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Troubleshooting HVAC/R systems using refrigerant superheat and subcooling

Application Note

Troubleshooting and servicing refrigeration and air conditioning systems can be a challenging process for both the entry level and experienced HVAC/R technician. Regardless of your experience, size of the equipment, or location, to troubleshoot the system it is essential that you have a solid understanding of the fundamentals of refrigeration—including the principles of superheat and subcooling. You also need to have the right tools and know-how to apply these principles to use the tool quickly and efficiently.

Troubleshooting techniques often require simultaneous knowledge of temperature, pressure, voltage, and current values in a system, which means that a single-function meter won't permit a complete analysis of the system. Frequently, multiple tools are required.

This application note provides information on troubleshooting the refrigeration system while applying the principles of superheat and subcooling to HVAC/R equipment. It will also teach you the proper methods to tackle some typical troubleshooting tasks using thermometers, digital multimeters, pressure/vacuum modules, and HVAC/R accessories. Basic refrigeration principles are provided solely to illustrate how digital thermometers, multimeters, and accessories can make servicing and maintaining HVAC/R systems straightforward, fast, and accurate.

The refrigeration cycle

Based on the principle that heat flows naturally from warmer areas to cooler areas, the refrigeration cycle consists of seven stages:

1. Compression of hot gas
2. Cooling
3. Condensing
4. Subcooling
5. Expansion
6. Evaporation
7. Super heating

A basic vapor compression refrigeration system consists of four primary components: a metering device (e.g. a capillary tube, fixed orifice/piston, or a thermostatic expansion valve), evaporator, compressor, and condenser.

(See Figure 1.) Compression energy elevates the vapor pressure to a boiling point that is below the condensing mediums' temperature. In other words, the compressor elevates the boiling point of the refrigerant to a point at which the air (or water) moving across the condenser is low enough to condense the refrigerant to a liquid. Additional passes in the condenser coil cool the liquid refrigerant below its boiling point to ensure it remains a liquid as it experiences pressure drop in its journey to the evaporator. This cooling below the boiling point is called subcooling.

Testing roof-top refrigeration system with a Fluke 561 Infrared Thermometer.
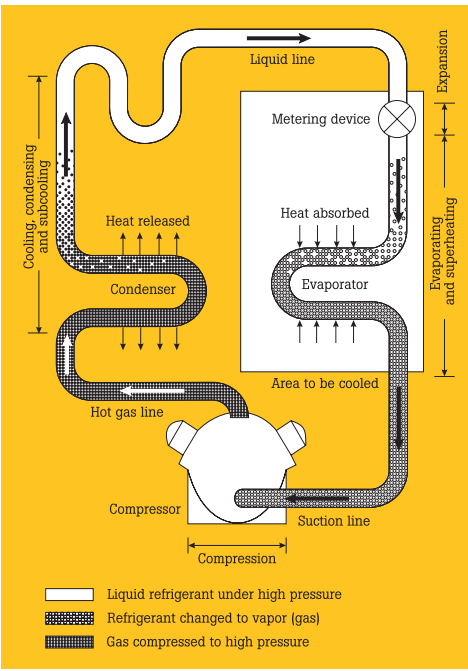
Figure 1. The refrigeration system. In a typical refrigeration system, the compressor sends hot gas to the condenser. Then the condensed liquid passes through an expansion valve into the evaporator where it evaporates and collects heat from the area to be cooled. The gaseous refrigerant then enters the compressor where the compression process raises the pressure and temperature. From the compressor, the refrigerant is routed back to the condenser and the cycle repeats.

A metering device at the evaporator inlet acts as a "dam" to restrict flow and drop the refrigerant pressure to a new lower boiling point. This new boiling point is below the evaporator medium (air or water) temperature so that the air or water across the evaporator will cause the refrigerant to boil. After all of the refrigerant in the evaporator has boiled to a vapor, the vapor will pick up additional heat through extra passes in the evaporator. The amount of vapor temperature increase above the boiling temperature is called superheat.

The compressor reduces the gas to a high pressure while simultaneously raising the temperature of the gas. The hot gas is then delivered to the condenser where it is cooled, dissipating the heat and steadily converting the gas back to a liquid state.

When the liquid under high pressure reaches the metering device, the cycle starts over.

While servicing most refrigeration systems, the technician will measure the temperature and pressure to determine system performance. Close monitoring of temperature and pressure to verify proper control and operation can ensure longer system life and reduce energy consumption.

Often, measuring temperatures or pressures at key points in a system can pinpoint trouble spots. Examples of such measurements follow.
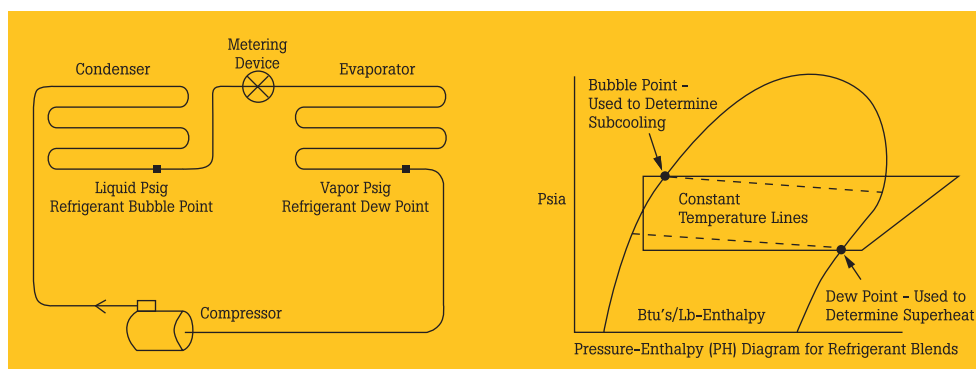
Figure 2. Superheat temperature measurement points.

Superheat and its measurement

In the system's evaporator, conversion of liquid to vapor involves adding heat to the liquid at its boiling temperature, commonly referred to as the saturation temperature. After all of the refrigerant has boiled to a vapor, any additional temperature increase above the boiling point is called superheat.

Finding suction line superheat requires finding the suction pressure and two temperatures—the evaporator boiling temperature at a given pressure and the temperature of the refrigerant at the outlet of the evaporator on the suction line, commonly referred to as the superheat temperature/pressure method.

Finding the boiling temperature is determined by using a pressure–temperature (PT) chart. On older CFC and HCFC refrigerants, and some newer ozone- friendly refrigerants such as R134a, boiling temperature remains constant during the saturation or boiling phase provided that the pressure remains the same within the evaporator.

On newer refrigerant blends, the temperature changes during the boiling or saturation phase. This is referred to as glide. Modern refrigerants with a temperature glide of 10 °F (5 °C) or higher use dew point (DP)

temperature. This is the temperature of the refrigerant when the last of the liquid has boiled into a vapor. Any vapor temperature increase above the dewpoint temperature is called superheat. (See Figure 2.)

The best method to determine superheat using Fluke products is to use the 80PK-8 Pipe Clamp Temperature Probe and a PV350 Pressure/Vacuum Module in conjunction with a suitable Fluke digital multimeter with type K thermocouple measurement and a mV input. The pipe clamp allows pipe temperature measurements to be made more quickly and accurately because it clamps directly to the pipe without the need to add insulation or tape, as in the case of a bead thermocouple. The pressure/vacuum module allows accurate and quick pressure measurements.

When measuring for superheat, remember to allow the system to run long enough for temperatures and pressures to stabilize while verifying normal airflow cross the evaporator. Using the pipe clamp or a Velcro pipe probe, find the suction line temperature by attaching the probe around a bare section of the pipe, at the outlet of the evaporator. Pipe temperature can be read at the inlet of the compressor on the suction line if the pipe is less than 15' from
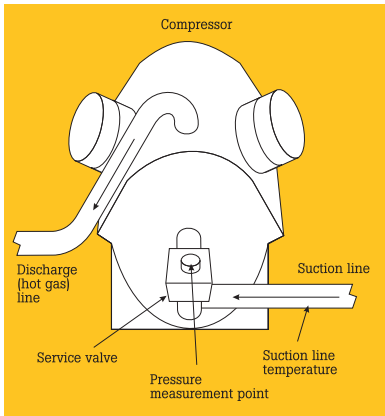
Figure 3. Suction line superheat using the temperature-pressure method. Measure the pressure at the suction line service valve. Find the evaporator boiling temperature from a temperature-pressure chart using suction line pressure. Subtract this temperature from the suction line temperature measured by the Fluke digital thermometer. The difference is superheat.

the evaporator and there is a minimum pressure drop between the two points. (See Figure 3.) Best results are obtained when the pipe is free of oxides or other foreign material. Next, attach the pressure/vacuum module to the suction line service valve (or refrigerant service port on your manifold gauge set). Make a note of the pipe temperature and pressure. This pressure reading will be that of the boiling refrigerant inside the evaporator, assuming no abnormal restrictions exist within the suction line. Using this pressure value, find the evaporator (or dewpoint) boiling temperature from a PT chart for the refrigerant type being used. (See Figure 4.) Subtract the boiling/dewpoint temperature from the suction line temperature to find the superheat.

The suction line temperature may also be taken by attaching a bead thermocouple to the suction line. Be careful to insulate the thermocouple and use heat-conducting compound to minimize errors due to heat loss to ambient air.

All pressures shown are in PSIG; Red print = Vacuum (inches of Mercury)

°F	12	22	502	134a	401A (MP39) VAP DP	401A LIQ BP	401B (MP66) VAP DP	401B LIQ BP	402A (HP80) VAP DP	402A LIQ BP	404A (HP62) (FX70)	408A (FX10)	409A (FX56) VAP DP	409A LIQ BP	410A (AZ20)
-40	11.0	0.5	4.1	14.5	14.3		12.8		5.6		4.6	2.8	13.1		11.6
-38	10.0	1.3	5.0	13.7	13.4		11.8		6.7		5.6	3.7	12.1		12.9
-36	8.9	2.2	6.0	12.8	12.4		10.7		7.8		6.6	4.6	11.1		14.2
-34	7.8	3.0	7.0	11.8	11.4		9.6		8.9		7.7	5.6	10.1		15.6
-32	6.7	4.0	8.1	10.8	10.3		8.5		10.0		8.8	6.6	9.1		17.0
-30	5.5	4.9	9.2	9.7	9.2		7.3		11.3		9.9	7.6	8.1		18.5
-28	4.3	5.9	10.3	8.6	8.1		6.0		12.5		11.1	8.7	6.9		20.1
-26	3.0	6.9	11.5	7.7	6.9		4.7		13.8		12.4	9.8	5.6		21.7
-24	1.6	7.9	12.7	6.2	5.6		3.3		15.2		13.3	11.0	4.4		23.4
-22	0.3	9.0	14.0	4.9	4.3		1.9		16.6		15.0	12.2	3.1		25.1
-20	0.6	10.1	15.3	3.6	2.9		0.4		18.0		16.4	13.4	1.9		26.9
-18	1.3	11.3	16.7	2.3	1.5		0.6		19.5		17.8	14.7	1.0		28.9
-16	2.1	12.5	18.1	0.8	0.0		1.3		21.1		19.3	16.1	0.0		30.1
-14	2.8	13.8	19.5	0.3	0.8		2.2		22.7		20.8	17.5	1.0		32.8
-12	3.7	15.1	21.0	1.1	1.6		3.0		24.4		22.4	18.9	1.9		34.8
-10	4.5	16.5	22.6	1.9	2.4		3.9		26.1		24.0	20.4	2.8		36.8
-8	5.4	17.9	24.2	2.8	3.2		4.8		27.9		25.7	22.0	3.7		39.1
-6	6.3	19.3	25.8	3.6	4.1		5.8		29.7		27.4	23.6	4.6		41.4
-4	7.2	20.8	27.5	4.5	5.0		6.8		31.6		29.2	25.2	5.4		43.8
-2	8.2	22.4	29.3	5.5	6.0		7.8		33.5		31.1	26.9	6.3		46.2
0	9.2	24.0	31.1	6.5	7.0		8.9		35.6		33.0	28.7	7.2		48.6
2	10.2	25.6	32.9	7.5	8.0		10.0		37.6		35.0	30.5	8.3		51.2
4	11.2	27.3	34.9	8.5	9.1		11.1		39.8		37.0	32.3	9.3		53.9
6	12.3	29.1	36.9	9.6	10.2		12.3		42.0		39.1	34.3	10.4		56.6
8	13.5	30.9	38.9	10.8	11.3		13.5		44.3		41.3	36.3	11.4		59.5
10	14.6	32.8	41.0	12.0	12.5		14.8		46.6		43.5	38.3	12.5		62.3
12	15.8	34.7	43.2	13.1	13.7		16.1		49.0		45.8	40.4	13.7		65.4
14	17.1	36.7	45.4	14.4	15.0		17.4		51.5		48.2	42.6	15.0		68.5
16	18.4	38.7	47.7	15.7	16.3		18.8		54.0		50.6	44.9	16.2		71.6
18	19.7	40.9	50.0	17.0	17.6		20.3		56.7		53.1	47.2	17.5		75.0
20	21.0	43.0	52.5	18.4	19.0		21.8		59.4		55.7	49.5	18.7		78.3
22	22.4	45.3	54.9	19.9	20.5		23.3		62.2		58.4	52.0	20.2		81.9
24	23.9	47.6	57.5	21.4	22.0		24.9		65.0		61.1	54.5	21.6		85.5
26	25.4	49.9	60.1	22.9	23.5		26.5		68.0		63.9	57.1	23.1		89.2
28	26.9	52.4	62.8	24.5	25.1		28.2		71.0		66.8	59.8	24.5		93.0
30	28.5	54.9	65.6	26.1	26.7		30.0		74.1		69.7	62.5	26.0		96.8
32	30.1	57.5	68.4	27.8	28.4		31.8		77.3		72.8	65.3	27.7		100.9
34	31.7	60.1	71.3	29.5	30.1		33.6		80.5		75.9	68.2	29.4		105.0
36	33.4	62.8	74.3	31.3	31.9		35.5		83.9		79.1	71.2	31.1		109.2
38	35.2	65.6	77.4	33.2	33.7		37.5		87.3		82.4	74.2	32.8		113.6
40	36.9	68.5	80.5	35.1	35.6		39.5		90.9		85.7	77.4	34.5		118.0
42	38.8	71.5	83.8	37.0	37.6		41.6		94.5		89.2	80.6	36.5		122.8
44	40.7	74.5	87.0	39.1	39.6		43.7		98.2		92.7	83.9	38.4		127.6
46	42.7	77.6	90.4	41.1	41.7		45.9		102.0		96.4	87.3	40.4		132.4
48	44.7	80.7	93.9	43.3	43.8		48.2		106.0		100.1	90.7	42.3		137.2
50	46.7	84.0	97.4	45.5	46.0	57.7	50.5	62.3	110	114	104.5	95.8	44.3	61.0	142.0
52	48.8	87.3	101.0	47.7	47.0	60.2	52.3	64.9	115	118	109.5	99.7	46.6	63.7	147.2
54	51.0	90.8	104.8	50.1	49.0	62.8	54.7	67.0	119	123	113.5	103.5	48.8	66.4	152.4
56	53.2	94.3	108.6	52.3	51.5	65.4	57.3	70.4	124	127	117.7	107.4	51.1	69.1	158.0
58	55.4	97.9	112.4	55.0	54.0	68.1	60.0	73.7	128	131	121.9	111.2	53.3	71.8	164.0
60	57.7	101.6	116.4	57.5	56.0	70.9	62.5	76.2	133	136	126.2	115.1	55.6	74.5	170.0
62	60.1	105.4	120.4	60.1		73.8		79.2		140.7	130.7	119.4		77.5	176.0
64	62.5	109.3	124.6	62.7		76.7		82.3		145.4	135.2	123.8		80.5	182.0
66	65.0	113.2	128.8	65.5		79.7		85.5		150.3	139.9	128.1		83.5	188.2
68	67.6	117.3	133.2	68.3		82.8		88.7		155.4	144.7	132.5		86.5	191.4
70	70.2	121.4	137.6	71.2		85.9		92.0		160.5	149.5	136.8		89.5	201.0
72	72.9	125.7	142.2	74.2		89.1		95.4		165.7	154.5	141.7		92.9	207.4
74	75.6	130.0	146.8	77.2		92.4		98.9		171.1	159.6	146.6		96.3	213.8
76	78.4	134.5	151.5	80.3		95.8		102.4		176.6	164.8	151.4		99.6	220.6
78	81.3	139.0	156.3	83.5		99.2		106.0		182.2	170.1	156.3		103.0	227.8
80	84.2	143.6	161.2	86.8		102.7		109.7		187.9	175.6	161.2		106.4	235.0
82	87.2	148.4	166.2	90.2		106.3		113.5		193.7	181.2	166.6		110.2	242.6
84	90.2	153.2	171.4	93.6		110.0		117.4		199.7	186.8	172.1		114.0	250.2
86	93.3	158.2	176.6	97.1		113.8		121.4		205.8	192.7	177.5		117.8	258.0
88	96.5	163.2	181.9	100.7		117.7		125.4		212.0	198.6	183.0		121.6	266.0
90	99.8	168.4	187.4	104.3		121.6		129.6		218.3	204.6	188.4		125.2	274.0
92	103.1	173.7	192.9	108.2		125.6		133.8		224.8	210.8	194.5		129.4	282.4
94	106.5	179.1	198.6	112.1		129.7		138.2		231.4	217.2	200.5		133.5	290.8
96	110.0	184.6	204.3	116.1		133.9		142.6		238.2	223.6	206.6		137.7	299.4
98	113.5	190.2	210.2	120.1		138.2		147.1		245.1	230.2	212.6		141.8	308.2
100	117.2	195.9	216.2	124.3		142.6		151.7		252.1	236.9	218.7		146.0	317.0
102	120.9	201.8	222.3	128.5		147.1		156.4		259.3	243.8	225.4		150.6	326.2
104	124.7	207.7	228.5	132.9		151.7		161.2		266.6	250.8	232.1		155.2	335.4
106	128.5	213.8	234.9	137.3		156.4		166.1		274.0	257.9	238.7		159.8	345.0
108	132.4	220.0	241.3	142.8		161.1		171.1		281.6	265.2	245.4		164.4	355.0
110	136.4	226.4	247.9	146.5		166.0		176.3		289.4	272.6	252.1		169.0	365.0
112	140.5	232.8	254.6	151.3		171.0		181.5		297.3	280.2	259.5		174.1	375.4
114	144.7	239.4	261.5	156.1		176.0		186.8		305.3	287.9	266.9		179.2	385.8
116	148.9	246.1	268.4	161.1		181.2		192.2		313.6	295.7	274.3		184.2	396.4
118	153.2	252.9	275.5	166.1		186.5		197.7		321.9	303.8	281.7		189.3	407.2
120	157.7	259.9	282.7	171.3		191.8		203.1		330.4	311.9	289.1		194.4	418.0
122	162.2	267.0	290.1	176.6		197.3		209.1		339.1	320.3	297.2		200.0	429.2
124	166.7	274.3	297.6	182.0		202.9		215.0		348.0	328.8	305.3		205.6	440.4
126	171.4	281.6	305.2	187.5		208.6		221.0		357.0	337.4	313.5		211.1	452.0
128	176.2	289.1	312.9	193.1		214.4		227.1		366.2	346.2	321.6		216.7	464.0
130	181.0	296.8	320.8	198.9		220.3		233.3		375.5	355.2	329.7		222.3	476.0
132	185.9	304.6	328.9	204.7		226.3		239.6		385.0	364.3	338.6		228.4	488.4
134	191.0	312.5	337.1	210.7		232.5		246.0		394.7	373.6	347.5		234.5	500.8
136	196.1	320.6	345.4	216.8		238.7		252.6		404.5	383.1	356.5		240.7	513.4
138	201.3	328.9	353.9	223.0		245.1		259.3		414.6	392.8	365.4		246.8	526.2
140	206.6	337.3	362.6	229.4		251.6		266.1		424.8	402.6	374.3		252.9	539.0

Figure 4. Pressure - Temperature Chart

Subcooling and its measurement

In the system's condenser, conversion of vapor to liquid involves removing heat from the refrigerant at its saturation condensing temperature. Any additional temperature decrease is called subcooling. Finding liquid line subcooling requires determining the condensing pressure and two temperatures—the condensing temperature at the measured condensing pressure and the temperature of the refrigerant at the outlet of the condenser on the liquid line. The liquid line temperature involves measuring the surface temperature of the pipe at the outlet of the condenser. (See Figure 5.)

Note:
Condensing temperature is derived from using the PT chart. On new refrigerant blends with high temperature glide, this is called the bubble point (BP) temperature. See Figure 2.

To measure subcooling with a pipe clamp, or a Velcro pipe probe, allow the system to run long enough for temperatures and pressures to stabilize. Verify normal airflow and then find the liquid line temperature by clamping the pipe clamp around the liquid line. Attach the pressure/vacuum module to a service

port on the liquid line (or discharge line at the compressor if a liquid line service valve port is not available). Make a note of the liquid line temperature and pressure. Convert the liquid line pressure to temperature using a PT chart for the refrigerant type being used. The difference of the two temperatures is the subcooling value.

Trouble diagnosis

Data from superheat and subcooling measurements can be useful for determining various conditions within the HVAC/R system, including the amount of refrigerant charge and verifying the operating condition of the metering device. These measurements can also be used to determine the efficiency of the condenser, evaporator, and compressor.

Before making conclusions from the measured data, it is important to check external conditions that influence system performance. In particular, you should inspect and verify the proper air flow in cubic feet per minute (CFM) across coil surfaces and line voltage to the compressor motor and associated electrical loads. Remember to look for obvious problems at the coil surfaces such as dirty air filters upstream of the evaporator, or leaves and outside debris restricting airflow on the condenser.

Using superheat to troubleshoot

The superheat value can indicate various system problems including a clogged filter drier, undercharge, overcharge, faulty metering device, restricted airflow, or improper fan motor or blower direction. Suction line superheat is a good place to start diagnosis because a low reading suggests that liquid refrigerant may be reaching the compressor. In normal operation, the refrigerant entering the compressor is
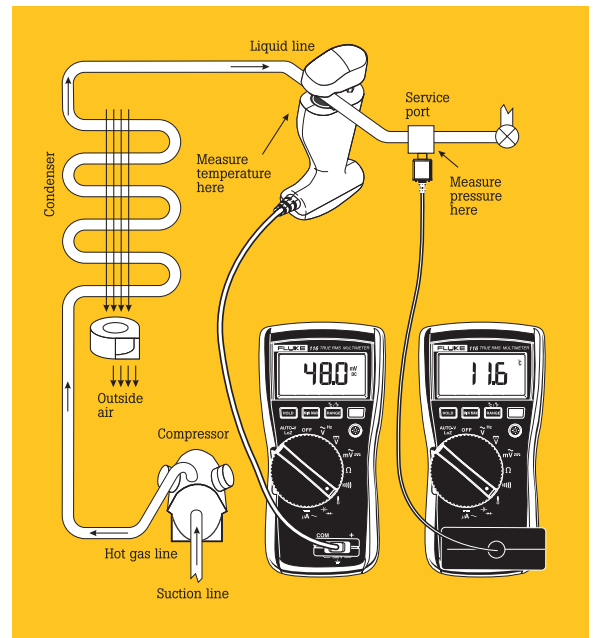
Figure 5. Subcooling. After verifying normal airflow, place the pipe clamp or Velcro probe on the liquid line. Note the temperature. Then attach the pressure/vacuum module to a port on the liquid line and measure the liquid line pressure. Determine the condensing temperature by using the temperature–pressure chart for the refrigerant type used. The difference in temperature is the subcooling value.

sufficiently superheated above the evaporator boiling temperature to ensure the compressor draws only vapor and no liquid refrigerant. On traditional HVAC/R systems, which utilize mechanical metering devices such as a TXV or cap tube, the superheat heating will vary between 8 °F to 20 °F. On newer systems, which use electronic expansion valves and solid state controllers, it is possible to see the superheat setting as low as 5 °F to 10 °F.

A low or zero superheat reading indicates that the refrigerant did not pick up enough heat in the evaporator to completely boil into a vapor. Liquid refrigerant drawn into the compressor typically causes slugging, which can damage the compressor valves and/or internal mechanical components. Additionally, liquid refrigerant in the compressor, when mixed with oil, reduces lubrication and increases wear, causing premature failure.

Measuring liquid line temperature with a DMM and a pipe clamp.

On the other hand, if the superheat reading is excessive—above 20 °F to 30 °F—it indicates that the refrigerant has picked up more heat than normal, or that the evaporator is being starved of refrigerant. Possible causes of this condition include a metering device that is underfeeding, improperly adjusted, or simply broken. Additional problems with high superheat could indicate a system undercharge, a refrigerant restriction, moisture in the system, a blocked filter drier, or excessive evaporator heat loads.

Using subcooling to troubleshoot

An improper subcooling value can indicate various system problems including overcharge, undercharge, liquid line restriction, or insufficient condenser airflow (or water flow when using water-cooled condensers).

The refrigerant is typically subcooled between 10 °F to 20 °F at the outlet of the condenser, however, some modern equipment may have subcooling values as low as 4 degrees in order to meet minimum efficiency standards.

For example, a very low reading between zero to 10 °F subcooling indicates that the refrigerant did not lose the normal amount of heat in its travel through the condenser. Possible causes for this condition include insufficient airflow over the condenser, metering device problems such as overfeeding, misadjustment, or being stuck too far open, or the system may be undercharged. Often times, the problem is simply that the condenser coil surface needs to be cleaned thoroughly to eliminate airflow restriction.

Excessive subcooling means the refrigerant was cooled more than normal. Possible explanations include an overcharged system, a restriction in the metering device, misadjusted (underfeeding), or faulty head pressure control during low ambient conditions.

Principles of the refrigeration cycle and troubleshooting summary

The next time you are called upon to service or maintain any HVAC/R equipment, remember to be patient and apply the principles you have learned in this application note. Check the superheat and subcooling at the unit. Be sure to do a visual inspection of the equipment to verify that all coil surfaces are clean and that fans are running in the right direction. You need to have the right tools and know-how to apply these principles to use the tool as it was designed. Fluke thermometers, digital multimeters, pressure/vacuum modules, and Fluke HVAC/R accessories will help you solve the problem and repair the equipment correctly the first time.

Measuring temperature and suction pressure to determine superheat.

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