CAPILLARY TUBES: THEORY AND PRACTICE

By: Henry Ahrens
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INTRODUCTION

When you look at a cap tube, you see a slender copper tube with a small inside diameter. If you install this tube between a condenser and an evaporator, it becomes a refrigerant control.

But placing cap tubes in the same category with thermostatic and automatic expansion valves, with low and high-side floats, would seem ludicrous. How can you compare precision needles and seats, bellows and diaphragms, floats and float chambers, springs, adjusting screws, and fittings to a piece of tubing?

The cap tube is inefficient, very slow to respond to evaporator loads, and without any compensating adjustments. "It is just a piece of tubing," you might say—and you would be right. However, since the first brass cap tube made its appearance in the 1930s—in a domestic refrigerator that used sulfur dioxide and a belt-driven compressor — the cap tube has overcome all of its unfavorable critics.

The combination of the sealed unit and the cap tube was a godsend to the refrigeration industry. Instead of being indifferent to the cap tube, manufacturers of domestic refrigerators, freezers, room air conditioners, and water coolers soon welcomed the cap tube and praised its simplicity, balancing action, and—most of all—its economy.

THEORY OF THE CAP TUBE AS A REFRIGERANT CONTROL

First and foremost, the cap tube acts as a pressure reducing device. If air or water is pressurized at the inlet, there will be a linear or equal reduction of pressure for each foot of tubing. For example, if water enters a cap tube at 50 psig, the pressure decreases at a constant rate as the water passes through the tube, as shown in Figure 1.

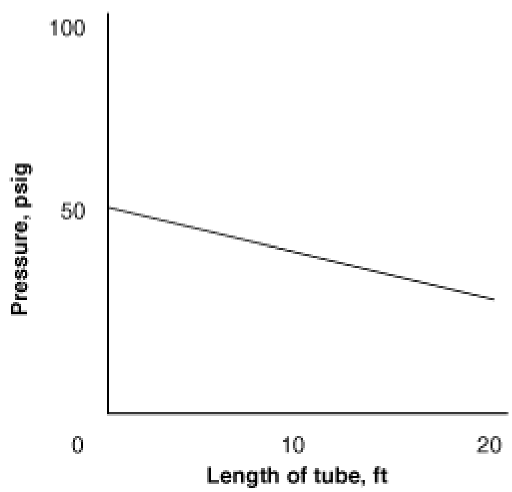

FIGURE 1 Water Pressure Drop

If refrigerant responded the same way as water, the cap tube could never be used as a refrigerant control. Why not? Because when the head pressure was low, the evaporator would be starved, and when the ambient temperature was high, the evaporator would be flooded with liquid (the flow rate would be greater than the rate of vaporization).

However, if there was a way to increase the flow rate when the head pressure was low, and decrease the flow rate at high ambient temperatures, you would have a refrigerant control. This modulating effect is exactly what happens when a cap tube is installed in a well-balanced system.

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The following two principles are involved:

- Liquid refrigerant flows faster than vapor (vapor restricts the flow of liquid).
- The colder the liquid, the faster the flow.

Figures 2, 3, and 4 show a condenser operating in three different ambient temperatures (with R-12). Note that in these figures and throughout this chapter, *all temperatures are in degrees Fahrenheit and all pressures are in psig*.

NOTE:

The temperature of the subcooled liquid at the inlet to the strainer varies inversely with the ambient temperature. As the ambient temperature rises, the temperature of the subcooled liquid is reduced. This is the basic reason why the flow rate modulates in a cap tube. Remember that vapor restricts the flow of liquid—a fact that will become more apparent as you discover what actually happens inside a cap tube.

The 20° subcooled liquid of the condenser in Figure 2 is entering a 10 ft. cap tube, shown in Figure 2A. Notice that the liquid refrigerant is reacting the same way as water—that is, the pressure drop is constant for each foot of tubing at 4 lb./ft. until the 8 ft. mark. Also note that the temperature remains the same until the 8 ft. mark. The numbers at the top of Figure 2A are those of the saturated temperature (the pressure scale is for R-12). It is interesting to note that as the liquid refrigerant passes through the cap tube, the subcooled temperature decreases. For example, liquid enters the tube at 20° subcooled, but at the 4 ft. mark the liquid pressure is 101 lb. and at the same temperature of 80°.

However, the scale shows that R-12 at 101 lb. should be 91°, which means that the liquid is only 11° subcooled. And at the 6 ft. mark, it is only 6° subcooled. Now look at the 8 ft. mark where both the temperature and the pressure of the liquid refrigerant inside the cap tube are at the saturation point and equal to the figures in the R-12 scale.

The controlling factor (the modulating effect) occurs after the 8 ft. mark. As the pressure drops after that point, the liquid refrigerant pressure will be below its saturation level. The refrigerant will boil (cause bubbles to form) inside the cap tube, in the same way as in an ordinary evaporator. The gas pockets, or bubbles, will restrict the flow of liquid, causing a lower flow rate, which will result in more violent boiling and, in turn, more restriction.

To summarize Figure 2A: liquid refrigerant enters the cap tube at 20° subcooled. The subcooled temperature decreases with each foot of tube until the liquid reaches the 8 ft. mark, where the refrigerant is at its saturation level. At that point, the liquid has traveled a distance of 8 ft. As the liquid travels further, bubbles start to form. The remaining 2 ft. are referred to as the bubble length. As the refrigerant travels through the bubble length, both the temperature and the pressure are reduced and remain at the saturated level.

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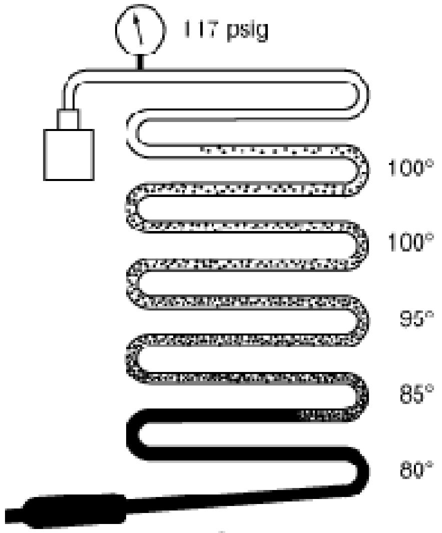

Figure 2

Condensing temperature 100°
Liquid out temperature 80°
Subcooled 20°

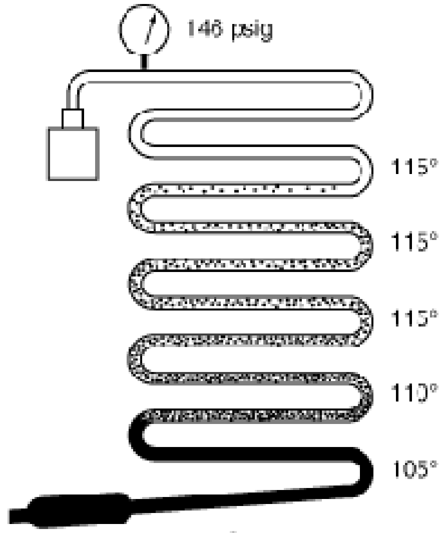

Figure 3

Condensing temperature 115°
Liquid out temperature 105°
Subcooled 10°

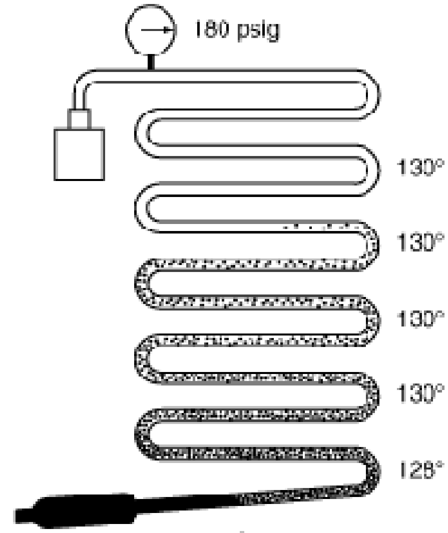

Figure 4

Condensing temperature 130°
Liquid out temperature 128°
Subcooled 2°

SATURATED PRESSURE TEMPERATURE R-12
Temperatures are indicated in degrees Fahrenheit.

PSIG	117	113	109	105	101	97	93	89	85	60	20
TEMP	100°	98°	96°	93°	91°	88°	86°	83°	80°	62°	19°

Figure 2A

PSIG	117	113	109	105	101	97	93	89	85	60	20

TEMP	80°	80°	80°	80°	80°	80°	80°	80°	80°	60°	19°
FEET	0	1	2	3	4	5	6	7	8	9	10

SATURATED PRESSURE TEMPERATURE R-12
Temperatures are indicated in degrees Fahrenheit.

PSIG	146	142	138	134	130	126	117	105	77	47	12
TEMP	115°	113°	111°	108°	107°	105°	100°	92°	75°	50°	6°

Figure 3A

PSIG	146	142	138	134	130	126	117	105	77	47	12

TEMP	105°	105°	105°	105°	105°	105°	100°	92°	75°	50°	6°
FEET	0	1	2	3	4	5	6	7	8	9	10

SATURATED PRESSURE TEMPERATURE R-12
Temperatures are indicated in degrees Fahrenheit.

PSIG	180	176	170	162	152	140	125	105	70	45	15
TEMP	130°	128°	126°	122°	118°	112°	105°	93°	70°	48°	10°

Figure 4A

PSIG	180	176	170	162	152	140	125	105	70	45	15

TEMP	128°	128°	126°	122°	118°	112°	105°	93°	70°	48°	10°
FEET	0	1	2	3	4	5	6	7	8	9	10

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The cap tube in Figure 3A is connected to the condenser in Figure 3, operating in a warm ambient temperature of 85°. The subcooled liquid is now only 10°. The liquid in the cap tube will reach its saturated level at the 5 ft. mark, which leaves the remaining 5 ft. as the restrictive bubble length.

The cap tube in Figure 4A is connected to the condenser in Figure 4, operating in a hot ambient temperature of 100°, with a 2° subcooled liquid. The liquid has to travel only 1 ft. to reach its saturated level. This leaves a 9 ft. bubble length to restrict the flow rate.

To sum up briefly: as the ambient temperature rises and falls, the temperature of the subcooled liquid in the condenser also changes. It is this variable subcooled temperature that determines the bubble length in the cap tube—which, in turn, modulates the flow rate. This phenomenon in effect transforms the cap tube from a pressure-reducing device to a refrigerant control.

The figures that are used to show temperatures and pressures inside the cap tube are not meant to be accurate, but simply to illustrate how the modulating flow is achieved. This leads to an important point: the cap tube does in fact have an advantage over the thermostatic expansion valve (TXV) when it comes to "runaway overloads."

For example, assume that a 3 ton central air conditioning system equipped with a thermostatic expansion valve and a liquid receiver is operating in a 100°F ambient temperature with a dirt-clogged condenser. The head pressure is above its designed maximum. The inefficiency of the condenser causes the back pressure to rise, which puts an additional load on the compressor and motor. As a result, the compressor can no longer maintain the evaporator load. This in turn causes an additional load on the condenser and an even higher head pressure—and so on until the overload mechanism is energized, resulting in a complete shutdown of the entire system.

However, in a cap tube system operating under the same conditions, the overloaded condenser results in a different outcome. Because the condenser cannot fully condense all of the vapor, liquid and vapor enter the cap tube. Now the entire length of the cap tube is the bubble length, applying the brakes to the flow rate and actually reducing the overall efficiency of the entire system. Instead of a total shutdown of the entire system, the rise in evaporator temperature alerts the proprietor to call the service contractor.

In the early 1960s, a manufacturer of window air conditioners took advantage of bubbles entering a cap tube by placing a small heater around the strainer before the cap tube inlet. The thermostat was in reality a rheostat that controlled the intensity of heat to the strainer—which in turn regulated the amount of bubbles entering the cap tube. The first stage of heat to the strainer was to reduce the subcooled liquid temperature (increasing the bubble length). The second stage was to create a boiling action, in various heat intensities, to decrease the overall efficiency of the evaporator.

Before the oil and electric power crunch, the ultimate in air conditioning comfort was to run air conditioning units continuously and adjust the compressor capacity or evaporator efficiency to the heat load. This method of regulation eliminated the discomfort of temperature fluctuations when the unit cycled on the thermostat.

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CAP TUBE SERVICE PROBLEMS

The two best problem solvers are the low- and high-side gauges. They can give you the answer to such questions as:

- Is the system short of refrigerant?
- Is the cap tube restricted?
- Is the compressor inefficient?
- Are there non-condensable gases present in the system?
- Is the reason for hard starting because the pressures in the system are not equalizing? (Up to 95% of all domestic refrigerators do not have start capacitors on the compressor motors. This type of "low starting torque" motor will not restart a compressor unless both high and low sides have equalized to the same pressures.)
- Is the system overcharged?

The most frequent problem is one in which the service engineer discovers that the evaporator is only 75% active on a "not cold enough" complaint. Is the system short of refrigerant, or is the cap tube slightly restricted? Installing a set of gauges may not show the difference. Figure 5 shows a schematic of a cap tube system that is short of refrigerant, and Figure 6 shows the same system with a restricted cap tube. Both evaporators are equally short of refrigerant, but the amount of liquid missing from the restricted cap tube system is backed up in the condenser.

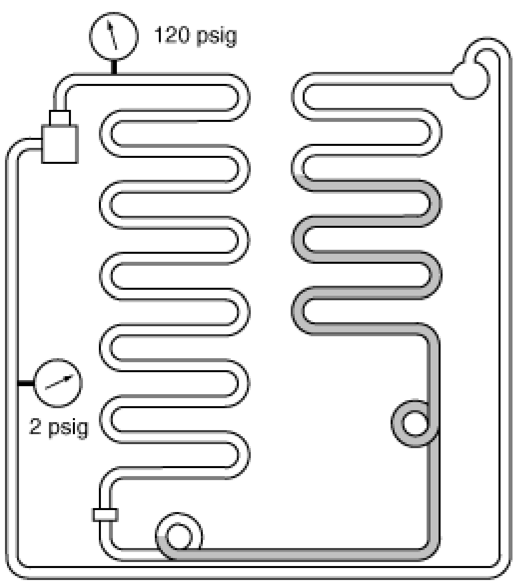

FIGURE 5 System Short of Refrigerant

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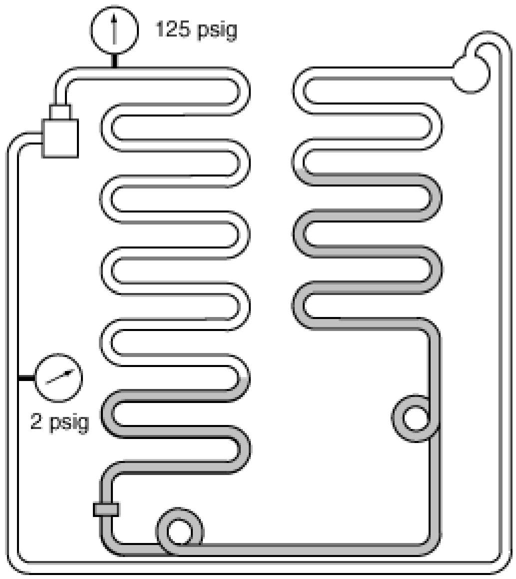

FIGURE 6 Restricted Cap Tube

Both the high-side and low-side gauges will show lower-than-normal readings. Although the high-side gauge on the system with the restricted cap tube may read 5 lb. higher than the gauge on the system that is short of refrigerant, it would remain a below normal high-side pressure reading.

Figure 7 illustrates what occurs when you add refrigerant to the system with the restricted cap tube. The additional refrigerant has now piled up higher in the condenser, decreasing the effective condensing area. The resulting high head pressure increases the flow rate in the cap tube, bringing the evaporator up to a normal operating level.

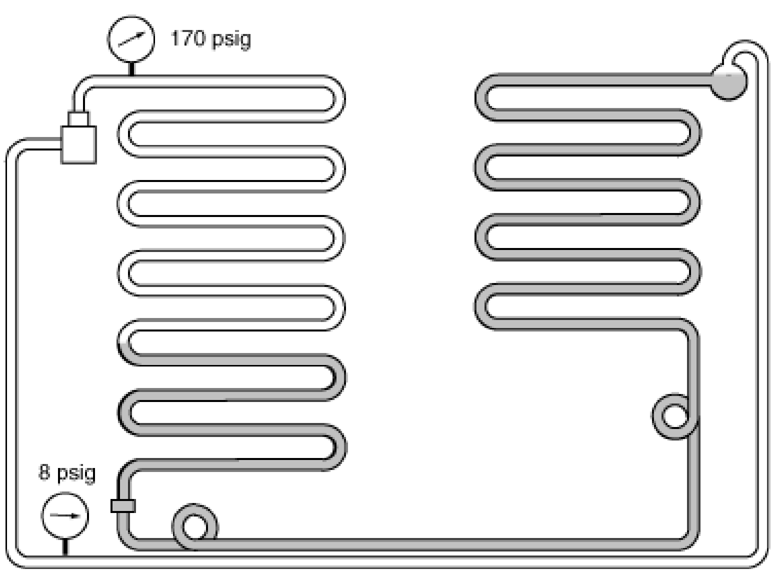

FIGURE 7 Refrigerant Added to Restricted Cap Tube

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If the restricted cap tube unbalanced the system, the additional refrigerant has now compounded the problem. On the off cycle, the system may never equalize its pressures before the unit restarts, causing the motor to cycle on the overload until the system does balance. The overheated winding that results from the excessive head pressures, plus the high locked-rotor amperages, will eventually burn the motor winding insulation.

The restricted cap tube problem is not always a black or white situation. There are some gray areas.

Are you ever justified in knowingly overcharging a system that has a restricted cap tube? That all depends on the system in question. In the case of a 20-year-old refrigerator, the service engineer may attempt to explain the situation to the consumer in this way: "I can give you better refrigeration by adding more refrigerant, but I honestly don't know how long the refrigerator will run before there is a total breakdown. To replace the defective cap tube would be too expensive in my opinion, because it involves a great deal of labor." In most cases, a new path has to be made for the cap tube because the original path is embedded in the rigid insulation that was foamed at the factory.

Window air conditioning cap tubes are the easiest to replace, providing the work is performed in the shop. Converting someone's home into a repair shop is inadvisable and dangerous.

In small central air conditioning and commercial refrigeration systems, a restricted cap tube must be replaced, even though the cost of labor is high for such a procedure. To circumvent the problem by overcharging the system will eventually multiply the cost 10 times.

It is very helpful to remember that all cap tube units are well balanced systems. Each component has a balanced relationship to every other component.

A replaced compressor must have the same volumetric capacity as the original. A higher capacity would throw the cap tube out of balance and react as a restricted cap tube. The original flow rate would be too low for the higher volume compressor. If a replaced compressor had a lower volumetric capacity, the system would function with an abnormally high back pressure. The compressor would not be able to keep up with the original cap tube flow rate. All the symptoms of an inefficient compressor would show up on the gauge readings.

If you have to change the condenser, be sure to have one as close to the original as you possibly can. By oversizing the condenser, you are not making the system more efficient. You are actually creating more problems by upsetting the balance of the entire system. First of all, an oversized condenser will liquefy the refrigerant faster than the flow rate through the cap tube. This will cause the refrigerant to back up in the condenser in the same manner as if the cap tube was restricted. Secondly, the system may not balance in time for the on cycle. Finally, when the system does balance, all the liquid refrigerant will spill over into the suction line, which may cause an oil slugging problem.

For units that have receivers, high efficiency condensers are an excellent choice. You do not have any of the problems that you have with cap tube systems, because the condensed liquid refrigerant empties into the receiver as fast as it is condensed.

The evaporator in a cap tube system is sometimes called the cold receiver, because it holds the entire charge after the unit pressure has balanced. The relationship of the evaporator to the condenser is such that the condenser must hold the full charge of the system in case the cap tube becomes totally clogged. Putting more refrigerant into the unit than the condenser can hold may cause extreme hydrostatic pressures that can burst the condenser tubes.

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The refrigerant charge also plays a part in the sometimes precarious balance of a refrigeration system, since any change in the original refrigerant charge can affect the efficiency of the entire system.

When it comes to refrigerant considerations, one of the most delicately balanced units is the room or window air conditioner. First of all, the evaporator operates at a temperature so close to the freezing point of water that the slightest loss of refrigerant will start a frost action on the evaporator. During the evening hours, when the load on the condenser diminishes, the slight frost can develop into a fully frozen evaporator. Secondly, if a new window air conditioner leaves the factory a few ounces short of refrigerant, there could be just enough refrigerant left in the system to produce a cooling effect in the room, but not enough to cool the compressor. A compressor that runs continuously during a hot spell will overheat if the return vapor is superheated to the high ambient temperatures of the compressor section. New compressors are vulnerable to bearing seizures if some of the clearances are marginal.

You might say that a window air conditioner is a very compact refrigeration system. To make it as small as possible and still maintain a reasonable EER (energy efficiency ratio), you must push a lot of air over the condenser and evaporator. To get the maximum BTU output from both evaporator and condenser tubes, you have to have as many fins per inch as possible without interfering with the air movements. The air blast has to be just below the decibel level that the consumer (and neighbors) are able to tolerate.

Pushing a lot of air through a lot of fins is the perfect recipe for trouble. In an urban environment, air contamination combined with water or moisture forms a paste that collects, in time, on the condenser fins. If the contaminants are not periodically removed from the fins, the heat of the condenser will harden this mess into something that will not only attack the fins, but will also defy all types of removal methods. The loss of some condenser efficiency in a compact system is usually the beginning of downhill struggle. High condensing pressures and temperatures start a series of problems that can end in irreparable damage.

Anything more than a 10% reduction in air over the evaporator generally ends up as a completely frosted evaporator. A clean evaporator and a clean air filter are good safeguards. However, if you should sense that there is still something wrong with the air flow, despite a clean evaporator and filter, check the air vanes on the squirrel cage fan. On older units, dust will collect on the vanes and fill in the curve, making them flat. This can reduce the air volume by as much as 20%.

One of the best diagnostic instruments for refrigeration problems is the digital thermometer that has two small sensors for remote readings. This instrument, combined with a good set of gauges, can pinpoint almost any defect in cap tube systems.

Frequently all the symptoms of a complaint point toward a defective thermostat, but in reality the unit is either short of refrigerant or has a restricted cap tube. These types of problems occur in systems that have the bulb of the thermostat attached directly to the evaporator. A particular case in point is an evaporator that has a frost and defrost cycle. The problem is that the evaporator keeps frosting up, does not defrost, and a warm cabinet is the result. This type of thermostat is supposed to maintain a constant cut-in point of about 36° to 40°F. Setting the thermostat colder or warmer controls only the cut-out point or the differential.

If the bulb clamp is holding the bulb securely to the evaporator, you will find that either the system is slightly short of refrigerant or the cap tube is restricted. The two tell-tale indications are:

- The low-side gauge reading will be lower than normal.
- The superheat across the evaporator will read more than 15°.

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You will get the same symptoms if the cap tube is slightly restricted, except that the head pressure readings will be lower than normal for a gas shortage and perhaps slightly higher for a cap tube restriction.

What actually happens is that only about 75% of the entire evaporator is being supplied with refrigerant. This reduces the load to the compressor, which pulls down that part of the evaporator to very low temperatures. The only way that the temperature will reach the thermostat bulb will be by the conductivity of the inactive part of the evaporator. When the thermostat finally cuts out, most of the evaporator is at a very low temperature compared to the inactive part (where the thermostat bulb is located). The inactive part, which does not contain any liquid refrigerant, warms up rapidly and starts the unit while the active part of the coil is still frosted.

When the thermostat does go out of adjustment, it is to the advantage of both contractor and consumer to replace it. Readjusting a thermostat in most instances is guesswork. In systems where the unit is controlled by the cabinet air temperature, the evaporator is usually the blower type. In this type of system, you can still get a frost-blocked evaporator with a perfect charge and good thermostat. The problem is in the misuse of the cabinet. A box that is controlled by the cabinet air temperature is designed mainly for storage, with infrequent door openings. If you take this cabinet and use it for retail sales—of canned beer, soda, etc.—the frequent door openings will cause the air thermostat to cut in the unit before the evaporator is fully defrosted. Once frost or ice starts to accumulate on the evaporator, it acts as a rolling snowball, until the unit has to be manually defrosted.

CHARGING CAP TUBE SYSTEMS

The charging and final checking of a cap tube system are time-consuming procedures. Whether you charge with a mixture of vapor and liquid, or even "dump" the full charge, you will not reduce the overall time it takes to complete the job.

The problem lies in overloading the condenser. When you add gas, or recharge the unit, you are putting more pressure into the low side than the system was designed for. The large volume of vapor will temporarily overload the compressor and condenser. This will cause the condenser to liquefy the refrigerant faster than the refrigerant can flow through the cap tube. The result is a backup of liquid in the bottom tubes of the condenser. Before you check out any cap tube system, you must stabilize the unit by shutting it down to equalize the pressures. This empties the condenser into the evaporator. When you restart the unit, observe both high- and low-side gauges and the superheat readings across the evaporator. (This will be detailed later, in the "Final Test" section.)

How fast should you charge a cap tube system? It all depends on the size of the system and its application. If the system contains about 1 lb. of refrigerant, you can charge mostly vapor. Larger units can be charged with a combination of liquid and vapor.

Of the three applications of cap tube systems—low, medium, and high back pressure—the most time-consuming work is on freezers. First of all, the cap tube is highly restrictive. Because of the low flow rate, the condenser can easily be overcharged. This fact makes it necessary to stabilize the unit more often and means that it takes a longer time to equalize. Many service contractors refuse to recharge a freezer in the field. Removing the cabinet to the shop relieves the service engineer of a time-consuming task and gives the shop personnel enough time to test the unit thoroughly.

The easiest cap tube system to charge is the room air conditioner or the small central air conditioning unit. Most of these units will stabilize in about two minutes, which simplifies the entire procedure.

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ADVANTAGES OF CHARGING SLOWLY

Charging a cap tube at a slow rate gives you a clearer picture of how all the components are working. The high-side gauge tells you how efficiently the compressor and condenser are reacting to the refrigerant. Most importantly, you can see by the gauges if the cap tube is clear. If the head pressure does go too high, you must ask yourself, "Did I charge too fast or is the cap tube restricted?" You will find the answer by shutting down the unit, balancing the pressures, and observing the gauges when you restart the compressor. A persistent excessive head pressure and very low back pressure will affirm a restricted cap tube. You should be able to spot a restricted cap tube before you are half way to fully charging the system. Now you can see the disadvantage to "dumping" the full charge. If you put the entire charge into the low side, you must be extremely careful to prevent oil slugging in the compressor (by running it intermittently). Each time you stop the unit, you have to wait for some equalization of pressures before you restart the compressor. Once the entire charge is in the system, it is the wrong time to check the cap tube.

If you put the entire charge in the condenser, you cannot restart the compressor until at least half of the condenser has emptied into the evaporator. When you do start the unit, the high-side pressures will go extremely high because half or more of the condenser is still filled with liquid. Shutting off the unit will not empty the entire condenser if the evaporator is warm. Only a small amount of refrigerant is required to cause the pressure to build up in a warm evaporator, and even though the pressures may equalize, there will still be a sizable amount left in the condenser. No matter how you do it, putting the entire charge in the system is a poor way to check for a restricted cap tube and, in the long run, a waste of time.

FINAL TEST

Obtaining the desired superheat temperatures across the evaporator is equally as important as good gauge readings. The amperage and voltage check should also be part of the final test.

The best instrument for checking superheat temperatures is a digital thermometer that has two sensors for remote readings. The sensors may be diodes, thermistors, or thermocouples. There are two methods of obtaining superheat temperatures:

- Place one sensor in the middle of the evaporator and the other at the outlet tube of the evaporator.
- Use the low-side gauge readings instead of the middle evaporator sensor. Using the low-side pressure with the saturated pressure temperature chart will give you the equivalent of the refrigerant temperature in the evaporator.

It does not make any difference whether the repair was a major one, such as replacing a compressor, or something minor like repairing a slight leak. The entire job now rests on the final check of the superheat across the evaporator. There is no way that you can determine the superheat by touching the suction line. You can say that the suction line feels "cool" or "cold," but you can never say that there is an 8° or 10° superheat across the evaporator unless you have temperature sensors that indicate the degree.

To illustrate the importance of obtaining the correct superheat, suppose that you have an evaporator with 50 ft. of tubing—ten rows of 5 ft. each. The evaporator is designed for 40°F at a 95°F ambient temperature. With a 5° superheat, you have nine rows of tubing at 40°F and the last row at 45°F. At 20° superheat, you have about five rows at 40°F, the sixth at 45°F, the seventh at 50°F, the eighth at 55°F, and the last row at 60°F.

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Touching a 60°F sweaty suction line on a hot, humid day may give you the illusion that the line is cold. In reality, the evaporator has an effective cooling area of only about 50%. By not obtaining the correct superheat, you can upset all the good work that was done on the system.

What is the best superheat? It all depends on the type of system you are charging. If it is a domestic refrigerator that has an accumulator at the outlet of the evaporator, the end thermocouple should be attached to the inlet side of the accumulator. You should look for superheat of 4° to 5°. Never place the sensor at the outlet of the accumulator, because you will be negating its purpose (preventing liquid from entering the suction line). When you are charging a room air conditioner, a good superheat is about 10° in an 85°F ambient temperature and about 5° in a 100°F ambient temperature.

Most air conditioner manufacturers want a cool return at the compressor in order to prevent any overheating. A long suction line should be carefully insulated to prevent an excess of superheat in the suction vapor.

The average temperature of the suction line (near the compressor) should be about 55°F with an outside ambient temperature of 90°F. There are a lot of variables that depend on the design and load on the evaporator.

Unfortunately, the service engineer cannot refer to a chart that gives specific temperature and pressure values for every manufacturer and every type of cap tube system. Unless you have their engineered standards, you have to make a qualified guess on the final test readings. But each time you charge a cap tube system and check it out to your satisfaction, you become more qualified at this type of "guesswork."

INEFFICIENT COMPRESSORS

Suppose that you are going to rate cap tube systems on a scale of 1 to 10. A perfectly balanced cap tube system would be rated 10. The compressor, condenser, evaporator, the flow rate of the cap tube, the amount of refrigerant—all would be rated 10.

Now imagine a refrigerator or an air conditioner that has a compressor rated a 2 or 3. You can recognize this kind of inefficiency easily by checking the gauge readings to see if they indicate a high back pressure or a very limited head pressure. However, a compressor rated a 7 or 8 may show almost normal characteristics in cool ambient temperatures by cycling on the thermostat. If it is a quiet-running compressor, no one would realize that it was running most of the time. But as the ambient temperature rises, either the temperature of the food or the temperature of the air conditioned space will tell the consumer that something is amiss.

Installing a compressor with a 7 or 8 rating in a cap tube system with a rating of 10 is similar to installing a 0.75 hp compressor in a 1 hp system. When you install a set of gauges, you get positive indications of an inefficient compressor. The back pressure will be higher than normal, and the head pressure lower than normal.

What, then, is a normal low-side reading? When a cap tube system with a rating of 10 is operating within its designed limits, the compressor is always ahead of the load. The longer the unit runs, the colder the evaporator and the lower the suction pressure. To be more specific, according to the saturated pressure temperature scale, the low-side pressure is actually slightly lower than the corresponding temperature of the liquid refrigerant. This is due to the compressor's ability to pull vapor from the evaporator at a faster rate than it is being boiled off by the refrigerant. On the other hand, an inefficient compressor struggles to keep up with the amount of vapor from the evaporator.

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Does an inefficient compressor (rated 8, say) deliver a lower superheated vapor to the condenser when compared to a compressor with a rating of 10? The answer can be yes or no. If the reduced efficiency is caused by worn pistons or leaky suction valves, the answer is yes. If the compressor has leaky discharge valves, you will get superheated vapor higher in temperature than with a 10 rated compressor.

This can best be explained by using a theoretical 10 rated compressor that draws 5 cubic inches (in^3) of vapor through the suction valve and discharges 5 in^3 through the discharge valve. If the piston is worn, it will still take in 5 in^3 on the downstroke. But on the (compression) upstroke, the vapor will go through the discharge valve, and some will "blow by" the worn piston. With a leaky suction valve, the piston draws in the 5 in^3, but on the upstroke, some of the vapor goes through the discharge valve and some back again through the leaky suction valve.

In the case of a leaky discharge valve, as the piston goes down, some of the hot discharge vapor follows the piston, and some of the vapor goes through the suction valve. As the piston goes up, all of the hot vapor goes through the discharge valve, but some will leak back again on the downstroke. It is this repeated re-compression that gives this type of inefficient compressor an unusually hot discharge vapor.

ROTARY COMPRESSORS

By the very nature of its design, the rotary compressor is more efficient than its piston cousin. The dome of the rotary compressor is different because it is on the high side. Vapor from the evaporator first enters a vertical accumulator before going directly into the low side of the compressor. The vapor then is discharged into the dome before it enters the condenser. In the piston-type compressor, vapor from the evaporator first enters the dome and then is drawn in by the piston and pumped through the case directly into the condenser. If the two compressors were on two units with identical loads, you could not tell the difference by gauge readings. However, if both cap tube units were shut down for 24 hours or more and then restarted, the gauges would show some startling differences.

In the piston-type compressor, vapor from the dome and evaporator is pumped directly into the condenser. In a few minutes, the pressure and temperature are high enough to condense the refrigerant, which then goes through the cap tube. You can see this on the low-side gauge when the back pressure, after going down, starts to level off and then begins to rise.

When the rotary compressor restarts, only the vapor from the evaporator is pumped into the dome and condenser. The refrigerant that had migrated into the dome will not go into circulation until there is enough heat from the compressor and winding to vaporize all the refrigerant. In the meantime, the compressor is pumping out all the vapor from the evaporator, and the gauge may go into a vacuum before there is enough refrigerant in the condenser to stop the downward swing of the low-side gauge. If you have no prior experience with rotary compressors and you install a set of gauges on this unit, you may panic when you see the action of the low-side gauge. "Must have a bad leak," you think. "I hope it's not on the low side. Or maybe it's a restricted cap tube." After you shut off the unit, there is enough pressure in the high side to convince you that there is refrigerant in the system. If checking for leaks is non-productive, restarting the unit will show a more reasonable low-side reading as more refrigerant goes into circulation.

The problem becomes a matter of time with the first cycle after a long shutdown period. The lower the operating temperatures of the evaporator, the more restriction there is in the cap tube, and the longer it will take for the first cycle. It is not uncommon for a freezer to take 4 to 6 hours to pull down the cabinet to only 32°F.

Most rotary compressors have a discharge valve. If this valve becomes inoperative, the motor may go into overload because of the double loading on the roller. As the roller passes the dividing blade to take in vapor from the low side, it exposes the discharge port, permitting the high-pressure vapor to mix with the low-side vapor that is about to be compressed. It is this high loading of the roller that causes the motor overload.

If the roller has lost some of its close tolerances, the compressor will show signs of inefficiency. But in most cases, the defective discharge valve will manifest itself as a high load on the motor.

NONCONDENSABLE GASES IN CAP TUBE SYSTEMS

Methane, carbon monoxide, carbon dioxide, nitrogen, and oxygen are the noncondensable gases usually found in hermetic systems. The last three mentioned are the most frequent gases and are often the result of air left in the system from the factory. They also may result from an inadequate evacuation after an installation or after repairs were made.

The destructive effects that these gases have on the system depend on three factors:

- the quantity of gas
- the size of the unit
- the amount of time that the gas is allowed to remain in the system.

If there is enough air in the system to raise the head pressure by 10%, you most assuredly have a time bomb in the unit. Whenever the ambient temperature goes to 90°F and above, the oxygen begins to attack the oil vapor. The amount of sludge, tar, and acid will depend both on the temperature and on how long it is sustained. Even short periods of time can have a worsening effect, because the damage is accumulative. Any damage to valves, valve plates, and bearing surfaces is nonreversible.

The life span of this system will depend on the discovery of the gases and their removal. The tell-tale evidence is excessive head pressure and discharge temperature, and both contribute to a loss of overall efficiency. The best time to remove all of the noncondensable gases from a cap tube system is when there is a liquid seal at the inlet to the cap tube. Purge from the top of the condenser immediately after the unit is turned off. Short purges of 1 second duration are usually sufficient.

Air will circulate throughout the system if there is no liquid seal at the cap tube inlet. On days when the load and ambient temperature encourage subcooling in the condenser, a liquid seal at the cap tube will prevent any air from entering the cap tube while the purging operation is in progress.

WHAT IS NORMAL HEAD PRESSURE?

You can estimate the average pressure for most air cooled condensing cap tube systems by using the factor of 35—that is, add 35° to the ambient temperature and then find the equivalent pressure on the saturated pressure temperature scale. In order to say what is normal for a particular cap tube system, you must refer to the manufacturer's service manual.

It is not uncommon to find a difference of 10% or more in head pressures from six different manufacturers of room air conditioners in their service manuals. In fact, it's not uncommon to find a 10% difference in head pressure specifications from one manufacturer on units that have the same horsepower but different EERs.

Experience is probably the best guide for the service engineer in determining head pressure. However, if you wish to know whether a particular unit is operating at its lowest head pressure, check the temperature at a mid-point of the condenser. Now, find the corresponding pressure for the temperature reading on a

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saturation pressure temperature chart. If the chart shows a lower pressure than the gauge pressure, it means that the condenser contains some noncondensable gases. If the chart and the gauge pressure are equal, it tells you only that there are no noncondensable gases present. It does not tell you that the unit is operating at the lowest possible head pressure.

Are the fins and tubes of the condenser clean? Are the fan blades clean? Is the condenser fan motor running at full speed? Condensers operating outdoors in urban areas should be cleaned at least every two years with approved solvents. All indoor units should be cleaned twice a year by the best method for the individual situation.

Cap tube units operating in ambient temperatures of 90°F or more with more than 10° subcooled liquid should be eyed with suspicion as a cause of excessive head pressure. A liquid backup in the condenser will bring on the subcooling and high head pressure in hot ambient temperatures.

A cap tube restriction, an overcharge, or a combination of both is the usual cause. Touch the return bends from the middle of the evaporator down to the bottom, and you can find where the liquid is backed up by feeling where there is a sudden drop in temperature.

In a situation where the head pressure remains high despite all the remedial methods, place a small screwdriver between the fins and try to move the fin away from the condenser tube. Fin tightness to the tube should be checked in different sections of the condenser. It is not unusual for some condenser manufacturers to release a number of condensers on which the fins do not make good contact with the tube before the error is discovered and corrected.

HARD-STARTING CAP TUBE UNITS

If a compressor does not start each time the thermostat calls for cooling, it is generally referred to as a hard-starting compressor. A hard-starting compressor is actually an intermittent problem. The compressor either starts most of the time or does not start most of the time-however, it does run.

Of all the reasons for hard-starting compressors, the most common is low voltage. All manufacturers of hermetic compressors guarantee that their compressors will start at plus or minus 10% of their rated voltage. This means that a 115-volt (V) unit must have at least 104 V during the starting high surge of current. What most service engineers fail to recognize is that the 104 V must be at the compressor terminals. Reading 115 or 110 V at the electrical outlet box does not tell you the entire story. From the outlet to the plug and lead wires, through the maze of connections and controls, only one slightly loose or corroded connection will result in a high-resistance connection and perhaps less than 95 V at the terminals.

A true low-voltage condition, in which the voltages at the outlet and the terminals are at the reduced 10% level during the starting surge, may require a "starting booster."

Where there is a starting problem, there may also be a running problem with units that draw more than 12 amperes (A) full load. You should not walk away from the unit after installing a starting booster until the voltage is measured while the unit is running. If the reading is hovering near a 10% reduced voltage, you may be sure it will get worse when the load increases. A motor overload device can work efficiently under lock rotor conditions (hard starting), but may not be sensitive enough to prevent the winding insulation from a slow breakdown. A unit running at low voltage overheats slowly as the winding temperatures climb to 250°F and more. Most burnouts are due to this type of malfunction, and the only remedy is to correct the cause for the low-voltage condition. If the voltage is good at the power meter, then the problem is on the premises. A low voltage reading at the meter can be explained or remedied by the power company.

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A low voltage reading at the compressor terminals but a good reading at the electrical box simply means that there is a high resistance junction somewhere in the electrical harness or control switches. One fast way to detect the culprit is to run the unit for at least ten minutes. Shut off all current and touch all junctions, connections, and control binding posts for hot spots. Using a digital ohmmeter is an accurate but time-consuming method of finding the high-resistance connection .

Most low-temperature cap tube systems use a capacitor-start motor. This motor has a high starting torque, which is necessary for starting the compressor against pressures that have not equalized. There are many occasions when the thermostat calls for cooling but, due to the high restrictive cap tube in freezers, the system cannot balance in time. Most manufacturers of split systems that utilize cap tubes in small central air conditioning units use capacitor-start compressors. The high starting torque of these units is necessary for starting an unbalanced system. In situations where the air handler is placed more than 20 ft. from the condensing unit, the long liquid line may extend the balancing time beyond the cut-in point of the thermostat.

In a hard-starting situation, where the voltage is adequate and there is no start capacitor on the compressor (these *permanent split capacitor* units are called PSC units), the installation of a set of gauges is a must.

Run the unit for at least 15 minutes before you shut it off and check how long it takes the system to balance. The "rule of thumb" is: the colder the design temperature of the evaporator, the more restriction there is in the cap tube, and the longer the system takes to balance. You can usually expect times like these:

- Room air conditioners—1 to 2 minutes.
- Central air conditioning unit—2 to 3 minutes.
- Combination refrigerators and freezers to 5 minutes.
- Freezers—5 to 7 minutes.

Most prolonged delays in balancing are basically caused by an excessive head pressure. The fundamental reasons for high head pressures are discussed in the previous section, "What Is Normal Head Pressure?"

Compressors with high starting torques (starting capacitor and relay) are rarely encountered in hardstarting situations. The exception occurs when a low-voltage condition causes the relay to chatter a few times before the compressor starts. Then it is just a matter of time before the contact points become pitted from the arcing. The inevitable result will be a hit-or-miss situation when good contact is required for starting the compressor. Checking the µFd (microfarad) rating of the start capacitor with an instrument is also advisable.

TIGHT COMPRESSORS

The tight compressor is a very "democratic" component. That is, it will associate with all types of refrigeration systems—small and large commercial units, small and large air conditioning systems, and every type of cap tube system. Because it is in the "tight" category and not in the "seized" or "stuck" group, it is actually an intermittent problem in the hard-starting family.

(For the record, most service engineers define an *intermittent* problem as a malfunction that only takes place while you are listening to the complaint on the phone. Either it corrects itself as you are on the way to the job, or it remains well hidden when you arrive, waiting to come out again as soon as you leave the premises!)

A *tight* compressor means that some component—the connecting rod, main bearings, or piston—has marginal clearance for lubrication and overheats during the running cycle. The overheating causes the bearings or piston to tighten on the moving surfaces. This tightening effect is just below the point of seizing, and it is the inertia of the rotor that keeps the motor and compressor running. But when the compressor cycles on the thermostat or some other control, a variety of hard-starting conditions comes into play, including the cooling down period and the amount of starting torque necessary for restarting.

This type of problem can be very frustrating to the service engineer, especially if you arrive on the job when the unit has been off for more than 4 hours, and it starts immediately.

The best the consumer can tell you is that the unit will not start again after it has stopped. If you suspect a low-voltage condition when the unit is acting up, you might install a starting booster and may inadvertently solve the original problem.

New compressors are vulnerable to overheated bearings if the bearing clearances are at minimum allowable specs. When a new compressor experiences the first high ambient temperature and evaporator load, the high bearing temperatures will either stabilize or continue to increase until galling starts to occur. (*Galling* means that a small particle of the bearing breaks loose and wedges itself between the rotating member and the bearing.) Once the compressor becomes stuck or seizes up while running, the damage of a galled bearing is permanent. While it is true that it is possible to restart the compressor after it has cooled down by reversing the direction, the compressor will continue to seize on the galled bearing. It must be replaced.