History of Thermostatic Expansion Valve

BY JORDAN C. LARSEN; BRIGITTE BUSCH

A thermostatic expansion valve (TXV)—an example of which can be seen in *Figure 1*—is a refrigeration and air conditioning throttling device that controls the amount of refrigerant liquid injected into a system's evaporator based on the evaporator outlet temperature and pressure, called the superheat.[1] *Figure 2* shows the different phases and pressures the refrigerant goes through as it is pumped through the system, moving through the evaporator, the compressor, the condenser, and the throttling device which injects liquid refrigerant into the evaporator before it evaporates and moves into the compressor.

TXV Parts

While there are different types of TXVs, each one has some things in common: a diaphragm, a power element, a setting spring and an orifice (*Figure 3*).

TXV Operation

There are three different forces at work in a TXV: bulb pressure, spring pressure and evaporator pressure (*Figure 4*). Bulb pressure comes from the bulb that is mounted at the outlet of the evaporator. The bulb senses the suction temperature, which generates an internal pressure in the bulb that drives the diaphragm down when the temperature increases. Spring pressure is constant and pushes up against the diaphragm, counter to the bulb pressure. The spring pressure is calibrated when the valve is set by the equipment manufacturer or the installer. The evaporator pressure pushes the diaphragm up when the suction pressure increases and comes from the evaporator load on the system, which varies according to different operating conditions, such as changing load conditions. Based on the balance between these three pressures, the valve will either open or close.

Factors That Led to the Development of the TXV

Many early refrigeration systems required a human operator[2] to constantly adjust the flow of refrigeration to prevent liquid refrigerant from flowing back into the compressor, which would cause irreparable damage. To properly address this challenge, an automatic refrigerant control was needed. Harry Thompson filed the first patent[3] for a TXV on August 24, 1927 (*Figure 5*). With Thompson's invention, refrigeration systems now had an automated throttling device that also protected against liquid refrigerant flowing back into the compressor.

Thompson's invention was so successful that he

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inadvertently created a whole new component category. Soon, others improved upon Thompson's original design. Danfoss' founder, Mads Clausen, first entered the refrigeration business by selling a TXV of his own design, the ARV, followed soon after by the TRV.

FIGURE 1 TXV.

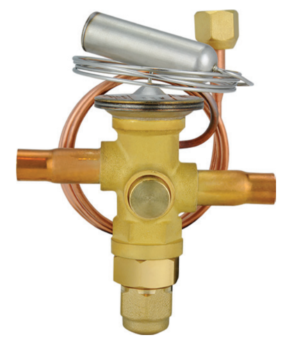
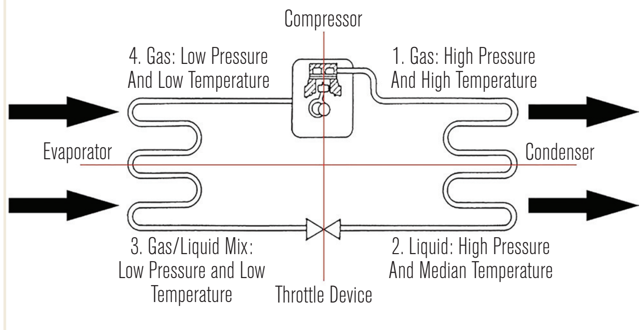


FIGURE 2 Cycle.



Design Modifications Over The Years

While early TXVs (such as the one seen in *Figure 6* (Page 42) were simpler than today's models, the basic formula created by Thompson more than 90 years ago has not changed. Whether old or new, all TXVs have a diaphragm, a power element, a setting spring and an orifice, though the size, shape and material of each piece may change. As manufacturing technology has improved and new materials developed, manufacturers have been able to adapt TXVs to a wider variety of applications. In fact, the differences between various types of modern TXV models are greater than the differences between early and modern models.

FIGURE 3 TXV parts.

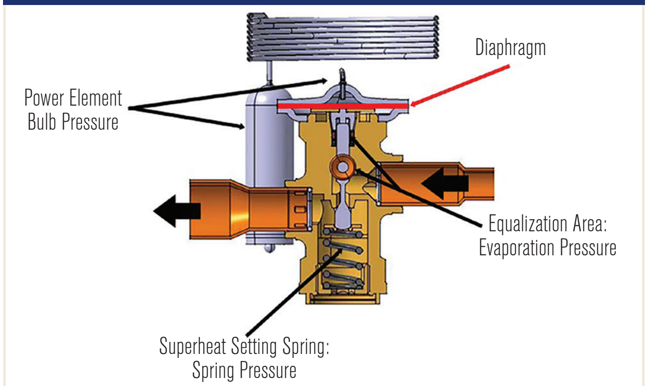
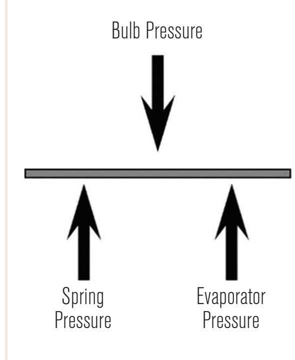


FIGURE 4 Pressures.



Differences in Various TXV Types

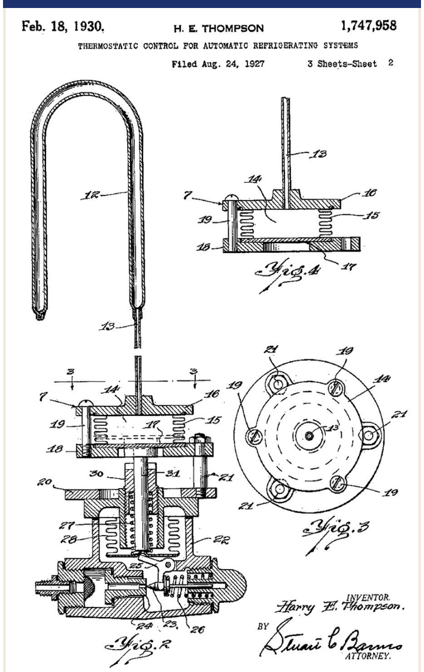
Internal Versus External Equalization

Figure 7 (Page 42) shows two types of TXVs, those available with internal or external pressure equalization. Externally equalized valves are recommended for multi-circuit systems because they account for excessive pressure drops coming from distributors and through the evaporator—externally equalized valves sense the evaporator pressure from the equalizer line connected to the evaporator outlet. Internally equalized valves sense the evaporator pressure at the outlet of the valve. Of the air-conditioning systems in the US that use TXVs, the majority—if not all—use valves that are externally equalized.

Conventional Port Versus Balanced Port Design

Figure 8 (Page 42) shows two different TXV port designs. In conventional or single port designs, the diaphragm can be influenced by pressure changes in the condenser. The general rule of thumb is that a conventional port design works best in systems with less than five tons of cooling capacity, while larger systems work best with a balanced port design (though it is not uncommon to use a balanced port valve in smaller systems). A balanced port design isolates the condenser pressure from

FIGURE 5 Harry Thompson patent.



affecting the opening of the valve, necessitating the use of a packing gland. However, the use of a packing gland might create friction/hysteresis in the valve, requiring design measures to negate frictional loss in the TXV.

FIGURE 6 Early TXV.

FIGURE 7 Internal versus external.

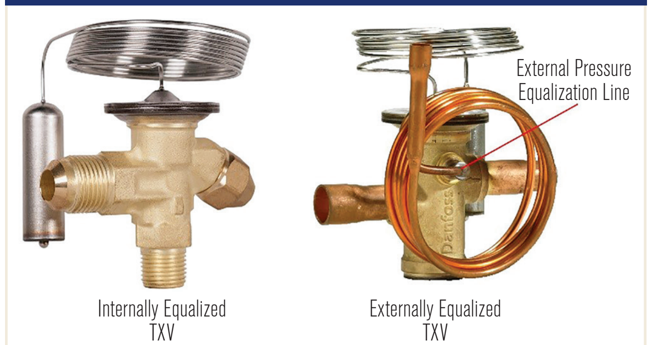


FIGURE 8 Conventional versus balanced.

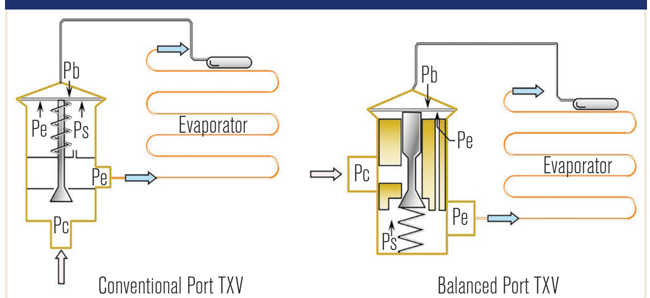
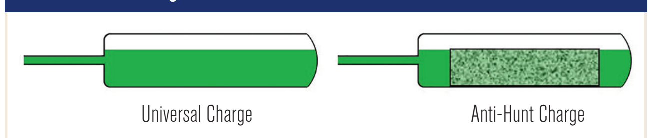


FIGURE 9 Bulb charges.



Universal Versus Anti-Hunt Bulb Charges

While there are several types of bulb charges, two common charges used in air-conditioning systems are universal charge and anti-hunt charge (*Figure 9*).

With a universal charge, the bulb is filled with a liquid cross charge. Whenever the bulb senses an increase in suction line temperature, the liquid expands, increasing the pressure in the enclosed volume, and pushes the diaphragm down, thereby opening the valve and allowing more liquid refrigerant into the evaporator. Unfortunately, vaporization is a dynamic process, which can produce sporadic superheat at the evaporator outlet. Think of liquid refrigerant changing to vapor like a pot of boiling water—the liquid does not instantaneously become a gas once the boiling point is reached, but changes into steam erratically. Similarly, the bulb might sense vapor one instant and liquid the next. In this scenario, a bulb with a universal charge will rapidly open and close the valve, a process called hunting. Hunting reduces the system's efficiency and increases the risk of liquid refrigerant making its way to the compressor, which will damage the compressor.

To avoid hunting, some TXVs have a ballast added to the bulb, creating what is known as an anti-hunt charge. The ballast dampens the rate of expansion within the bulb, stabilizing the bulb pressure against the diaphragm by dampening the rate of phase change to the bulb charge compared to the rate of temperature change of the suction line. This stabilization ensures that the TXV operates more in line with the dynamics of the system and better protects the compressor.

Bulb Charge Fluid

There are different ways to approach the charging of a TXV bulb. The one Danfoss recommends is called a cross charge. Cross-charged bulbs mix a combination of different refrigerants with gases to flatten the pressure-temperature (P-T) curve (*Figure 10*). Cross charges enable the TXV to perform similarly regarding the change in opening degree for a given change in superheat across a range of evaporator temperatures.

TXVs Compared to Other Throttling Devices[4]

TXVs earned the place as one of the most common types of modulating-orifice throttling devices in air-conditioning and refrigeration systems worldwide by being both efficient and affordable. But how do TXVs compare to other throttling devices? Fixed-orifice devices like capillary tubes or pistons are cheaper, so why are TXVs so popular?

TXVs Vs. Fixed Orifices

Fixed-orifice devices are ideal throttling devices if conditions never change. If the load on the system is constant and the ambient temperature remains steady, then a simple capillary tube or piston (*Figure 11*) would be preferable to a modulating-orifice device like a TXV. However, outside of a laboratory, static conditions are

FIGURE 10 Valve cross charge.

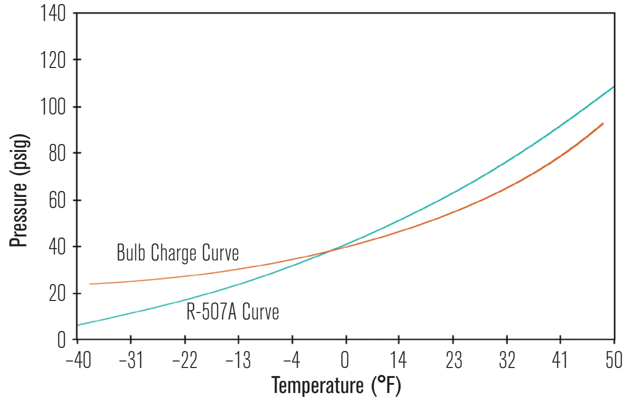
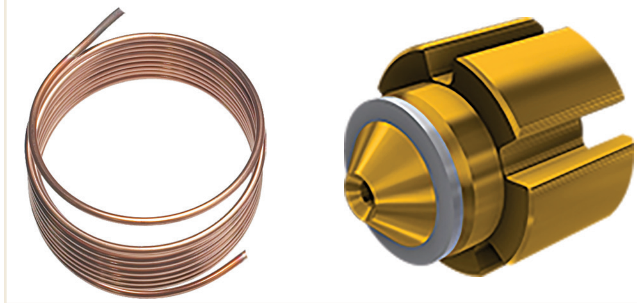


FIGURE 11 (Left) Cap tube. (Right) Piston (small).



simply not realistic.

Seasonal temperature changes have a profound effect on system performance, as does increasing the heat load inside. For example, summer brings warmer weather, which increases the condensing pressure of the refrigerant in the air conditioner. Since the throttling device acts as a type of dam within the system, a fixed orifice device will not open more when the load increases to allow more refrigerant through, which increases the superheat to the compressor. Additionally, once the load decreases (perhaps at night), the back pressure drops, which significantly increases the risk of liquid refrigerant making it to the compressor, which would likely damage it.

A TXV will modulate open or closed based on changing conditions and will adjust to maintain a constant superheat. This modulation ensures that efficiency is optimized and that the compressor is protected against damage from liquid refrigerant. Unless the system is in a laboratory and only tested under one condition, a TXV will always be the better choice.

While TXVs were originally invented for use in refrigerators, today they are used in a wide range of applications from refrigeration to air conditioning. Because TXVs are able to better regulate the flow of refrigerants based on the needs of a system, compared to other throttling devices, systems with TXVs have shorter pulldown times.

Not All TXVs Are Created Equal[5]

TXVs are not just about efficiency and compressor protection—another important factor is reliability. The power element is the most common part of a TXV to fail, so having a power element that is made from high-quality materials will extend the life of the valve. Laser-welded, stainless steel power elements (*Figure 12*) offer the longest life possible, with many valves testing above 200,000 cycles.

Another common point of failure is the sensing bulb capillary tube (*Figure 13*). Once again, stainless steel offers flexibility and durability not available with other metals. Stainless steel sensing bulb coils can be bent and flexed over and over without fear of cracking, as is typical with copper capillary tubes.

Finally, TXVs are often used to upgrade a system from a fixed-orifice device, so a TXV that is easy to install is most ideal. Retrofitting a fixed-orifice device system with a TXV is simple, especially when the valve comes packed with the most common fittings to attach to the evaporator distributor, like flare, Aeroquip, or Chatleff, making upgrades hassle-free.

Factors That Led to the TXV's Popularity in the Market

The two major factors that have led to TXVs' popularity: performance and price. As discussed above, TXVs outperform fixed-orifice throttling devices while also better protecting against liquid refrigerant from flowing back into the compressor. However, there is a device that can even outperform a TXV: an electronic expansion valve (EEV). As will be discussed later, EEVs are more precise than TXVs but are currently much more expensive. With TXVs in in the middle, both in terms of price and performance, it is easy to see why so many have chosen TXVs for their cooling system.

The Key Role of TXVs in the High-Efficiency Market

In the United States

In the US, there are two significant energy efficiency governing bodies: ASHRAE Standard 90.1[6] and the US Department of Energy (DOE).

90.1 sets the standard of what constitutes a high-efficiency building, including setting minimum efficiency

FIGURE 12 TR6.

FIGURE 13 Broken cap tube.

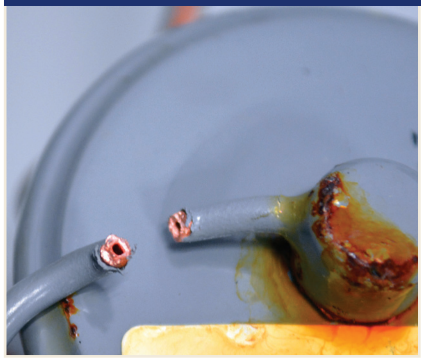


FIGURE 14 EEV.

standards for a building's cooling equipment, though adoption is a slow process. As a result of this slow adoption, the DOE has stepped in to regulate air-conditioning equipment, setting new, federallymandated guidelines to circumvent the need for state-by-state adoption.

In 2003, the minimum seasonal energy efficiency ratio (SEER) rating for residential air conditioning systems in the U.S. was SEER 10, which meant that most systems used a fixed-orifice metering device and only high-efficiency systems used an active metering device like a TXV. Then in 2004,[7] the U.S. DOE announced a new minimum SEER standard of 13 for air-conditioning and heat pump systems manufactured after January 23, 2006, increasing the energy efficiency of each system by 30%. With the new SEER requirements, OEMs realized that fixed-orifice throttling devices would not be sufficient and the demand for TXVs skyrocketed.

In the Rest of the World

The European Union (EU) started aggressively combating climate change in 2006, particularly through tighter energy-efficiency regulations. The first initiative was the Green Paper on Energy Efficiency,[8] which outlined its "Efficiency First" policy. The Green Paper has since been replaced multiple times with ever-stricter efficiency standards, the latest coming in 2016 as an amendment to the 2012 Energy Efficiency Directive. As in the U.S., TXVs have helped Europeans meet ever-increasing efficiency demands.

China's plan to combat climate change has been even more aggressive. Starting in 2012,[9] China launched the One Hundred Energy Efficiency Standards Promotion Projects, which have had a huge impact on lowering the energy usage of products used within the country, especially residential air conditioners. As in the U.S. and Europe, TXVs helped increase the efficiency of cooling systems, though other measures were also employed, such as variable-speed compressors.

The Future of TXVs[10]

Digitalization has been a growing trend for years, with no signs of slowing. Add the more recent development of Internet of Things (IoT) solutions, and it becomes clear that the future—including the future of the HVAC&R industry—is increased control through digitalization. The likely candidate for digitalizing TXVs is the EEV introduced earlier.

EEVs, as seen in *Figure 14*, are top-of-the-line throttling devices. While TXVs are purely mechanical, EEVs can be programmed to work with the other components in the system, allowing them to further optimize performance and efficiency. While EEVs can outperform TXVs, the gains often do not justify the higher cost. A standard TXV can increase efficiency versus a fixed-orifice device by about 30% for only a small increase in cost, whereas an EEV will be significantly more expensive, and there is no guarantee that it will improve efficiency.

One reason for the greater expense is that EEVs need additional components to work properly, including sensors and a controller. While TXVs have been engineered to be self-contained, EEVs are best seen as part of a greater whole, operating according to the data the sensors collect and the commands the controller and its underlying software sends out. And while a TXV can be a drop-in replacement for a piston or capillary tube, the same cannot be said for an EEV.

Systems that require exact precision—such as data centers, mobile phone network exchanges, and server rooms—will benefit from having an EEV and complimentary components. However, an EEV is only as good as the algorithms dictating its operation, so choosing the right software for the system is just as important as having the correct hardware.

EEVs are not for every system and may not be worth the price of retrofitting an existing system, but for those looking for extremely accurate control, especially when designing a new system, EEVs offer a precision that TXVs simply cannot match. And as energy-efficiency regulations become ever stricter, demand is likely to increase, which will drive down component costs.

For nearly 90 years, TXVs have performed a vital role in refrigeration and air-conditioning systems by metering out refrigerant into the evaporator. While the TXV was first invented as way to protect the compressor, it proved a valuable tool in both performance and efficiency. And EEVs may one day take the place of TXVs as the most popular metered throttling device, that day is likely far off in the future.

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