

# THEORY AND FIELD PROBLEMS OF THE CAPILLARY TUBE

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## INTRODUCTION

The capillary or restrictor tube needs no formal introduction to refrigeration service or design engineers. In fact everyone in the refrigeration industry has either heard of, or has had some experience with the cap tube, as we shall call it from now on.

Of all the controls used in the refrigeration industry, if we pick out those that are used as pressure reducing devices, we find that they work the same way, in principle, in other industries. For instance, the automatic expansion valve is the same type of control used in reducing the pressure from oxy-acetylene tanks. The same type of valve is also used in water or air reduction. Some of the principles of the thermostatic expansion valve are also used in gas heating controls.

But when the cap tube is used in other industries it can only be used as a pressure reducing device, never as a controlling or regulating mechanism.

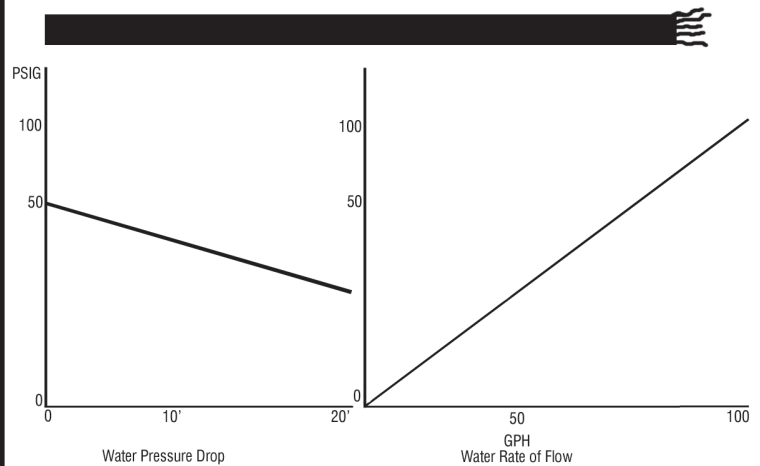
We shall see later on how a fixed length of tubing with a fixed bore can regulate the flow of refrigerant, and therefore can be classified as a refrigerant control.

What makes the cap tube unique to the refrigeration design engineer is that the cap tube is not an "off the shelf" item. In fact it isn't an item he can calculate from tables and charts as he would a condenser or evaporator. The best that the tables can do for the design engineer is to establish a basic length and bore. Then the system first has to go thru test procedures of high and low ambients, under various loading conditions, with current, pressure and temperature recorders. The bore and length may have to be changed many times to achieve the most efficient system, and to finalize the results may take weeks and months. One might ask that if a cap tube system is so critical why not take an "off the shelf" valve and be done with it. Well, the investment of time and energy does pay off, because the finished cap tube will outlast all the other components of the system; plus the fact that you cannot beat the economics of the cap tube and its equalizing action.

But when you have service problems with the cap tube, all service engineers tend to avoid it like the plague. Actually it's not the diagnosis, but the remedy that gives all the grief. Which takes us back to the design engineer. He never makes provisions to replace the cap tube. It's soldered and welded and sometimes hidden in the return line. He's not 100% wrong in his optimistic thinking, because the only thing

that can go wrong with a cap tube, is that it can become restricted or clogged, and it's always protected by a strainer to prevent this from happening.

But the cap tube does become clogged and restricted despite the strainer, which we will discuss after we look at the theory and principles of cap tubes.



Here we see a cap tube with water flowing thru it. The graph at left shows that the pressure drop is linear; in other words, for every foot of tubing we have an equal pressure drop. The graph at the right shows that the flow rate thru the tube is linear; that is, as the pressure increases the flow rate increases in direct proportions.

If refrigerant acted the same way as water, we could never use the cap tube as a refrigerant control, because when the head pressures were low the evaporator would be starved and when the head pressures were high the flow rate could exceed the compressor capacity.

Now, if there were a way to INCREASE the flow rate at low ambients and DECREASE the flow rate at high ambients, sort of a modulating effect, we would have a control device. This is exactly what happens when refrigerant flows thru a cap tube that has been properly engineered.



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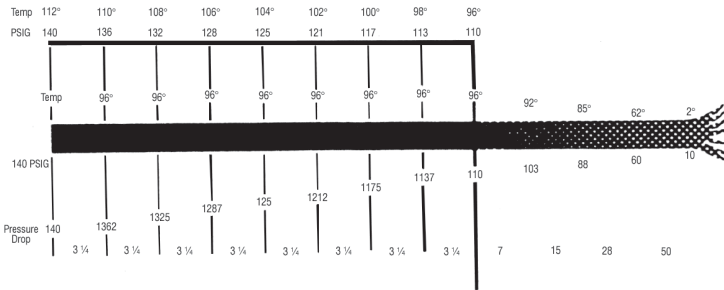
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- 1 Liquid Refrigerant Flows Faster Than Gas
- 2 The Colder The Liquid The Faster The Flow

Saturated Temperature and Pressure - R12



This illustrates the 2 laws that govern the flow rate of refrigerant thru a cap tube.

1. Liquid flows faster than gas
2. The colder the liquid, the faster the flow

The scale on the bottom shows the drop in pressure for every foot of tubing. The scale immediately above the tube shows the temperature of the refrigerant; and the top scale shows the same pressures as the lower scale except that we also have the equivalent saturation temperatures of R12.

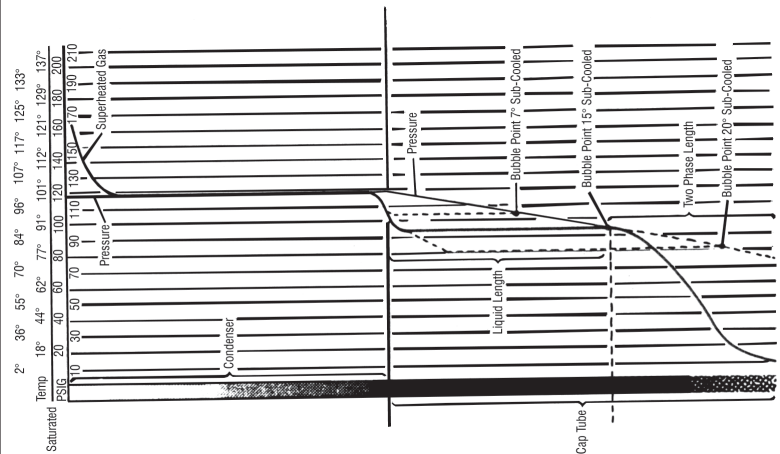
Let us now follow the refrigerant as it flows thru the cap tube.

Notice that the R12 enters the cap tube at 96° which is 16° sub cooled below its condensing temperature of 112° on the top scale, and at a pressure of 140 lbs. Also notice that for the first 8 ft. the refrigerant acts like water. The temperature remains the same and the pressure drop is linear; for every foot of tubing we have an equal pressure drop. Now let us closely examine the heavy vertical line, which is at the 8-foot mark. The pressure dropped from 140 lbs. To 110 lbs. Now if we look at the top saturation scale we find that the pressures and temperatures of 110 lbs. And 96° are now equal to refrigerant in the cap tube.

Now, what happens to the refrigerant after the 8-foot mark separates the cap tube from a pressure-reducing device to a refrigerant control.

As the refrigerant continues and the pressure is further reduced, we find that the pressure is now BELOW its saturation point. This reduction causes the refrigerant to flash or boil and bubbles from the cap

tube. In fact we have the same effect in the cap tube as the common evaporator. The main difference is that the gas pockets or bubbles in the cap tube further restrict the flow of liquid. This restriction causes the pressure to drop at a higher rate, which causes more flashing – more restriction; etc. where the first bubble occurred is known as the bubble point, which in this case was at the 8-foot mark. The main reason why the bubble point started there was because the liquid refrigerant entered the cap tube at 16° sub cooled.



In this illustration we see the effective bubble point at different sub cooled temperatures. At the left of the illustration we have the condition of the refrigerant throughout the system. The horizontal line represents the strainer before the cap tube. The heavy vertical line in the middle is the temperature of the refrigerant. The thin vertical line is the pressure of the refrigerant.

Note how the gas temperature loses its superheat rapidly and then remains constant throughout the condenser; it is then sub cooled before it enters the cap tube. The pressure is almost constant which accounts for the slight pressure drop across the entire condenser. So you might say that prior to sub cooling, the pressures and temperatures were at the saturation point. I have noted all the important factors that are related to the theories of regulation or modulation.

1. The bubble point
2. The liquid length of the cap tube prior to the bubble point.
3. The two phase length, which is after the bubble point



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Notice how the sub cooling below its condensing temperature makes a cap away from its condensing pressures. And it's this gap which governs where the bubble point will occur.

Notice the difference in two-phase lengths after the bubble point with 7°, 15°, and 20° sub cooling. The different bubble points are shown where the dotted lines meet.

It is most important to realize that as the loading or ambients change, the degree of sub-cooling changes, as a result, the two-phase length also changes, which gives you the necessary controlling factor of the total refrigerant flows.

There is one interesting point I would like to bring out, and that is, when the condenser becomes overloaded and the pressures go very high, you have another controlling factor. At this point of high loading not all the refrigerant is condensed and some vapors enter the cap tube as gas pockets. These gas pockets further restrict the refrigerant flow without affecting the head pressure.

This is one advantage the cap tube system has over the thermostatic expansion valve in preventing an overload on the motor.

To summarize on the theory of cap tubes although the head pressures have a direct effect to the flow rate, it's the changing two phase lengths that counters this action; to speed up the flow at low ambients, and act as a brake at high ambient. It is these minimum and maximum flow rates that play an important factor when designing a cap tube system.

## SERVICE PROBLEMS

The service problems of the cap tube itself are very simple. It can only become restricted in various degrees; which brings us to the question "How can the cap tube become restricted if there is a strainer in front of it"?

There are two causes: 1) is factory made 2) is either caused by a clogged condenser or a stuck fan motor. There are times when a very small amount of contamination is left in the system after the unit leaves the factory. It could be alkali or acidic, in either case, given enough time these chemicals react with the

refrigerant and the variety of metals in the system to form microscopic particles as fine as talcum powder. These tiny particles can easily pass thru the finest screen or felt, in fact go right on thru the cap tube itself. However, when these particles cling to the inside wall of the tubing they reduce the diameter and cause the restriction.

The excessive head pressures and temperatures caused by a clogged condenser or stalled fan motor will tend to break down the oil vapors. This condition will also form microscopic particles and the results will be the same.

Although the service problems of the cap tube itself are simple, it's the entire system that more than often leads to complications that involve the customer, serviceman, service manager, the owner of the company, the factory sales manager, the president of the factory, even the better business bureau finds itself involved. The many hours of aggravation on the phone and the threats of attorneys by mail usually starts with what is seemingly a very minor service call: the evaporator is not fully frosted. All texts and service manuals describe this as a very simple problem and I quote "the undercharged evaporator can be caused by a slight shortage of refrigerant in the system or a slight restriction in the cap tube". That is the same as a doctor diagnosing a patient's complaint of a stomach pain as either indigestion or cancer.

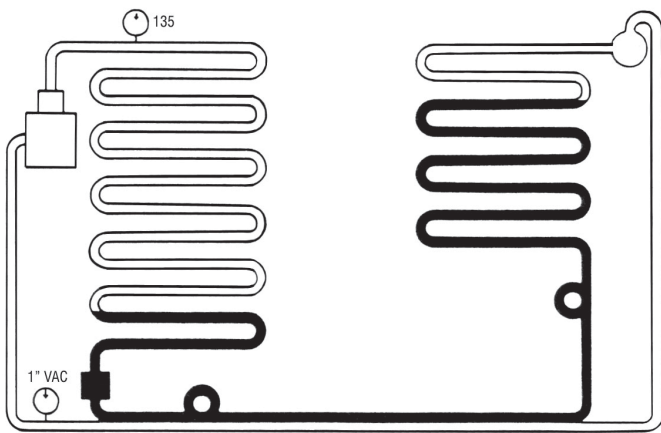
Most servicemen are eternal optimists and just never think of a restricted cap tube because of its complicated ramifications. Especially the highly experienced who know that a "shot of gas" will solve the problem. I did say highly experienced not highly skilled.

Of course there are many instances where there is a very slight leak in the system in the magnitude of a half-ounce a year and in 4 or 5 years the system responds to the shortage.

In such cases it may be most practical to add some gas without subjecting the customer to the expense of locating and repairing the leak.

However, let us follow one of these servicemen on a job that has a restricted cap tube and see what actually happens.



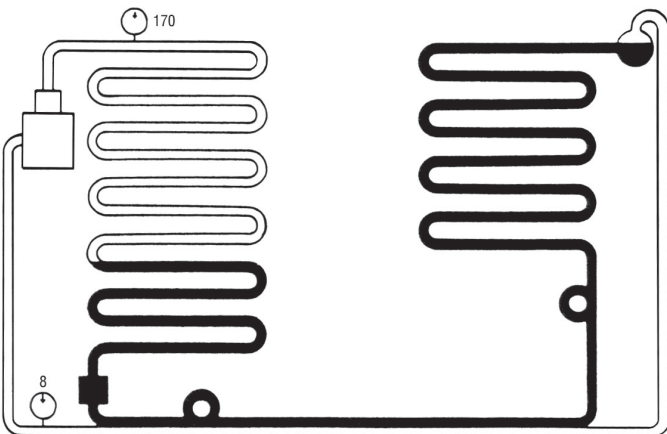


Here we see a schematic of a domestic refrigerator. Notice that the evaporator is undercharged; but not the system. The amount of refrigerant missing from the evaporator is now backed up and accumulated in the condenser. You can also say that the system is out of balance; the new reduced flow rate, because of the restriction, cannot keep the evaporator in a flooded condition and the volumetric capacity of the compressor is now greater than the flow rate.

Now, if a serviceman were to install a low side gauge he would get no more information than if he had a thermo-couple attached to the freezing portion of the evaporator. However, if he also installed a high side gauge, he would notice the unbalanced condition.

But our serviceman has no time for extensive diagnosing. He installs a low side-piercing valve, adds some gas and "presto" the entire evaporator is fully charged and frosted. The customer compliments him for his skill and technical efficiency while he quickly gathers up his tools and leaves.

Let's see what he accomplished.



Here we see the same system as before, but now not only are the evaporator fully charged we also have a condenser that is 1/3 filled with liquid. The head pressure is almost 170 lbs. And it's this excessive pressure that made the serviceman look so successful. By overcharging the system and loading the condenser, he has reduced the effective condensing area about 30% and increased the head pressure to the flow rate of the cap tube and is able to maintain the evaporator in a fully charged condition.

If the original restriction caused an unbalanced condition, the overcharge of refrigerant has now compounded the problem. First of all the excessive amount of refrigerant in the condenser would cause an extreme delay in equalizing after the system reached temperature. If the thermostat cut-in during this delay the unit would cycle in locked rotor condition on the overload. Secondly when the system did equalize and the entire condenser emptied into the evaporator, the liquid would overflow and drain into the suction line. The unit would start with a flooded suction and operate on a high back and high head pressure condition for a considerably long "on cycle".

During a hot spell the 170 lbs. Head pressure can easily become 220 lbs. And cycling on overload and operating in a constant high amperage condition will eventually burn out the unit.

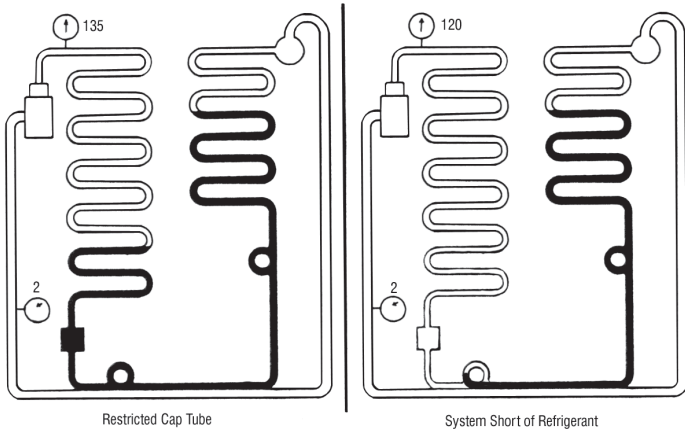
This is the final result of a wrong diagnosis of an undercharged evaporator, either by choice of just being misinformed. A shortage of refrigerant in the evaporator can be very deceptive and to rely only on a low side gauge or electrical instruments can only add to the deception if you are trying to diagnose the difference between a restricted cap tube and slight refrigerant leak.

One of the most reliable methods of solving this problem is to use a high side gauge, and many times the use of your hands can confirm your findings. Unfortunately, the sealed system has given birth to a new breed of serviceman; he only uses the "touch method". Using a wet finger on an evaporator, he can tell temperature; touching the dome, he knows the amperage its drawing; and touching the condenser, he can sense the head pressure.

The serviceman who uses his eyes, ears and hands can obtain a lot of useful information to aid him in diagnosing a defect, but they won't tell you pounds per square inch, and in a cap tube system its very important to know the head pressure. Let me illustrate this by the next diagram.







Restricted Cap Tube

System Short of Refrigerant

Notice that both evaporators are undercharged and both low side gauges read the same but the head pressures are different. Now, at an ambient of between 75° and 80° the head pressure of a restricted cap tube system will always read normal or slightly above normal, but the pressure of a system short of refrigerant will always read lower than normal. To confirm your diagnosis your hands can locate a few differences.

The strainer on a restricted cap tube should be about room temperature because of the sub cooled liquid that has backed up, and running your hand down slowly from the top of the condenser the temperature should be warm then suddenly cool to room temperature to the level where the liquid refrigerant has backed up.

In a system that is short of refrigerant the condenser would have a gradual change in temperature from the top all the way down to the strainer. In fact the strainer will be slightly above room temperature.

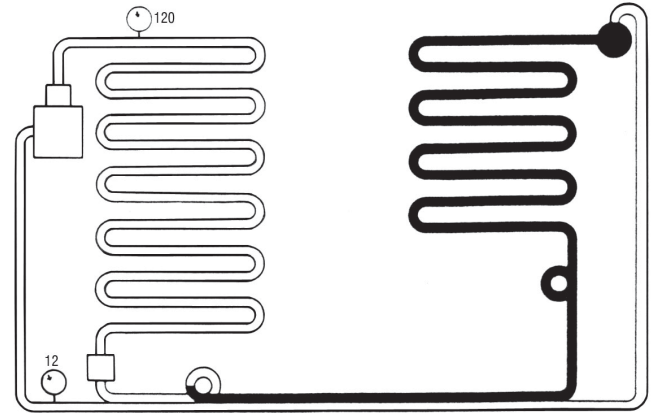
Another method of diagnosing the difference is to either blanket a static condenser or partially block a fan cooled condenser, the increased head pressure will raise the liquid level of the evaporator in the restricted cap tube system but if the system was short of gas there would be little change if any.

But while your head gauge is connected the most positive check is to add a few ounces of refrigerant. The restricted unit will show a sharp rise to an excessive head pressure and the strainer will still be at room temperature. Running our hand down from the top of the condenser you will notice that the point of sudden cooling has risen to a new level.

The unit that was short of refrigerant will show a slow rise in the head pressure to slightly above normal depending upon how fast you are adding the gas; and the strainer will get hot.

To summarize the differences between a restricted cap tube and short of refrigerant, you might say that I have overemphasized and elaborated in the diagnosing procedures, but don't forget that we are dealing with the comparison of indigestion and cancer. Whereas in our extreme case, the system can be saved by changing the cap tube – a wrong diagnosis can kill the entire system.

To those servicemen who insist on not using a set of gauges, the inefficient compressor is the “coup de gras”. However, the service engineer who uses gauges finds that the inefficient compressor becomes the easiest problem to diagnose.



There are many degrees of inefficiency, so let us be more specific and diagnose the most difficult of all; a compressor that has lost about 15% of its original capacity.

The complaint on this type of system is that the unit runs continuously. In fact in many cases of this type the complaint is that the food freezes so the “touch method” serviceman adjusts the thermostat. This is as helpful as taking a few aspirins for a broken leg.

Their symptoms of an inefficient compressor would be as follows: the evaporator would be flooded or fully frosted touching the condenser should give you the impression that there isn't much heat there and the temperature would be almost the same to the strainer. A thermocouple near the thermostat feeler bulb should read about 5 degrees above it's cut out point. The suction line should be unusually cold.

What you are actually witnessing is a state of equilibrium. The entire load on the unit equals the capacity of the compressor. If the ambient temperature should rise the evaporator temperature would also rise. If the ambient temperature should go low enough the unit may cycle.



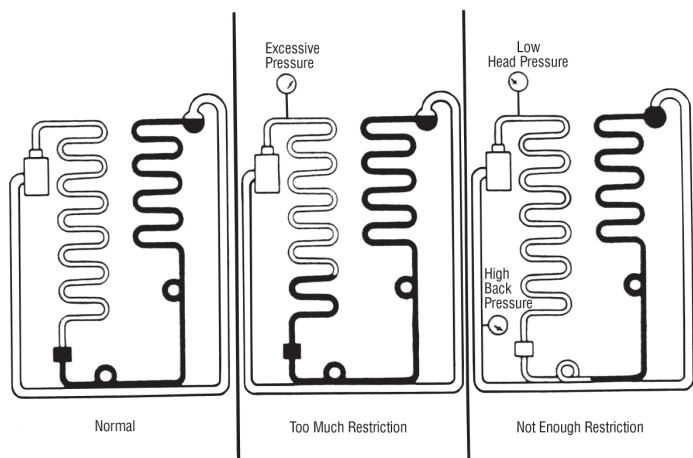
Installing a set of gauges should tell the story. The backpressure would be high and the head pressure lower than normal. The inefficient compressor is the only condition that gives you this type of pressure combination so you cannot be mistaken.

These are the same symptoms if you installed an oversized cap tube or an undersized compressor.

Now as far as selecting cap tubes for replacement is concerned, the object is to duplicate the original flow rate and replacing the original length and bore would be the easiest, but it's never available when you need it.

There are many companies who offer replacements and we of sealed unit parts claim to have the best. I only say this because it's true.

But no matter where you get the replacement, the use of a set of gauges is very important.



Here are 3 schematics that may help you in determining if you have the proper cap tube.

At our left is the perfect working unit and to best describe its operation is to say that the low side gauge will react almost the same as if you had a thermostatic expansion valve. In other words the longer the unit runs the colder the evaporator, and the low side gauge will react accordingly. The evaporator must maintain its full working capacity throughout the cycle. No frost should appear on the suction line during the cycle or on the start up. The strainer should always be slightly warmer than room temperature and the condenser should be hot at the top and gradually change to the temperature of the strainer.

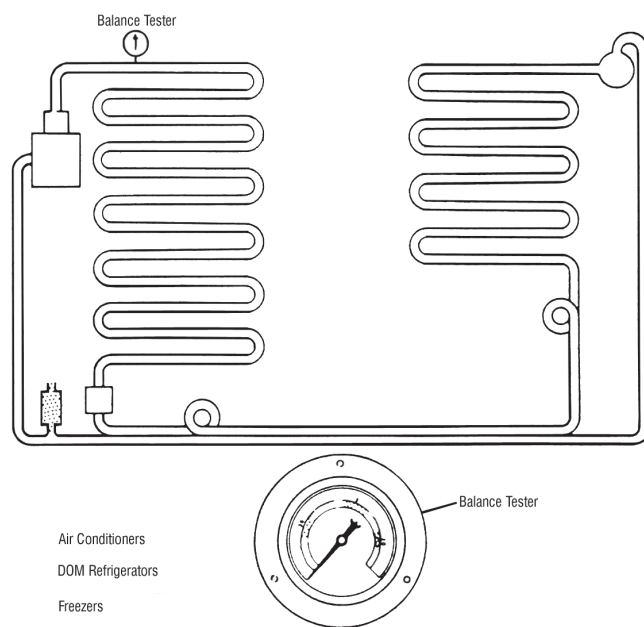
The center diagram has a cap tube with too much restriction. The head pressure will be too high and running

your hand down the condenser you will be able to judge where the liquid refrigerant is backed up to. Purging the excess off will leave the evaporator short.

The unit at the right has a cap tube that has too high a flow rate. Running this unit will show the same symptoms as an inefficient compressor. The backpressure remains high while the head pressure will be lost.

Speaking about replacement cap tubes I must tell you about my invention. I actually invented a cap tube and compressor efficiency tester; it's so revolutionary that I was granted a patent. There's only one problem with the beast, we cant' sell it. It's so simple no one understands it.

Let me show you how it works.



Let us suppose that you know that there is a restriction in the system but you're not sure if it is in the cap tube or in the strainer. You first change the strainer then before you charge the system you install the balance tester on the high side tap or service valve. You then install a drier on the low side tap or service valve and start the unit.

As the compressor starts, it immediately takes in a small amount of air thru the drier and builds up a pressure on the high side; simultaneously air from the high side starts to flow thru the cap tube. In other words after a few seconds of operation, air from two sources is taken in by the compressor; thru the drier and from the cap tube. However, as the pressure increases more and more air will flow thru the cap tube.



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The pressure builds up to a point and stops; this is called the balance point. The reason why the gauge stops, and this is very important, is that the compressor is no longer taking in air thru the drier; instead all the air to the compressor is being supplied by the volume coming thru the cap tube.

We now have a balanced condition or a state of equilibrium where the flow rate thru the cap tube is equal to the compressor capacity; in fact at this point if we were to remove the drier and install a low side gauge, it would read zero points.

What I have done now is to formulate the pressures into evaporator temperatures. If you are testing a room air conditioner, you know that the range of evaporator temperatures will be between 34° and 42°. If the balance tester should read 25°, it means that there is a restriction in the cap tube or strainer. If the tester balances at 60° you know that the compressor is inefficient. It is that simple. But the most useful part of the instrument is that after you have replaced a cap tube, a two-minute balance test will tell you if your cap tube will work BEFORE you charge the system.

Ad supposing you haven't the right size cap tube all you have to do is to install 10 or 12 feet of any size near the original bore. If the balance tester shows too much restriction, keep shortening the length until you have balance at the right temperature. I think it's a very efficient instrument. Thanks for letting me get in a product plug.

A final word about cap tubes.

Since most of the cap tubes are in completely sealed systems with no access valves for servicing, the serviceman often has difficulty in diagnosing a problem because he looks at the unit as he sees it. A complete system. The picture changes immediately when he installs a set of gauges. Now he sees the individual components in operation and can easily isolate the problem to the source. A point worth remembering is, that unlike "off the shelf" items, the cap tube system was painstakingly engineered and it is, by comparison to other systems, very critical with very little tolerances.

The cap tube system cannot afford to lose much refrigerant and it will not tolerate much of an overcharge. The cap tube itself cannot increase its flow rate and it doesn't take much of a restriction to throw it off balance. It's a factory pre-set system with no adjustments.

A serviceman can become highly experienced and proficient in low temperature cap tube systems only to find that he has to start all over again when he is confronted with room air conditions. The major difference is that in low temperature systems the cap tube is highly restrictive and the response to loading fluctuations is slow – whereas in room air conditioners you find high velocity flow rates and a more rapid response to evaporator loading. Some find it hard to believe that the cap tube in a room air conditioner is the most critical of all systems. The reason is that the evaporator operates so close to the freezing point of water that the slightest restriction will start a freeze up on some part of the evaporator which will eventually clog all the fins by a chain reaction, and today's close finned coils multiplies the problem.

I suppose many of you have heard the story of the scientist who first invented the cure before the disease was discovered, well one manufacturer made a combine action refrigerator and freezer that had two cap tubes in series with the two evaporators. Technically speaking it was a great success but they had to take it off the market because very few men could service the monster.

And in closing, if I have changed your opinion about cap tubes, even slightly, I'm glad; if I've solved some of your problems, I'm happy, and if I have confused you, why worry, it's only a piece of tubing.



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