9	18.4	56.6
21	-6.1	44.2	80.5	38.0	19.2	57.9
22	-5.6	45.3	82.3	39.1	19.9	59.3
23	-5.0	46.5	84.1	40.2	20.6	60.6
24	-4.4	47.6	85.9	41.3	21.4	62.0
25	-3.9	48.8	87.8	42.4	22.1	63.4
26	-3.3	50.0	89.7	43.6	22.9	64.8
27	-2.8	51.2	91.6	44.7	23.7	66.2
28	-2.2	52.4	93.5	45.9	24.5	67.7
29	-1.7	53.7	95.5	47.1	25.3	69.2
30	-1.1	54.9	97.5	48.4	26.1	70.7
31	-0.6	56.2	99.5	49.6	26.9	72.1
32	0.0	57.5	101.6	50.9	27.8	73.8
33	0.6	58.8	103.6	52.1	28.6	75.3
34	1.1	60.2	105.7	53.4	29.5	76.9
35	1.7	61.5	107.9	54.8	30.4	78.5
36	2.2	62.9	110.0	56.1	31.3	80.2
37	2.8	64.3	112.2	57.5	32.2	81.7
38	3.3	65.7	114.4	58.9	33.1	83.5
39	3.9	67.1	116.7	60.3	34.1	85.2
40	4.4	68.6	118.9	61.7	35.0	86.9
41	5.0	70.0	121.2	63.1	36.0	88.6
42	5.6	71.5	123.6	64.6	37.0	90.4
43	6.1	73.0	125.9	66.1	38.0	92.2
44	6.7	74.5	128.3	67.6	39.0	94.0
45	7.2	76.1	130.7	69.1	40.0	95.8
46	7.8	77.6	133.2	70.6	41.1	97.6
47	8.3	79.2	135.6	72.2	42.2	99.5
48	8.9	80.8	138.2	73.8	43.2	101.4
49	9.4	82.4	140.7	75.4	44.3	103.3
50	10.0	84.1	143.3	77.1	45.4	105.3
55	12.8	92.6	156.6	106.0	51.2	115.3
60	15.6	101.6	170.7	116.2	57.4	126.0
65	18.3	111.3	185.7	127.0	64.0	137.4
70	21.1	121.5	201.5	138.5	71.1	149.3
75	23.9	132.2	218.2	150.6	78.6	161.9
80	26.7	143.7	235.9	163.5	86.7	175.4
85	29.4	155.7	254.6	177.0	95.2	189.6
90	32.2	168.4	274.3	191.3	104.3	204.5
95	35.0	181.9	295.0	206.4	113.9	220.2
100	37.8	196.0	316.9	222.3	124.1	236.8
105	40.6	210.8	339.9	239.0	134.9	254.2
110	43.3	226.4	364.1	256.5	146.3	272.5
115	46.1	242.8	289.6	274.9	158.4	291.9
120	48.9	260.0	416.4	294.2	171.1	312.1
125	51.7	278.1	444.5	314.5	184.5	333.4
130	54.4	297.0	474.0	335.7	198.7	355.6
135	57.2	316.7	505.0	357.8	213.5	379.1
140	60.0	337.4	537.6	380.9	229.2	403.7
145	62.8	359.1	571.7	405.1	245.6	429.6
150	65.6	381.7	607.6	430.3	262.8	456.8
155	68.3	405.4	645.2	456.6	281.0	484.8

Italics indicates vacuum (inches of mercury) Standard font indicates pressure (pounds per inch gauge)

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TurboCor Oil Free Magnetic Bearing Compressor

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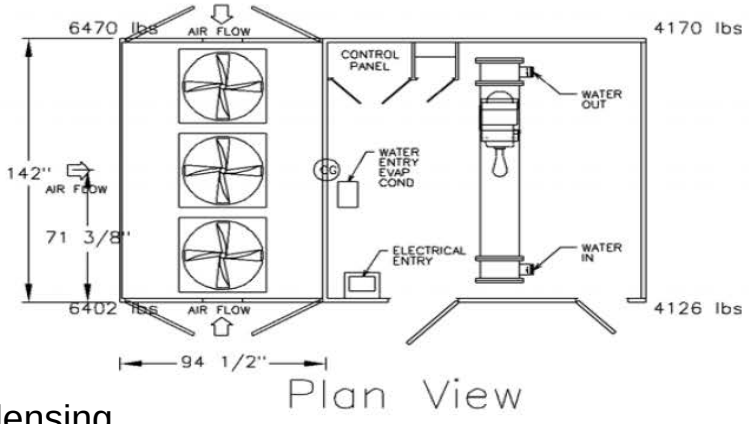
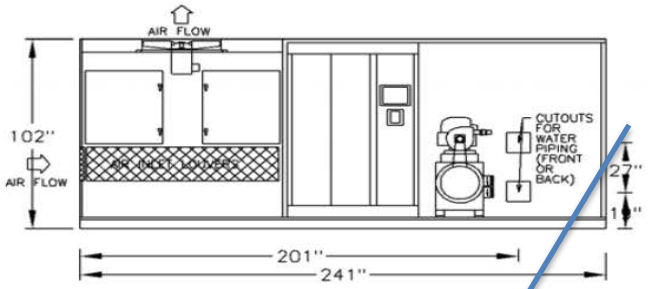
120 Ton Unit Ratings



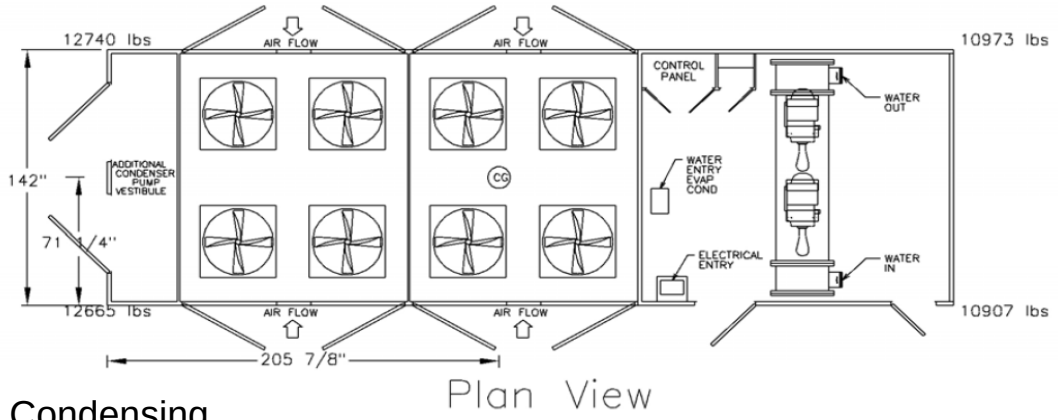
Plan View

120 ton Evaporative Condensing Chiller with Oil Free Centrifugal Compressor



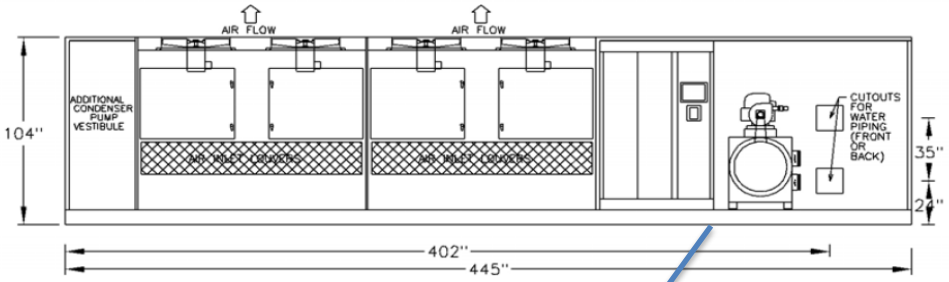
% Full Load x Comp Qty	Tons	Unit kW	Comp kW	Cond kW	Unit EER / kW/Ton	Comp kW/Ton	DB / WB	GPM	EWT	LWT
100% x 1	120.45	90.98	81.51	9.47	15.89 / 0.76	0.68	95.0 / 75.0	288.00	54.00	44.00
75% x 1	90.33	53.95	44.48	9.48	20.09 / 0.60	0.49	88.8 / 68.8	288.00	51.50	44.00
50% x 1	60.22	31.14	21.67	9.48	23.20 / 0.52	0.36	82.5 / 62.5	288.00	49.00	44.00
25% x 1	30.11	15.19	12.68	2.50	23.79 / 0.50	0.42	76.2 / 56.2	288.00	46.50	44.00

300 Ton Unit Ratings



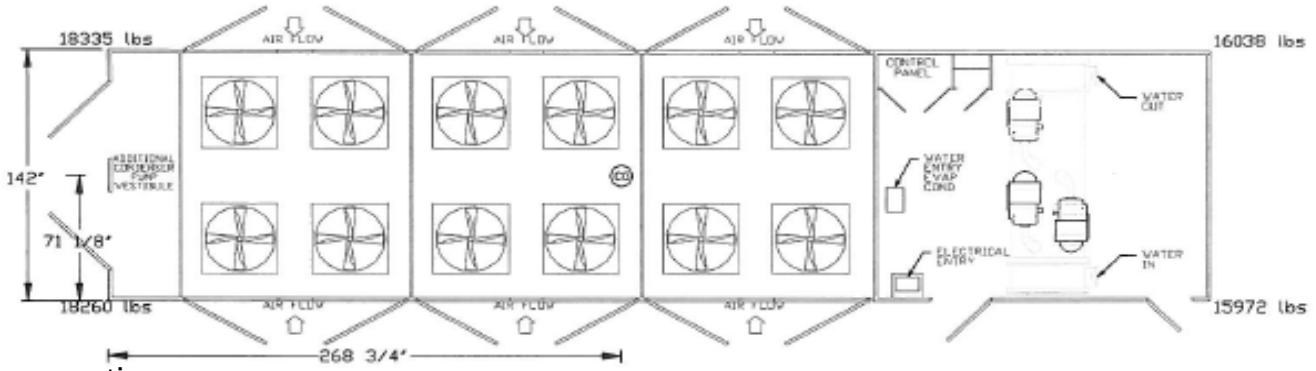
Plan View

300 ton Evaporative Condensing Chiller with Oil Free Centrifugal Compressor

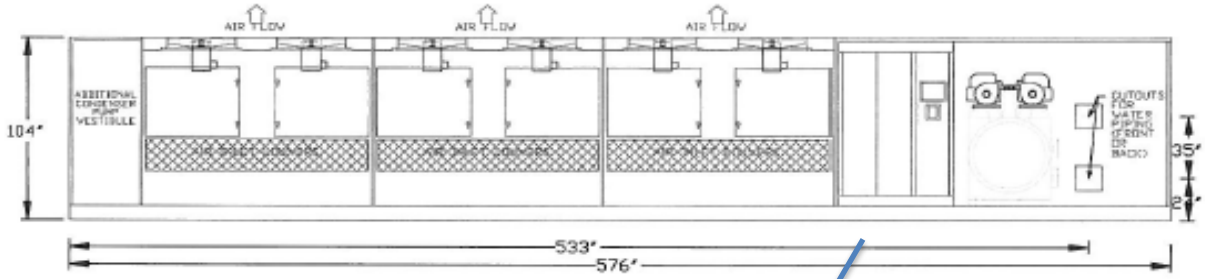


% Full Load x Comp Qty	Tons	Unit kW	Comp kW	Cond kW	Unit EER / kW/Ton	Comp kW/Ton	DB / WB	GPM	EWT	LWT
100% x 2	280.37	199.27	175.60	23.67	16.88 / 0.71	0.63	95.0 / 75.0	670.40	54.00	44.00
75% x 2	210.28	121.97	98.29	23.67	20.69 / 0.58	0.47	88.8 / 68.8	670.40	51.50	44.00
50% x 2	140.19	64.42	49.17	15.25	26.11 / 0.46	0.35	82.5 / 62.5	670.40	49.00	44.00
25% x 1	70.09	36.00	31.03	4.97	23.37 / 0.51	0.44	76.2 / 56.2	670.40	46.50	44.00

540 Ton Unit Ratings



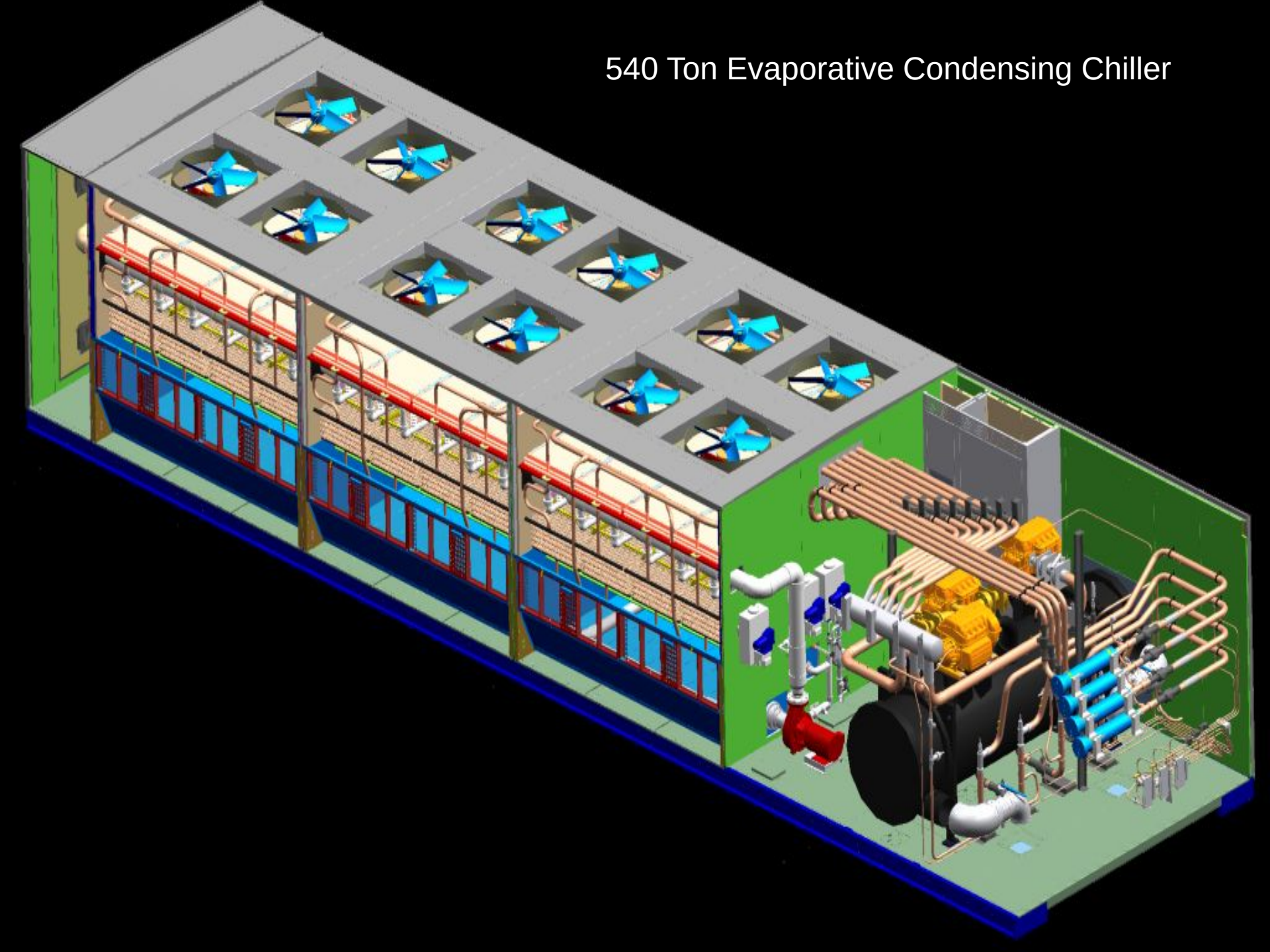
540 ton Evaporative Condensing Chiller with Oil Free Centrifugal Compressor



Compressor IPLV = .42 kW/ton
Unit IPLV = .55 kW/ton

% Full Load x Comp Qty	Tons	Unit kW	Comp kW	Cond kW	Unit EER / kW/Ton	Comp kW/Ton	DB / WB	GPM	EWT	LWT
100% x 3	540.00	378.23	335.76	42.47	17.13 / 0.70	0.62	95.0 / 75.0	1296.00	54.00	44.00
75% x 3	405.00	241.59	199.12	42.47	20.12 / 0.60	0.49	88.8 / 68.8	1296.00	51.50	44.00
50% x 3	270.00	141.50	99.02	42.47	22.90 / 0.52	0.37	82.5 / 62.5	1296.00	49.00	44.00
25% x 2	135.00	66.44	51.96	14.49	24.38 / 0.49	0.38	76.2 / 56.2	1296.00	46.50	44.00

540 Ton Evaporative Condensing Chiller



Aaon Evaporative Condensing Chiller

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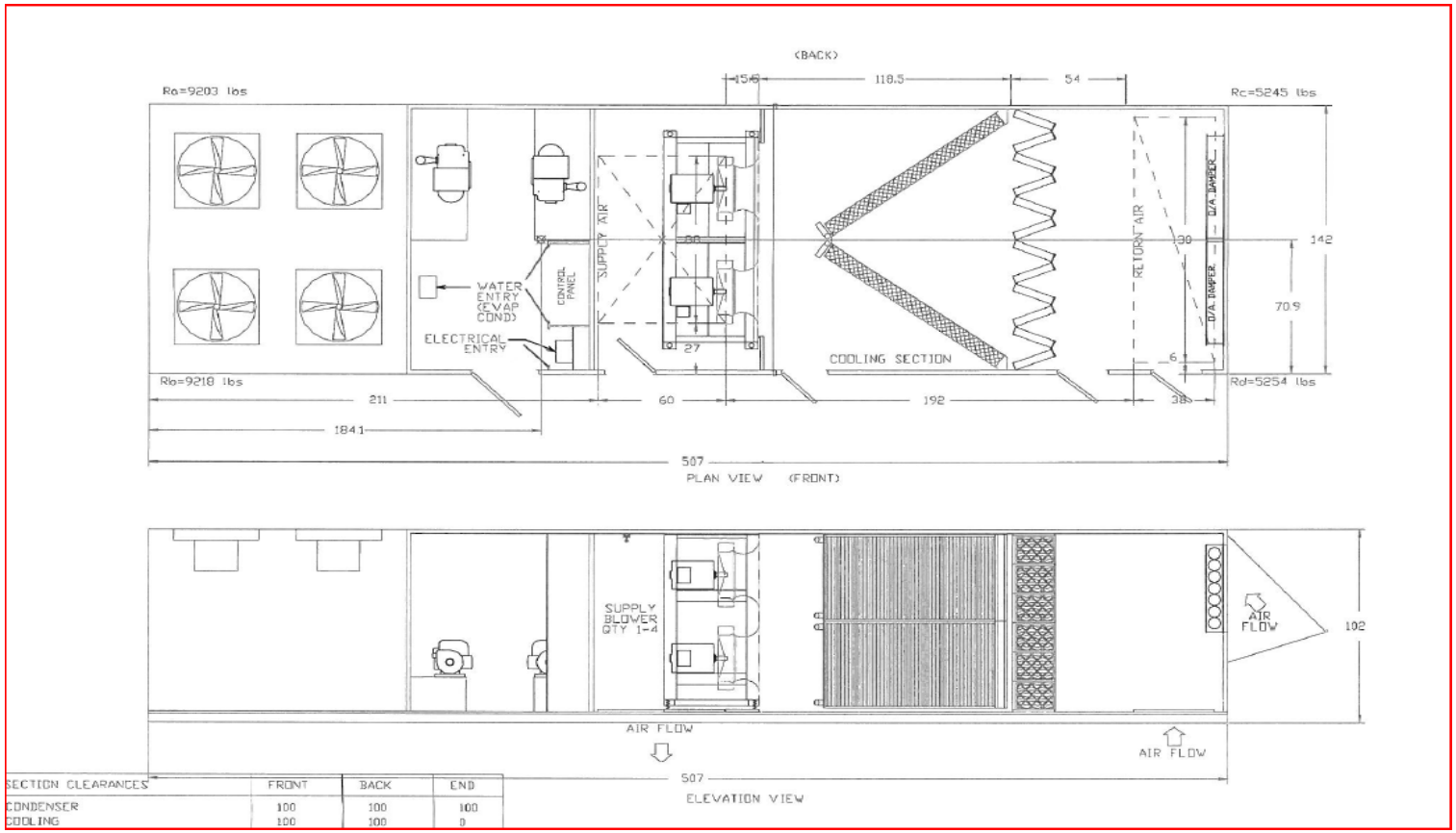
Aaon Rooftops w/ Oil Free Magnetic Bearing Centrifugal Compressors - from 90-300 Tons



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Evaporative Condensing

- Water Treatment similar to…but…however…

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Water Treatment

- As recirculated water evaporates in an evaporative condenser, the dissolved solids in the makeup water continually increase as more water is added. Continued concentration of these dissolved solids can lead to scaling and/or corrosion problems.
- In addition, airborne impurities and biological contaminants are often introduced into recirculated water. If these impurities are not controlled, they can cause sludge or biological fouling. Simple blowdown (discharging a small portion of the recirculating water to a drain) may be adequate to control scale and corrosion on sites with good-quality makeup water, but it does not control biological contaminants such as *Legionella*.

Langelier Saturation Index (LSI)

- The potential for scaling is calculated using the Langelier Saturation Index (LSI). This is a calculated parameter to predict the calcium carbonate stability of water using pH as the main variable.

Langelier Index	Description	General Recommendation	Risk
-5	Severe Corrosion	Treatment Essential	Plumbing Annihilation
-4	Severe Corrosion	Treatment Essential	Plumbing Annihilation
-3	Moderate Corrosion	Treatment Recommended	Long-term Pipe Death
-2	Moderate Corrosion	Treatment Recommended	Possible Trouble
-1	Milder Corrosion	Treatment May Be Needed	The Long Finger ?
-0.5	Milder Corrosion	Treatment May Not Be Req.	Hope All Goes Well
-0.3	None Mild Corrosion	Probably No Treatment	Looking Good
0	Near Balanced	No Treatment	Just right
0.3	Some Faint Coating	Probably No Treatment	Looking Good
0.5	Some Mild Coating	Treatment May Not Be Needed	Hope All Goes Well
1	Mild Scale Coating	Treatment May Be Needed	The Long Finger ?
2	Moderate Coating	Treatment May Be Needed	Possible Trouble
3	Moderate Coating	Treatment Advisable	Long-term Pipe Death
4	High Scale Coating	Treatment Very Advisable	Plumbing Annihilation

Traditional Evaporative Condenser

Langelier Saturation Calculator

Langelier Saturation Index Calculator

T = 160.0 [F] 71.1 [C]

pH = 7.100

TDS = 660.0 [mg/L]

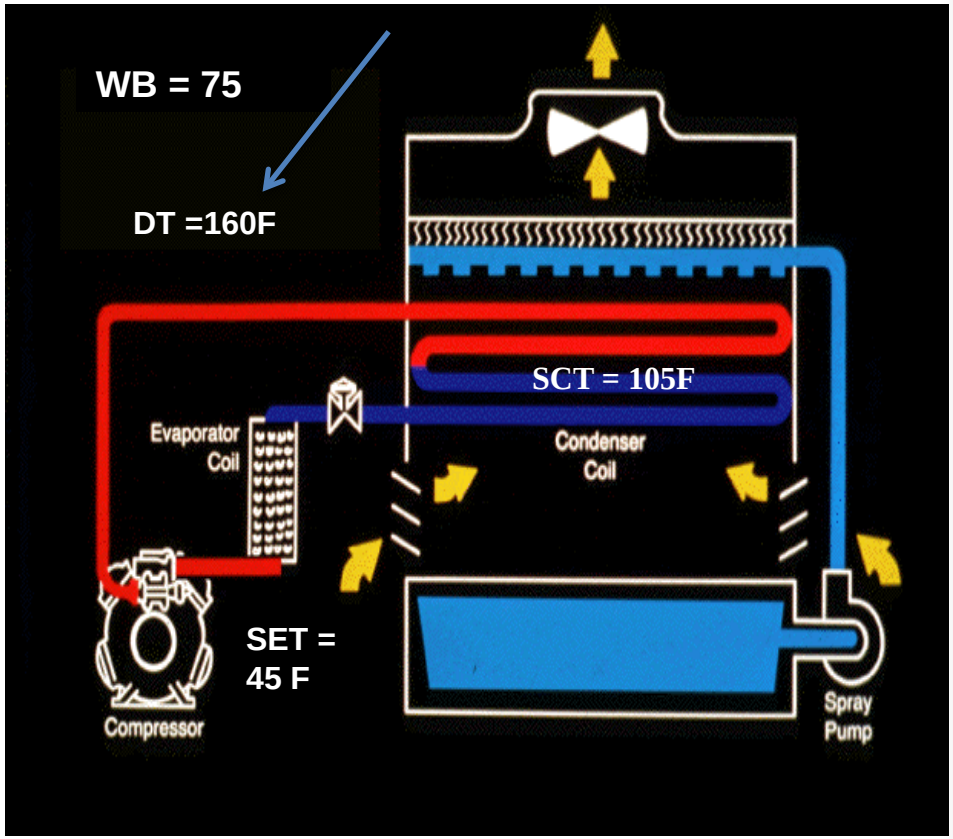
Calcium = 392.0 [mg/L as $CaCO_3$]

Alkalinity = 76.0 [mg/L as $CaCO_3$]

$Conductivity_{Approximate}$ = 1,453 [micro-mho/cm]

LSI = 0.4236

Definite Scale Potential



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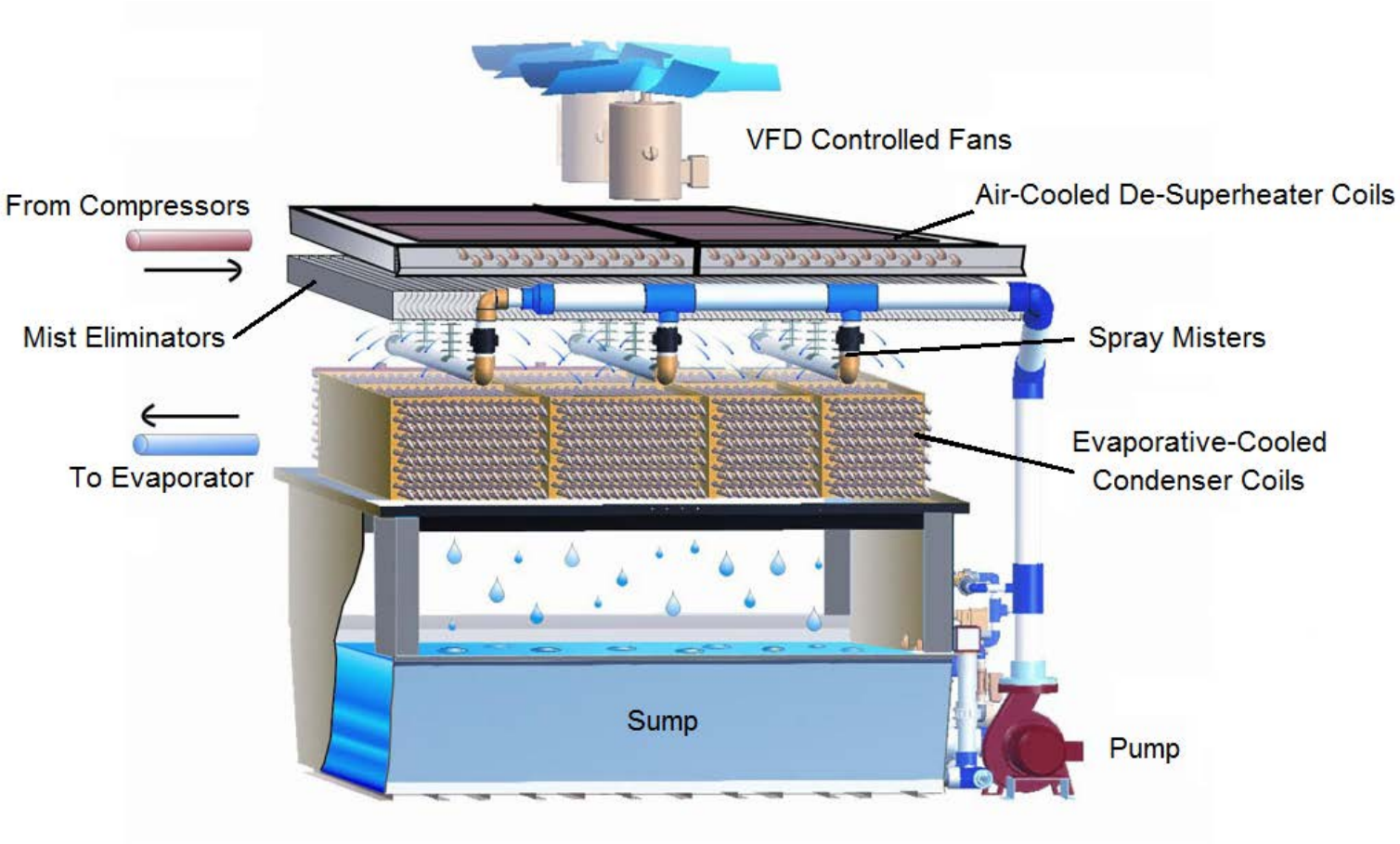
Evaporative Condenser w/ De-Superheater



JACCO

Evaporative Condenser w/ De-Superheater

Langelier Saturation Index Calculator

T = 101.7 [F] 38.7 [C]

pH = 7.100

TDS = 660.0 [mg/L]

Calcium = 392.0 [mg/L as $CaCO_3$]

Alkalinity = 76.0 [mg/L as $CaCO_3$]

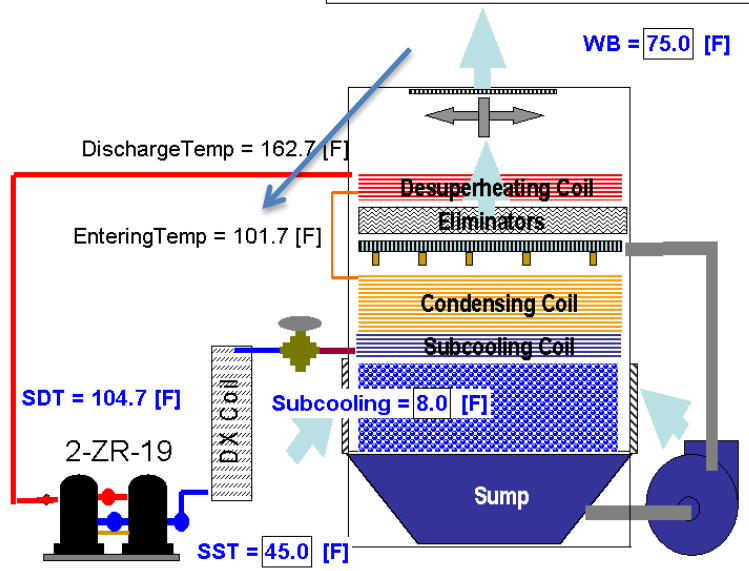
$Conductivity_{Approximate}$ = 1,453 [micro-mho/cm]

LSI = -0.1396

Border Line Scale Potential

LSI Calculator | LSI Help

Internet Link to Information on Corrosion



KWperTON = 0.708 $EER_{Compressor}$ = 16.9 [Btu/(watt-hr)]

Evaporative Condenser Cycle Analysis

DesuperheatingHeatRejection = 106,275 [Btu/hr]

CondensingHeatRejection = 383,002 [Btu/hr] WaterEvaporationRate = 364.8 [lb/hr]

THR_{total} = 489,277 [Btu/hr] WaterSavings% = 21.7 [%]

JACCO

Evaporative Condenser w/ De-Superheater

Benefits

- 22-100% Less Water usage
- 22-100% Less Chemical usage
- Lower energy consumption due to reduced fouling and more efficient heat transfer
- Reduced tendency to form scale in the wetted coil section
- Longer condenser fan motor life due to reduced relative humidity of ambient air
- Unit can run dry

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At 70 DB the system will operate at ~60% capacity….DRY

Thank You

Jerry Cohen
President
Jacco & Assoc.