Using P-T Analysis As A Service Tool

Manufacturers of refrigerants, controls, and other suppliers distribute hundreds of thousands of pressure-temperature charts to the trade every year. It would be rare indeed to find a service technician who could not put their hands on a pressure-temperature chart or application at a minute's notice.

In spite of the widespread availability and apparent reference to the pressure-temperature relationship, very few service technicians use the P-T chart/application properly in diagnosing service problems.

The purpose of this article is to demonstrate the proper use of the pressure-temperature relationship, and to illustrate how it can be used to thoroughly analyze a refrigeration or air conditioning system.

P-T Chart Features:

- Refrigerants 134a, 404A, 407A, 507, 744 - CO_2
- Instructions for determining superheat
- Systematic Analysis
- Handy pocket size
- Android / iOS Mobile App

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Refrigerant In Three Forms

Before getting into the proper use of the P-T chart/application, let's review briefly the refrigeration system and examine exactly how the pressure-temperature relationship can be applied.

The refrigerant in a refrigeration system will exist in one of the following forms:

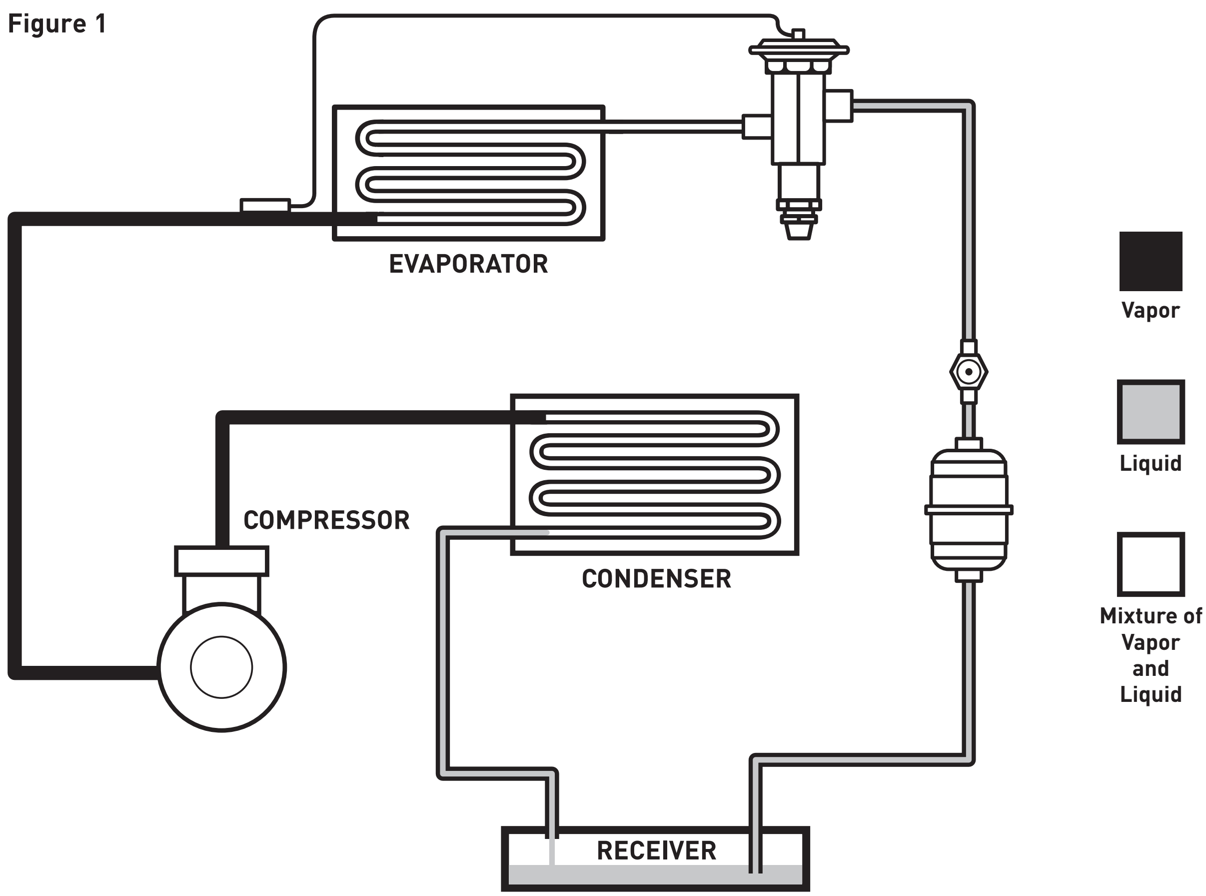
1. All liquid
2. All vapor
3. A mixture of liquid and vapor

Figure 1 illustrates the form in which refrigerant is found at various points in a normal operating refrigeration system.

Notice that the high side contains refrigerant in all of the three conditions listed above. The discharge line contains all vapor. The condenser where the vapor condenses into a liquid contains a mixture of liquid and vapor. The line between the condenser and the receiver usually contains all liquid, although it would not be abnormal for this line to also have some vapor mixed with the liquid. Since the receiver has a liquid level at some point, it has a mixture of liquid and vapor at the surface of the liquid level. The liquid line leading from the receiver to the thermostatic expansion valve should contain all liquid. A sight glass or liquid indicator is frequently installed in the liquid line to assist in determining if the liquid refrigerant is completely vapor-free.

The low side of the system will usually contain refrigerant in only two of the three forms that were listed previously. That is, the low side will contain all vapor in the suction line, and a mixture of liquid and vapor from the outlet of the thermostatic expansion valve to nearly the outlet of the evaporator.

Figure 1



State of refrigerant in a normally operating refrigeration system.

When Refrigerant is "Saturated"

The important thing to remember is that the pressure-temperature relationship as shown by a P-T chart/application is only valid when there is a mixture of refrigerant liquid and vapor.

Therefore, there are only three places in the normally operating refrigeration system where the P-T relationship can be guaranteed with certainty. That is the evaporator, the condenser, and the receiver — places where a mixture of refrigerant liquid and vapor are known to exist. When refrigerant liquid and vapor exist together, the condition is known as "saturated."

This means that if we are able to determine the pressure at any of these points, we can easily determine the "saturation" temperature by merely finding the pressure on a P-T chart/application and reading the corresponding temperature. Conversely, if we can accurately measure the temperature at these three locations, we can also determine the "saturation" pressure from the P-T relationship by finding the pressure corresponding to the temperature that we have measured.

When Superheat or Subcooling is Indicated

At the points in the system where only vapor is present, the actual temperature will be above the saturation temperature. In this case, the difference between the measured temperature and the saturation temperature at the point in question is a measure of superheat. The temperature of the vapor could be the same as the saturation temperature, but in actual practice, it is always above. If these temperatures were the same then the amount of superheat would be zero.

Where it is known that only liquid is present such as in the liquid line, the measured temperature will be somewhere below the saturation temperature. In this case, the difference between the measured temperature and the saturation temperature is a measure of liquid subcooling. Again, it is possible to find that the actual measured temperature is equivalent to the saturation temperature, in which case the amount of subcooling would be indicated as zero.

Analyzing Refrigerant Condition

Figure 2 shows some actual pressure-temperature measurements throughout a normally operating system using R-134a refrigerant. This may give a better insight into the condition of the refrigerant at the various points. The measured temperature at the evaporator inlet is 19°F (-7.2°C). A gauge installed at this point indicates a pressure of 18 psig (1.2 bar); 18 psig (1.2 bar) on the P-T chart/application indicates a temperature of 19°F (-7.2°C). It might also be said that the superheat is zero and the subcooling is zero. Therefore, the refrigerant is at saturation, or in other words, at the boiling point. This P-T relationship will hold true when refrigerant liquid and vapor are present together.

A gauge installed in the suction line measures 16 psig (1.1 bar). If there were a mixture of liquid and vapor at this point, the measured temperature would be the same as the saturation temperature or 16°F (-8.9°C). However, our actual measured temperature in this case is 27°F (-2.8°C). The amount of superheat in the vapor is the difference between the measured temperature of 27°F (-2.8°C) and the saturation temperature (according to the P-T chart/application) of 17°F (-8.7°C). Therefore, the superheat is 10°F (5.4K).

If we also measure 16 psig (1.1 bar) at the compressor inlet with the measured temperature of 47°F (8.3° C), our superheat in this case would be 30°F (30K), calculated by subtracting the saturation temperature equivalent to 16 psig (1.1 bar) (17°F /-8.7°C) from the measured temperature of 47°F (8.3° C).

Let's now examine the gauge we have installed midway in the condenser which reads 158 psig (10.9 bar). According to the P-T chart/application, the saturation temperature will be 115°F (46.1°C). This is the temperature that we would be able to measure if we placed a thermocouple in the refrigerant at the point where it is changing from a vapor to a liquid. At this point, there is no difference between the measured temperature and the saturation temperature. It might also be said that the superheat is zero and the subcooling is zero. Therefore, the refrigerant is saturated, or in other words, at the boiling point.

In our example we also measure 158 psig (10.9 bar) at a discharge line of the compressor. The measured temperature here is 200°F (93.3°C). Calculating the superheat in the

Figure 2 – °F

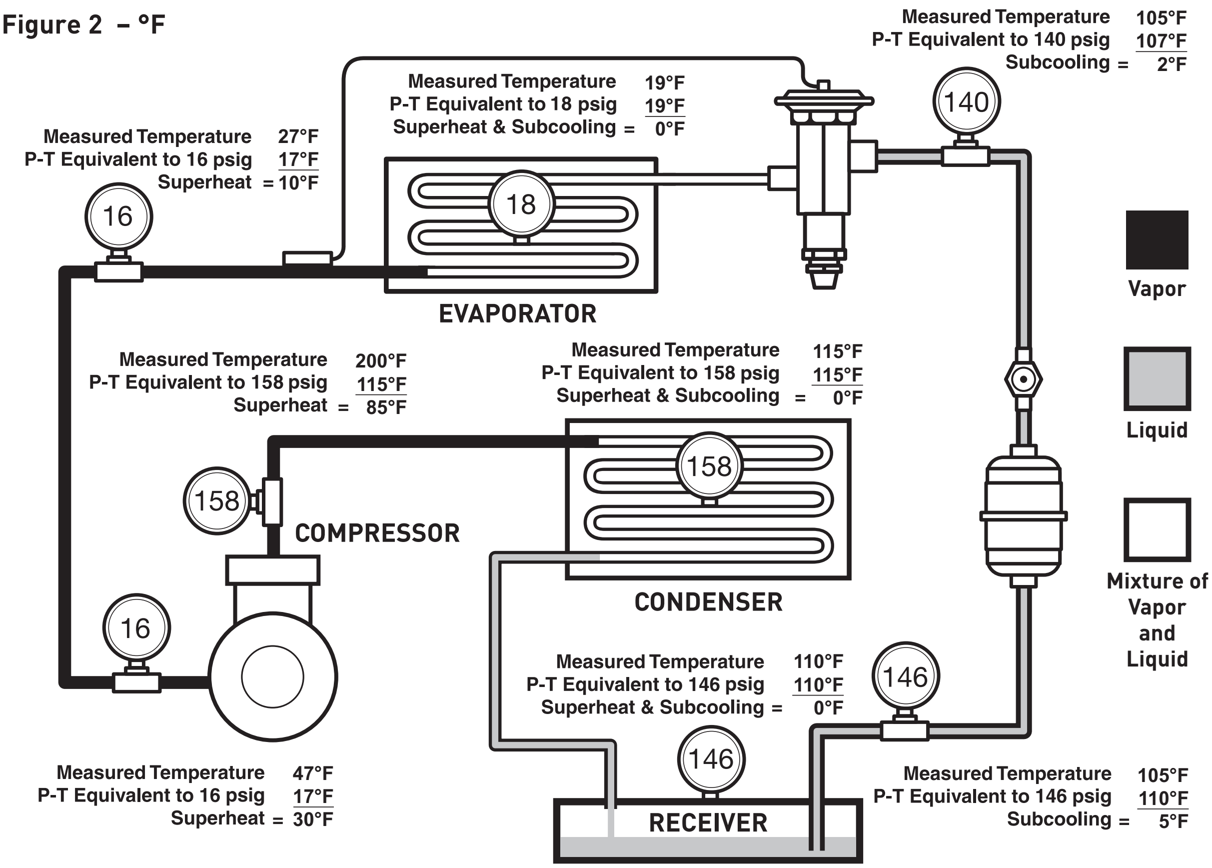
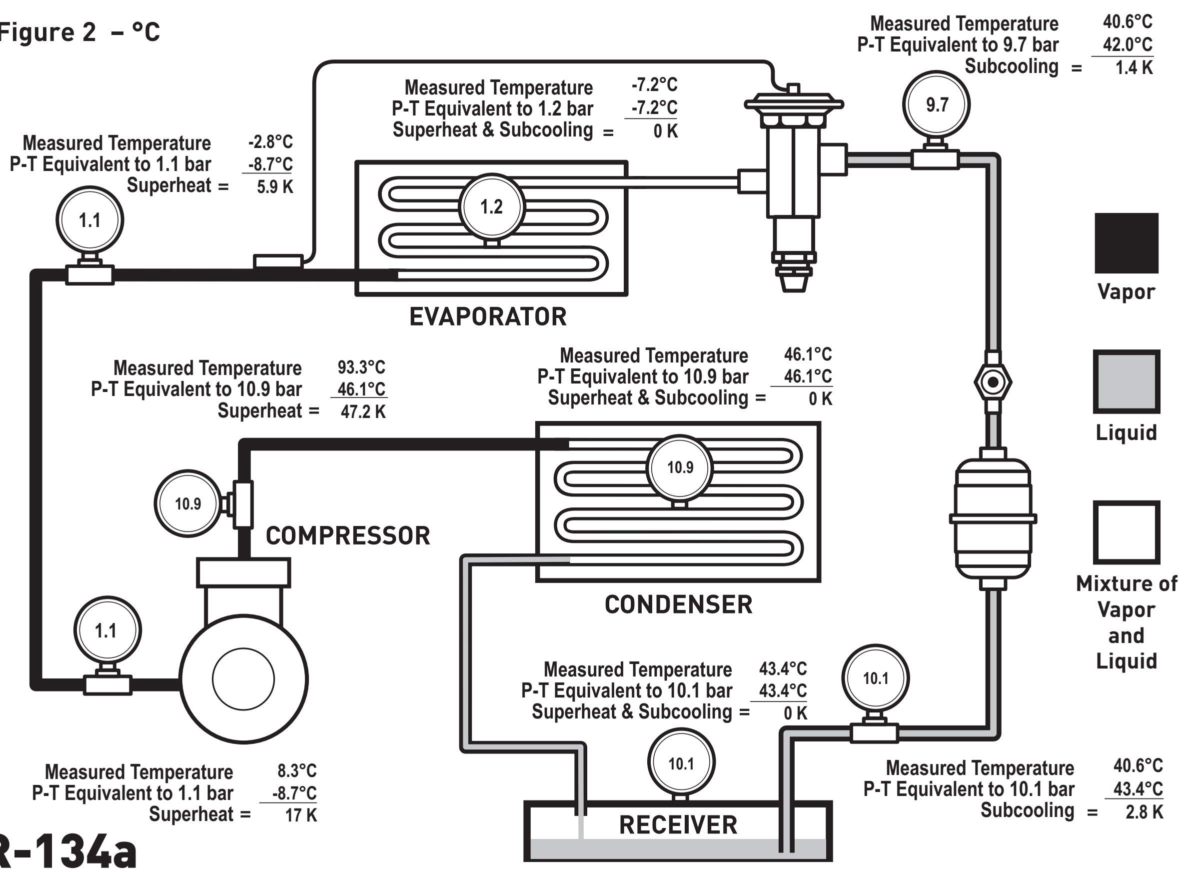


Figure 2 – °C



R-134a

Example of actual pressure-temperature measurements in a normally operating system.

same way as it was done on the suction line (difference between measured temperature and saturation temperature), it is determined that the superheat is 85°F (47.2K).

When a system employs the use of a liquid receiver, there can be no subcooling at the surface of the liquid in the receiver. The reason is that when liquid refrigerant and vapor exist together, they must obey the P-T relationship or the refrigerant must be saturated. In our example the measured pressure in the receiver is 146 psig (10.1 bar); the refrigerant at the surface of the liquid level in the receiver must therefore be at 110°F (43.3°C).

Once a solid column of liquid is formed, subcooling of the refrigerant can take place by lowering its temperature with the use of liquid-suction heat exchangers, subcoolers, or from lower ambient temperatures surrounding the line.

Subcooling is a lowering of a temperature below the saturation point or boiling point. In our illustration in Figure 2, subcooling of 5°F (2.8K) and 2°F (1.4K) has been determined as illustrated at two points.

Of course, it is important to maintain some liquid subcooling in the liquid line to prevent flash gas from forming in the liquid line and entering the thermostatic expansion valve.

With the use of a P-T chart/application, we should be able to determine the condition of the refrigerant at any point in the system by measuring both the pressure and the temperature and observing the following rules:

A. Liquid and vapor are present together when the measured temperature corresponds to the P-T relationship. (It is theoretically possible to have "100% saturated liquid" or "100% saturated vapor" under these conditions, but practically speaking in an operating system, it should be assumed that some liquid and some vapor are present together under these conditions.)

B. Superheated vapor is present when the measured temperature is above the saturation temperature corresponding to the P-T relationship. The amount of superheat is indicated by the difference.

C. Subcooled liquid is present when the measured temperature is below the saturation temperature corresponding to the P-T relationship. The amount of subcooling is represented by the difference.

Practical Limitation to Gauge Locations

In our illustration we have located gauges at points in the system where it is not always feasible to do so on an actual installation. Because of this, we must oftentimes make deductions and assumptions when dealing with an actual system.

As an example, we would normally assume that the 158 psig (10.9 bar) read on the gauge installed at the compressor discharge line is also the pressure that exists in the condenser. That is, we assume that there is no pressure loss of any consequence between the compressor discharge and the condenser. With this reasoning, we arrive at a condensing temperature of 115°F (46.1°C). If an undersized discharge line or other restrictions are suspected, we cannot make this assumption and other pressure taps may be necessary to locate the troublesome area.

It is also common practice to assume that the pressure measured at the suction service valve of the compressor is the same pressure that exists at the outlet of the evaporator at the expansion valve bulb location. This is particularly true on close-coupled systems where it has been determined that the suction line is of the proper size. By making this assumption, we can determine the expansion valve superheat without installing an additional pressure tap at the bulb location. However, to eliminate any doubt as to the amount of suction line pressure drop and to be absolutely precise in measuring superheat, a gauge must be installed in the suction line at the bulb location.

Care must be taken to make a reasonable allowance for pressure drops within the system. Excessive pressure drops can be detected by applying the principles of the P-T relationship. As an example, in Figure 2, with gauges installed only at the suction and discharge of the compressor and reading as indicated, a significant pressure drop through the evaporator would be indicated by a high temperature of, say, 50°F (10°C) measured at the evaporator inlet which would correspond to a pressure at that point of approximately 45 psig (3.1 bar). That would mean that there is a pressure drop of 29 psi (2.0 bar) from the evaporator inlet to the compressor inlet (45 minus 16/3.1 minus 1.1). While this would be considered excessive on a single-circuit evaporator, it should be remembered that on multi-circuit evaporators there will be a pressure drop through the refrigerant distributor assembly. A pressure drop through the distributor assembly on R-134a may be in the vicinity of 25 psi (1.7 bar). This means that with the use of a refrigerant distributor, a measured temperature between the outlet of the thermostatic expansion valve and the inlet of the distributor of approximately 50°F (10°C) would not be abnormal in the system illustrated in Figure 2.

Checking on Noncondensables

The proper use of the P-T relationship can be helpful in discovering the presence of air or other noncondensable gases in the system. These undesirable gases will accumulate in the condenser and add their pressure to that produced by the refrigerant, resulting in a higher total pressure. Therefore, if this condition exists, the P-T relationship will be distorted so that the actual refrigerant temperature in the condenser will be lower than the P-T chart/application indicates.

Assuming an air cooled condenser, the relationship between leaving air temperature and actual refrigerant temperature (in condenser) is lower than a comparable system having no noncondensables.

This is the result of the noncondensable interfering with the amount of condensing surface and making the condenser less efficient.

Summary

With an understanding of the refrigerant pressure-temperature relationship, the widely available P-T chart/application is a valuable tool. A P-T chart/application, along with accurate gauges and thermometers, allows us to determine at any point in the system if the refrigerant is saturated, subcooled or superheated. This is very important in properly diagnosing system problems.

Test Your P-T Know-How

Figure 3 is an exercise to test your knowledge and use of the P-T relationship. The pressure and temperature are shown at various points in the system. Check the square that indicates the condition of the refrigerant at each point. In the case of superheated vapor and subcooled liquid, indicate the amount in the blank shown.

Vacuum-Inches of Mercury
Bold Italic Figures

TEMPERATURE PRESSURE CHART - at sea level

Pressure-Pounds Per Square Inch Gauge

TEMPERATURE		REFRIGERANT (SPORLAN CODE)				
(°F)	(°C)	134a (J)	404A (S)	407A (V)	507 (P)	744 - CO_2
-60	-51.1	***21.8***	***7.3***	***14.2***	***5.8***	79.9
-55	-48.3	***20.3***	***3.9***	***11.5***	***2.2***	91.1
-50	-45.6	***18.7***	***0.1***	***8.6***	0.9	103.4
-45	-42.8	***16.9***	2.0	***5.3***	3.0	116.6
-40	-40.0	***14.8***	4.3	***1.6***	5.4	131.0
-35	-37.2	***12.5***	6.8	1.3	8.1	146.5
-30	-34.4	***9.8***	9.6	3.5	11.0	163.1
-25	-31.7	***6.9***	12.7	6.1	14.1	181.0
-20	-28.9	***3.7***	16.0	8.8	17.6	200.2
-18	-27.8	***2.3***	17.4	10.0	19.1	208.3
-16	-26.7	***0.8***	18.9	11.2	20.6	216.5
-14	-25.6	0.4	20.4	12.5	22.2	225.0
-12	-24.4	1.1	22.0	13.9	23.8	233.8
-10	-23.3	1.9	23.6	15.2	25.5	242.7
-8	-22.2	2.8	25.3	16.7	27.3	251.9
-6	-21.1	3.6	27.0	18.1	29.1	261.3
-4	-20.0	4.6	28.8	19.7	30.9	271.0
-2	-18.9	5.5	30.7	21.3	32.8	280.9
0	-17.8	6.5	32.6	22.9	34.8	291.0
1	-17.2	7.0	33.6	23.7	35.8	296.2
2	-16.7	7.5	34.6	24.6	36.9	301.5
3	-16.1	8.0	35.6	25.5	37.9	306.8
4	-15.6	8.5	36.6	26.4	39.0	312.1
5	-15.0	9.1	37.7	27.3	40.1	317.6
6	-14.4	9.6	38.7	28.2	41.1	323.1
7	-13.9	10.2	39.8	29.1	42.3	328.6
8	-13.3	10.8	40.9	30.1	43.4	334.2
9	-12.8	11.3	42.0	31.0	44.5	339.9
10	-12.2	11.9	43.1	32.0	45.7	345.7
11	-11.7	12.5	44.3	33.0	46.9	351.5

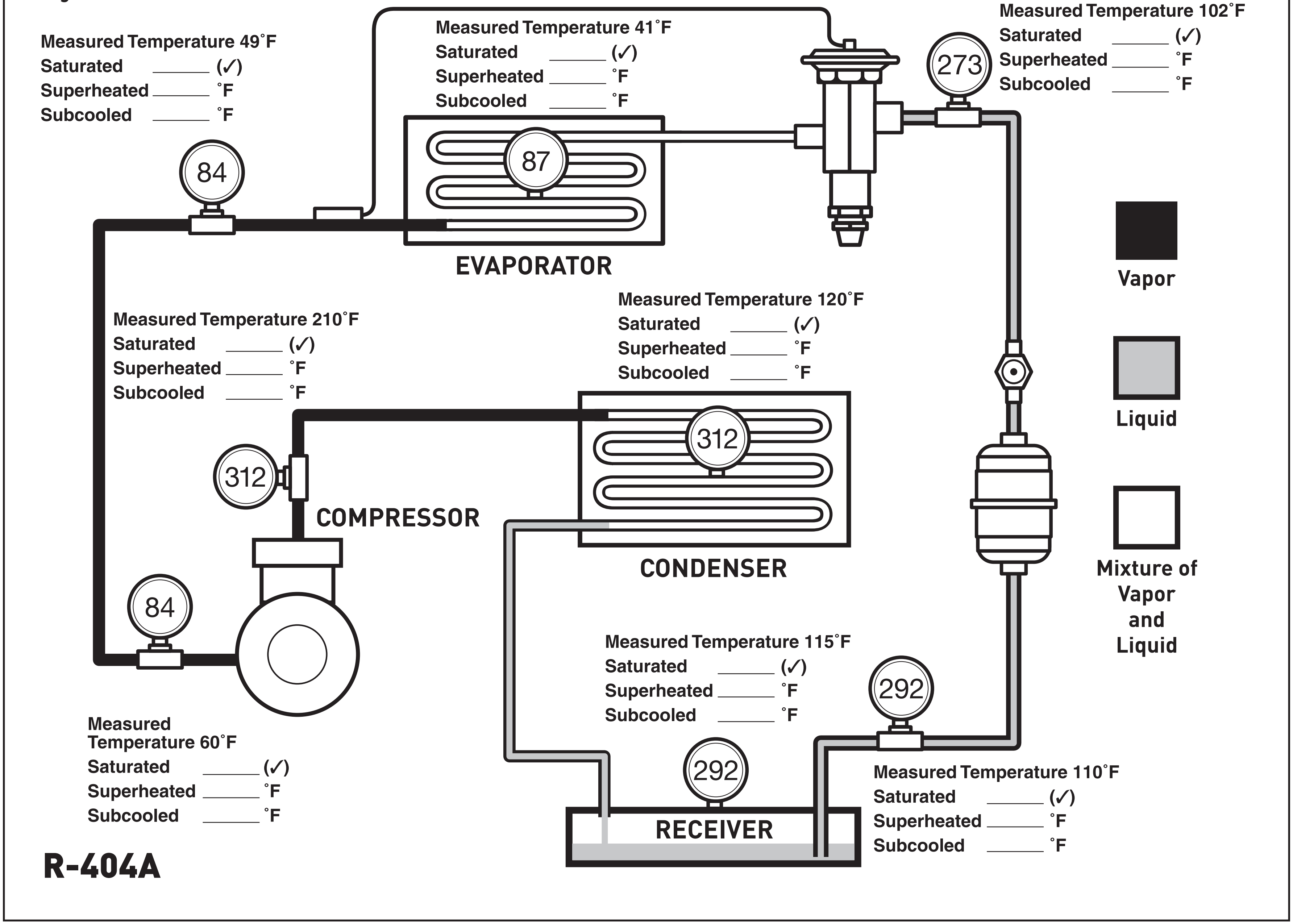
TEMPERATURE		REFRIGERANT (SPORLAN CODE)				
(°F)	(°C)	134a (J)	404A (S)	407A (V)	507 (P)	744 - CO_2
12	-11.1	13.1	45.4	34.0	48.1	357.4
13	-10.6	13.8	46.6	35.0	49.3	363.4
14	-10.0	14.4	47.8	36.1	50.5	369.5
15	-9.4	15.0	49.0	37.2	51.8	375.6
16	-8.9	15.7	50.2	38.2	53.0	381.8
17	-8.3	16.4	51.5	39.3	54.3	388.0
18	-7.8	17.0	52.7	40.4	55.6	394.3
19	-7.2	17.7	54.0	41.6	56.9	400.7
20	-6.7	18.4	55.3	42.7	58.3	407.2
21	-6.1	19.1	56.6	43.9	59.6	413.8
22	-5.6	19.9	58.0	45.1	61.0	420.4
23	-5.0	20.6	59.3	46.3	62.4	427.1
24	-4.4	21.3	60.7	47.5	63.8	433.8
25	-3.9	22.1	62.1	48.7	65.3	440.7
26	-3.3	22.9	63.5	50.0	66.7	447.6
27	-2.8	23.7	64.9	51.3	68.2	454.6
28	-2.2	24.5	66.4	52.6	69.7	461.7
29	-1.7	25.3	67.8	53.9	71.2	468.8
30	-1.1	26.1	69.3	55.2	72.7	476.1
31	-0.6	26.9	70.8	56.6	74.3	483.4
32	0.0	27.8	72.4	58.0	75.9	490.8
33	0.6	28.6	73.9	59.4	77.5	498.3
34	1.1	29.5	75.5	60.8	79.1	505.8
35	1.7	30.4	77.1	62.2	80.7	513.4
36	2.2	31.3	78.7	63.7	82.4	521.2
37	2.8	32.2	80.3	65.2	84.1	529.0
38	3.3	33.1	82.0	66.7	85.8	536.9
39	3.9	34.1	83.7	68.2	87.5	544.8
40	4.4	35.0	85.4	69.7	89.2	552.9
41	5.0	36.0	87.1	71.3	91.0	561.0

TEMPERATURE		REFRIGERANT (SPORLAN CODE)				
(°F)	(°C)	134a (J)	404A (S)	407A (V)	507 (P)	744 - CO_2
42	5.6	37.0	88.8	72.9	92.8	569.3
43	6.1	38.0	90.6	74.5	94.6	577.6
44	6.7	39.0	92.4	76.1	96.5	586.0
45	7.2	40.1	94.2	77.8	98.3	594.5
46	7.8	41.1	96.0	79.5	100.2	603.1
47	8.3	42.2	97.9	81.2	102.1	611.7
48	8.9	43.2	99.8	82.9	104.1	620.5
49	9.4	44.3	101.7	84.6	106.0	629.3
50	10.0	45.4	103.6	86.4	108.0	638.3
55	12.8	51.2	115.3	115.2	118.3	684.4
60	15.6	57.4	126.0	126.0	129.2	733.1
65	18.3	64.0	137.3	137.4	140.7	784.2
70	21.1	71.1	149.3	149.6	153.0	838.1
75	23.9	78.7	162.0	162.5	165.9	894.9
80	26.7	86.7	175.4	176.1	179.6	954.9
85	29.4	95.2	189.5	190.5	194.1	1018
90	32.2	104.3	204.5	205.7	209.3	**
95	35.0	113.9	220.2	221.8	225.4	**
100	37.8	124.2	236.8	238.7	242.3	**
105	40.6	135.0	254.2	256.5	260.1	**
110	43.3	146.4	272.5	275.2	278.8	**
115	46.1	158.4	291.8	294.9	298.5	**
120	48.9	171.2	312.1	315.6	319.2	**
125	51.7	184.6	333.3	337.3	340.9	**
130	54.4	198.7	355.6	360.1	363.8	**
135	57.2	213.6	379.1	384.0	387.8	**
140	60.0	229.2	403.7	409.0	413.0	**
145	62.8	245.7	429.6	435.2	439.5	**
150	65.6	262.9	456.8	462.6	467.4	**
155	68.3	281.0	485.5	491.3	497.0	**

To determine ***subcooling*** for R-404A and R-407A, use BUBBLE POINT values (Temperatures above 50°F — Gray Background); to determine ***superheat*** for R-404A and R-407A, use DEW POINT values (Temperatures 50°F and below).
** = exceeds critical temperature

Form 1C

Figure 3 – °F


Measured Temperature 49˚F
Saturated ______ (✓)
Superheated ______ ˚F
Subcooled ______ ˚F
84
Measured Temperature 41˚F
Saturated ______ (✓)
Superheated ______ ˚F
Subcooled ______ ˚F
87
EVAPORATOR
273
Measured Temperature 102˚F
Saturated ______ (✓)
Superheated ______ ˚F
Subcooled ______ ˚F
Vapor
Liquid
Mixture of Vapor and Liquid
Measured Temperature 210˚F
Saturated ______ (✓)
Superheated ______ ˚F
Subcooled ______ ˚F
312
COMPRESSOR
Measured Temperature 120˚F
Saturated ______ (✓)
Superheated ______ ˚F
Subcooled ______ ˚F
312
CONDENSER
84
Measured Temperature 60˚F
Saturated ______ (✓)
Superheated ______ ˚F
Subcooled ______ ˚F
Measured Temperature 115˚F
Saturated ______ (✓)
Superheated ______ ˚F
Subcooled ______ ˚F
292
RECEIVER
292
Measured Temperature 110˚F
Saturated ______ (✓)
Superheated ______ ˚F
Subcooled ______ ˚F
R-404A

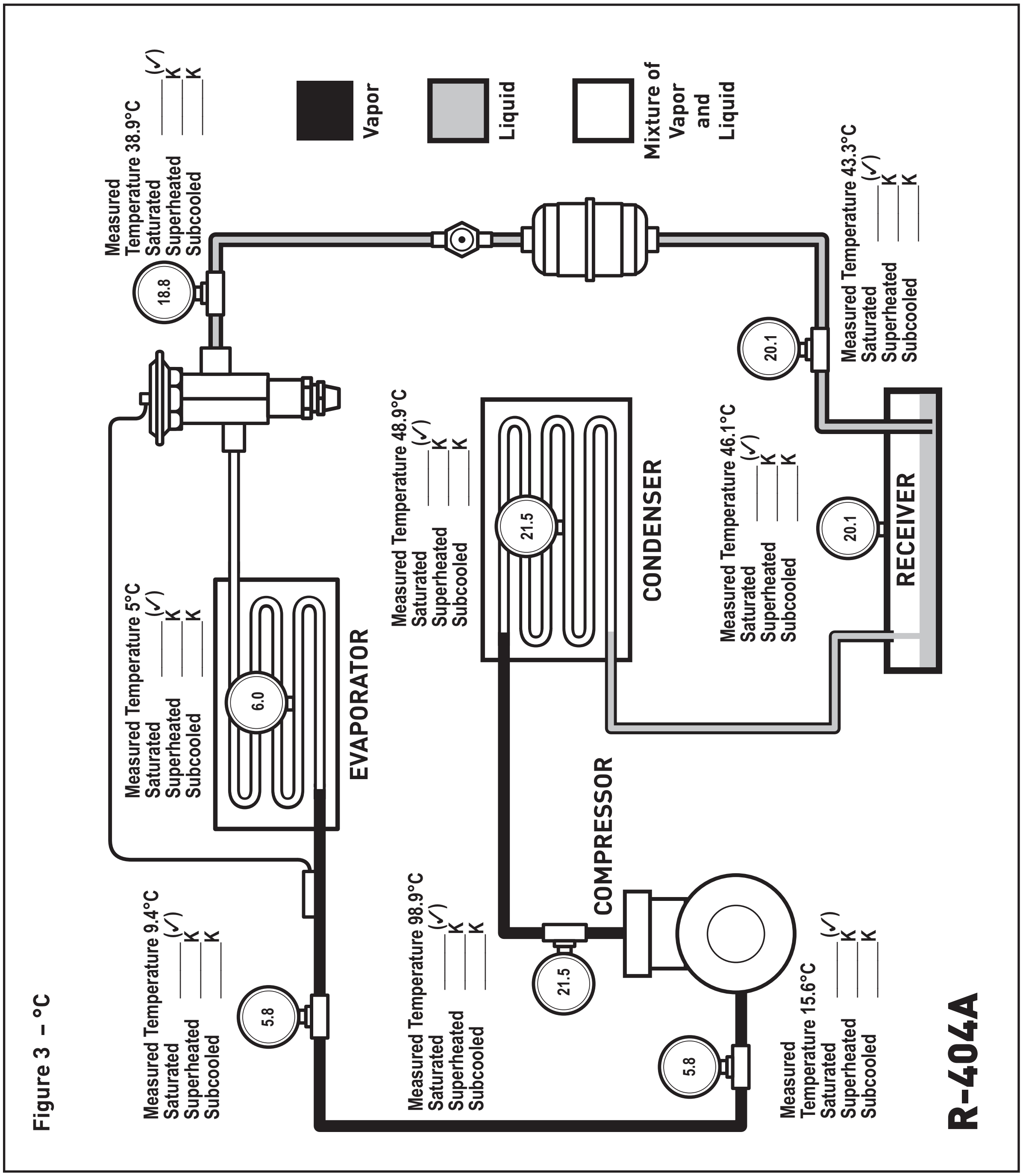


Figure 3 – °C

Form 10-135 / 52013

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