Chapter 5

Refrigerant flow control and Regulators Devices

Part 1: Expansion devices

5-1 Introduction

An expansion device is one of the basic components of a refrigeration system. The functions of expansion device, in refrigeration systems are:

- Reduce pressure from condenser pressure to evaporator pressure, and
- Regulate and control the refrigerant flow from the high-pressure liquid line into the evaporator at a rate equal to the evaporation rate in the evaporator (low pressure evaporator).

The expansion devices used in refrigeration systems can be divided into *fixed opening type* or variable opening type. As the name implies, in fixed opening type the flow area remains fixed, while in variable opening type the flow area changes with changing mass flow rates.
In most cases, the pressure reduction is achieved through a variable flow orifice, either modulating or two-position.
There are basically multi types of refrigerant expansion device, such as: capillary tubes, orifice, constant pressure or automatic expansion valve (AEV), thermostatic expansion valve (TEV), float type expansion valve, high side float valve, low side float valve and electronic expansion valve.
Capillary tube and orifice belong to the fixed opening type, while the rest belong to the variable opening type.

5-2 Capillary Tube: A capillary tube is a long, narrow tube of constant diameter typical tube diameters of refrigerant capillary tubes range from **0.5- 3 mm** and the length ranges from **1- 6 m**. The **pressure reduction** in a capillary tube occurs due to **two** factors:

1- The refrigerant has ***to overcome the frictional resistance*** offered by tube walls. This leads to some pressure drop, and
2- The liquid refrigerant flashes (evaporates) into mixture of liquid and vapor as its pressure reduces. The density of vapor is less than that of the liquid. Hence, the average density of refrigerant decreases as it flows in the tube. The mass flow rate and tube diameter (area) being constant, the velocity of refrigerant

increases. ***The increase in velocity or acceleration of the refrigerant also requires pressure drop***.

Several combinations of length and bore are available for the same mass flow rate and pressure drop. However, once a capillary tube of some diameter and length has been installed in a refrigeration system. The capillary tube is only fitted on factory-built and tested equipment, with exact refrigerant charges. A capillary tube may also be constructed as a part of a heat exchanger, particularly in household refrigerators.

With capillary tubes, the length of the tube is adjusted to match the compressor capacity. Other considerations in determining capillary tube size include condenser efficiency and evaporator size. Capillary tubes are most effective when used in small-capacity systems.

5-3 Low-pressure float valves

Flooded evaporators require a constant liquid level, so that the tubes remain wetted. A simple float valve suffices, but must be located with the float outside the evaporator shell, since the surface of the boiling liquid is agitated and the constant movement would cause excessive wear in the mechanism. The float is therefore contained within a separate chamber, coupled with balance lines to the shell (see Figure 5.1).

Such a valve is a metering device and may not provide positive shut-off when the compressor is stopped. Under these circumstances, refrigerant will continue to leak into the evaporator until pressures have equalized, and the liquid level might rise too close to the suction outlet. To provide this shut-off, a solenoid valve is needed in the liquid line.

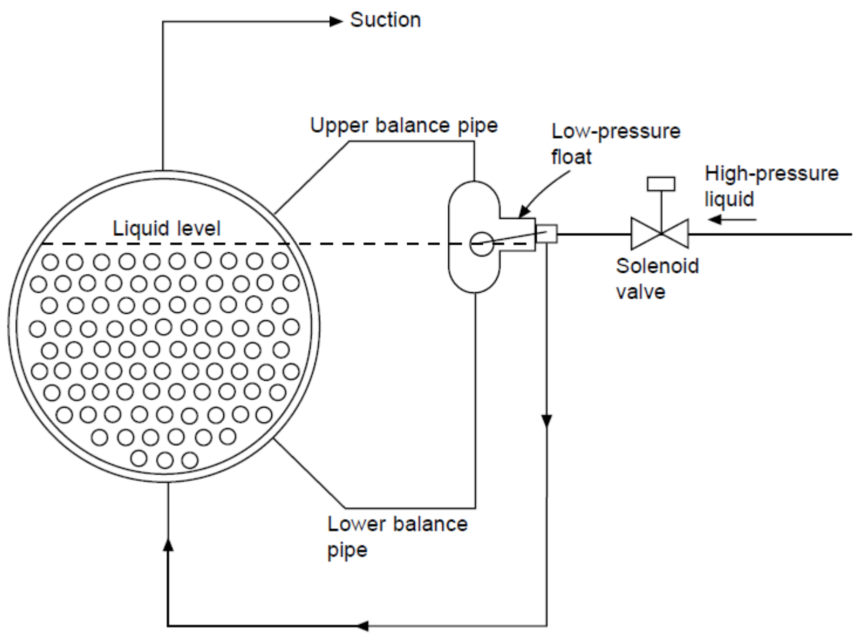

Fig. 5-1: Low-pressure float valve on flooded cooler.

5-4 High-pressure float valve

On a single-evaporator flooded system, a float valve can be fitted which will pass any drained liquid from the condenser direct to the evaporator. The action is the same as that of a steam trap. The float chamber is at condenser pressure and the control is termed a high pressure float (Figure 5-2).

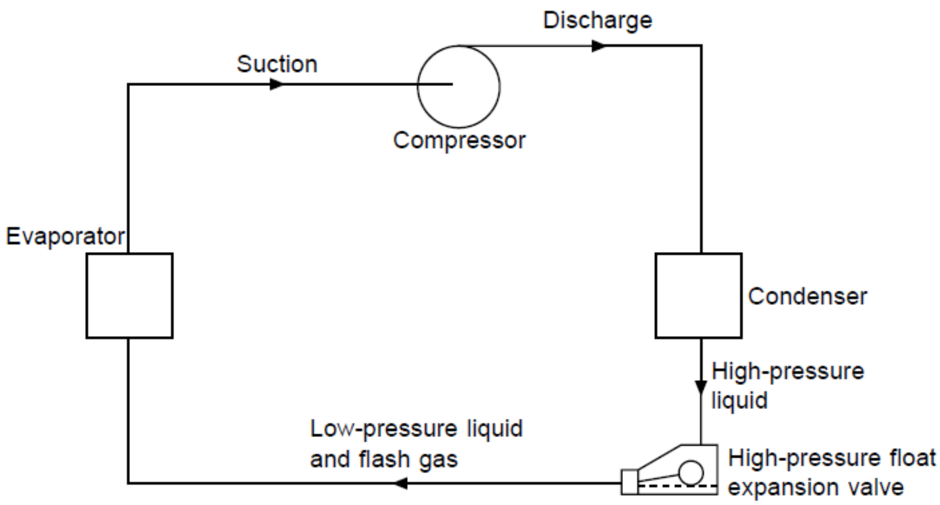

Fig. 5-2 High-pressure float valve.

The refrigerant charge of such a system is critical, since it must not exceed the working capacity of the evaporator. It is not possible to have a receiver in circuit and this control cannot feed more than one evaporator, since it cannot detect the needs of either.

The difficulty of the critical charge can be overcome by allowing any surplus liquid refrigerant leaving the evaporator to spill over into a receiver or accumulator in the suction line, and boiling this off with the warm liquid leaving the condenser. In this system, the low-pressure receiver circuit, liquid is drained from the condenser through the high-pressure float, but the final step of pressure drop takes place in a secondary expansion valve after the warm liquid has passed through coils within the receiver. In this way, heat is available to boil off surplus liquid leaving the evaporator (see Figure 5-3).

Two heat exchangers carry the warm liquid from the condenser within this vessel. The first coil is in the upper part of the receiver, and provides enough superheat to ensure that gas enters the compressor in a dry condition. The lower coil boils off surplus liquid leaving the evaporator itself. With this method of refrigerant feed, the evaporator has a better internal wetted surface, with an improvement in heat transfer.

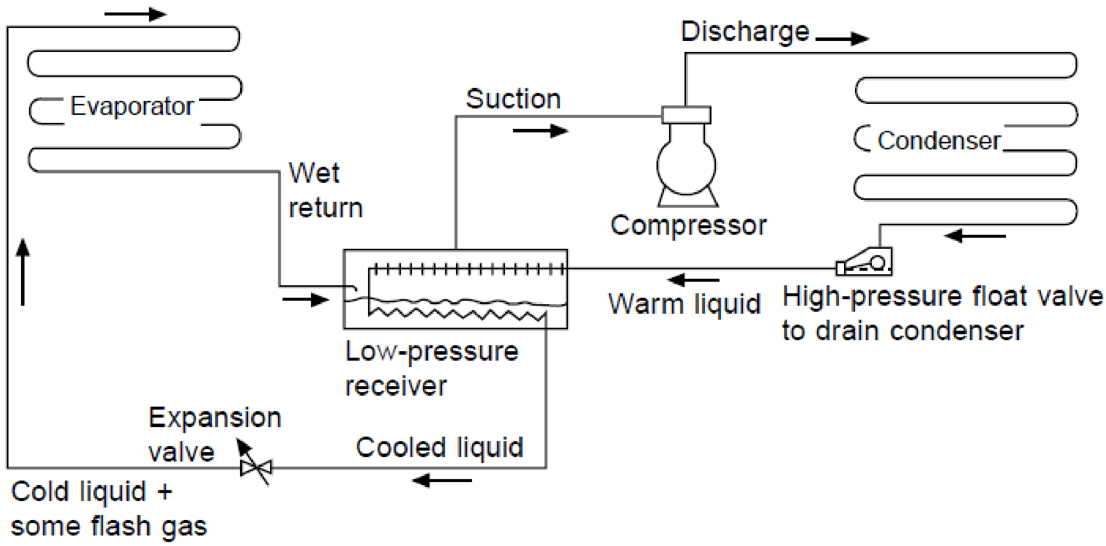

Figure 5-3 Low-pressure receiver circuit.

The low-pressure receiver system can be adapted to compound compression and can be fitted with hot gas defrost by reverse gas flow. In both circuits the low-pressure receiver provides the safety vessel to prevent liquid entering the compressor. Providing the high pressure float is correctly sized, this system can operate at low condenser pressures, saving compressor energy in cool weather.

5-5 Automatic Expansion Valve (AEV):

*An AEV also known as **a constant pressure expansion** valve acts in such a manner so as to maintain a constant pressure and thereby a constant temperature in the evaporator*. The schematic diagram of the valve is shown in Fig. 5-4.

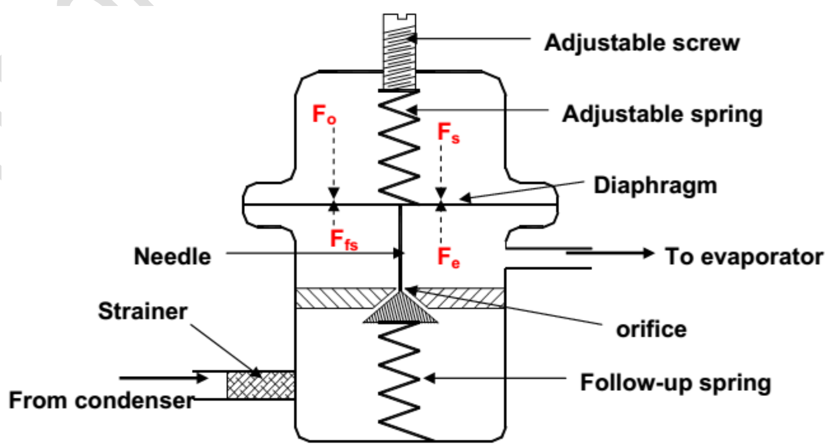

Fig.5-4: Schematic of an Automatic Expansion Valve

As shown in the figure, the valve consists of an ***adjustment spring*** that can be adjusted to maintain the required temperature in the evaporator. This exerts force ***Fs*** on the top of the diaphragm. The ***atmospheric pressure***, ***Po*** also acts on top of the diaphragm and exerts a force of $\boldsymbol{Fo = Po\ A_d}$, $\boldsymbol{A_d}$ being the area of the diaphragm. The evaporator pressure ***Pe*** acts below the diaphragm. The force due to evaporator pressure is $\boldsymbol{Fe = Pe\ A_d}$**.** The net downward force ***Fs + Fo - Fe*** is fed to the needle by the diaphragm. This ***net force*** along with the force due to ***follow-up spring***, $\boldsymbol{F_{fs}}$ controls the location of the needle with respect to the orifice and thereby controls the orifice opening.

If $\boldsymbol{Fe + F_fs > Fs + Fo}$ *the needle will be pushed against the orifice and the valve will be fully closed. On the other hand if* $\boldsymbol{Fe + F_fs < Fs + Fo}$, *the needle will be away from the orifice and the valve will be open*. **Hence the relative magnitude of these forces controls the *mass flow rate* through the expansion valve**. The adjustment spring is usually set such that during off-cycle the valve is closed, that is, the needle is pushed against the orifice. Hence, $\boldsymbol{Feo + F_fso > Fso + Fo}$ Where, *subscript **o** refers to forces during off cycle*. During the off-cycle, the refrigerant remaining in the evaporator will vaporize but will not be taken out by the compressor; as a result the evaporator pressure rises during the off-cycle.

When the compressor is started after the off-cycle period, the evaporator pressure ***Pe*** starts decreasing at a very fast rate since valve is closed; refrigerant is not fed to evaporator while the compressor removes the refrigerant from the evaporator. As ***Pe*** decreases the force ***Fe*** decreases. At one stage, the sum ***Fe*** **+** F_fs becomes less than ***Fs + Fo,*** as a result the needle stand moves downwards (away from the needle stand) and the valve opens.

5-5-1 Effect of Load Variation

The mass flow rate through the valve is directly proportional to the pressure drop through the orifice **(*Pc–Pe*)** and the area of the orifice opening (needle position). *At constant condenser pressure the mass flow rate will decrease if the evaporator pressure* ***pe*** *increases or as the orifice opening becomes narrower.*

5-5-2 Applications of automatic expansion valve:

The automatic expansion valves are used wherever constant temperature is required; for example, milk chilling units and water coolers where freezing is ***disastrous***. In air-conditioning systems it is used when humidity control is by DX coil temperature. Automatic expansion valves are simple in design and are economical. These are also used in home freezers and small commercial refrigeration systems where hermetic compressors are used. Normally the usage is limited to systems of less than 10 TR capacities with critical charge. Critical charge has to be used since the system using AEV is prone to flooding. Hence, no receivers are used in these systems. In some valves a diaphragm is used in place of bellows.

5-6 Thermostatic Expansion Valve (TEV):

Thermostatic expansion valve is the most commonly used in refrigeration systems. *An TEV also known as* ***a constant pressure expansion*** *valve acts in such a manner so as to maintain a constant pressure and thereby a constant temperature in the evaporator*, hence it is most effective for dry evaporators in preventing the slugging of the compressors since it does not allow the liquid refrigerant to enter the compressor. The schematic diagram of the valve is given in Figure 5-5.

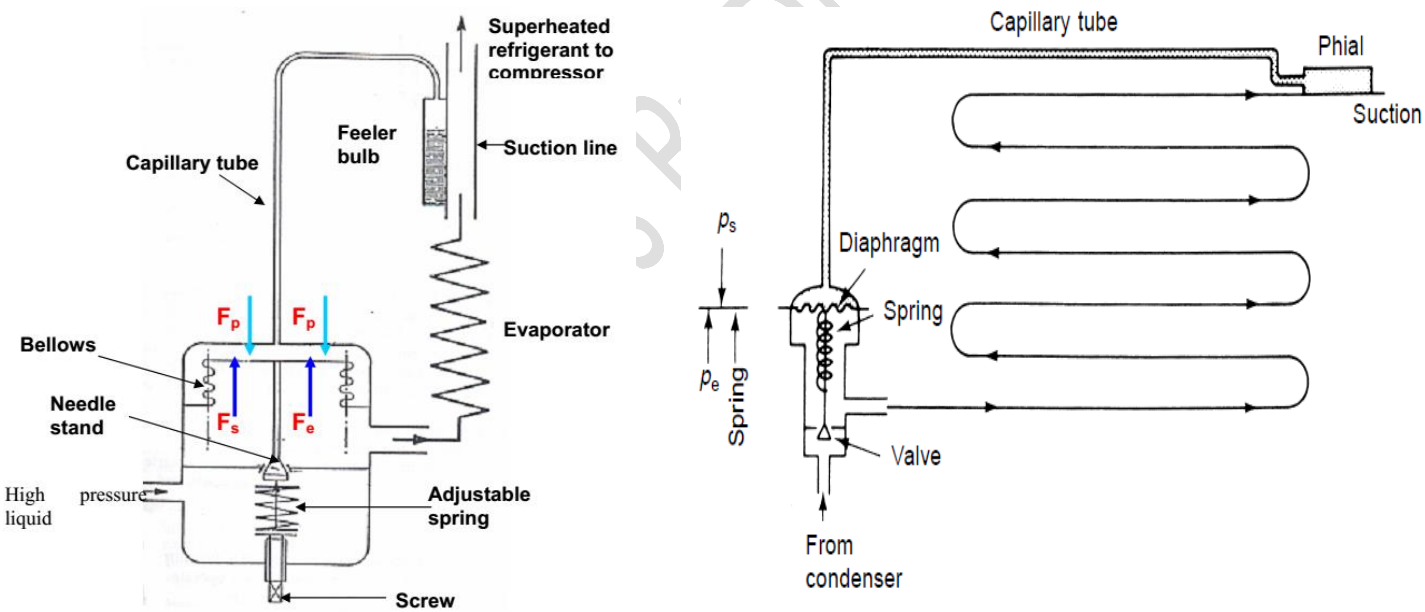

Fig.5-5 Schematic of a Thermostatic Expansion Valve (TEV)

This consists of a feeler bulb that is attached to the evaporator exit tube so that it senses the temperature at the exit of evaporator. The feeler bulb is connected to the top of the bellows by a capillary tube. The feeler bulb and the narrow tube contain some fluid that is called ***power fluid.*** The power fluid may be the same as the refrigerant in the refrigeration system, or it may be different. In case it is different from the refrigerant, then the TEV is called ***TEV with cross charge***. The pressure of the power fluid P_p is the saturation pressure corresponding to the temperature at the evaporator exit. If the evaporator temperature is ***Te*** and the corresponding saturation evaporator pressure is **Pe,** then the purpose of **TEV** is to maintain a temperature ***Te + ΔTs*** at the evaporator exit, where ***ΔTs*** is the degree of superheat required from the **TEV**. The power fluid senses this temperature ***Te + ΔTs*** by the feeler bulb and its pressure P_p is the saturation pressure at this temperature. The force ***Fp*** exerted on top of bellows of area A_b due to this pressure is given by: $\mathbf{Fp = A_b\, P_p}$

The evaporator pressure is exerted below the bellows. In case the evaporator is large and has a significant pressure drop, the pressure from evaporator exit is fed directly to the bottom of the bellows by a narrow tube. This is called pressure equalizing connection. Such a **TEV** is called ***TEV with external equalizer***, otherwise it is known as ***TEV with internal equalizer*****.** The force *Fe* exerted due to this pressure ***Pe*** on the bottom of the bellows is given by $\mathbf{Fe = A_b\, Pe}$

The difference of the two forces ***Fp*** and ***Fe*** is exerted on top of the needle stand. There is an adjustment spring below the needle stand that exerts an upward spring force ***Fs*** on the needle stand. In steady state there will be a force balance on the needle stand, that is, **Fs = Fp – Fe.** During off-cycle, **Te** is same as room temperature throughout, that is, degree of superheat ***ΔTs*** is zero. If the power fluid is the same as the refrigerant, then P_p = ***Pe*** and ***Fp = Fe***. Therefore any arbitrarily small spring force ***Fs*** acting upwards will push the needle stand against the orifice and keep the TEV closed. If it is ***TEV with cross charge*** or if there is a little degree of superheat during off-cycle then for TEV to remain closed during off-cycle, *Fs* should be slightly greater than ***(Fp - Fe)*****.**

As the compressor is started, the evaporator pressure decreases at a very fast rate hence the force *Fe* decreases at a very fast rate. This happens since TEV is closed and no refrigerant is fed to evaporator while compressors draw out refrigerant at a very fast rate and tries to evacuate the evaporator.

The force ***Fp*** does not change during this period since the evaporator temperature does not change. Hence, the difference ***Fp-Fe***, increases as the compressor runs for some time after starting. At one point this difference becomes greater than the spring force *Fs* and pushes the needle stand downwards opening the orifice. ***The valve is said to open up.*** Since a finite downward force is required to open the valve, a minimum degree of superheat is required for a finite mass flow rate. As the refrigerant enters the evaporator it arrests the fast rate of decrease of evaporator pressure. The movement of needle stand also slows down. The spring, however gets compressed as the needle stand moves to open

5-6-1 Effect of Load Variation

If the load on the plant increases, the evaporation rate of liquid refrigerant increases, the area available for superheating the vapor increases. As the degree of superheat increases, pressure of power fluid $\boldsymbol{P_p}$ increases, the needle stand is pushed down and the refrigerant flow increases. This is the ideal case. The evaporation rate of refrigerant is proportional to the load and as a result the mass flow rate through the expansion valve.

On the other hand, if the load on the plant decreases, the evaporation rate of refrigerant decreases, as a result the degree of superheat decreases. The thermostatic expansion valve reacts in such a way so as to reduce the mass flow rate through it. ***Hence, this valve always establishes balanced flow condition of flow between compressor and itself***.

5-6-2 TEV with External Pressure Equalizer:

Difficulties arise when compressors are run at reduced load and the refrigerant mass flow falls below the valve design range. It is helpful to keep the condensing pressure steady, although it does not have to be constant and can usually be allowed to fall in colder weather to save compressor power. Valves on small systems may be seen to fully close and fully open at times. The continual hunting of the thermostatic expansion valve means that the evaporator surface has an irregular refrigerant feed with a resulting slight loss of heat transfer effectiveness. It is probable that this valve will be superseded by the electronic expansion valve for many systems.

The pressure drop of the refrigerant is quite significant in large evaporators, for example in direct expansion coils with a single long tube. ***TEV maintains*** $\boldsymbol{Fp - Fe = A_b(P_p - Pe)}$ ***at a constant value equal to spring force***. The pressure $\boldsymbol{P_p}$ is the saturation pressure at $\boldsymbol{(Te + \Delta Ts)}$ while ***Pe*** is saturation pressure at ***Te.*** In a large evaporator, due to pressure drop ΔPe, the pressure at exit is say, $\boldsymbol{Pe}$ - ΔPe and corresponding saturation temperature at exit of evaporator is $\boldsymbol{Te\text{-}\Delta Te}$**.** The superheat ΔTs corresponds to evaporator pressure ***Pe*** and temperature **Te**. Therefore, effective superheat at evaporator exit is $\boldsymbol{\Delta Ts + \Delta Te}$**.** This may become very large and may result in low COP and lower volumetric efficiency of compressor. To correct for this, TEV is provided with a tapping, which feeds the pressure Pe - ΔPe from evaporator exit to the bottom of bellows. This will result in a degree of superheat equal to the set value ΔTs. A TEV with this provision is called *TEV with External Pressure Equalizer*. In this TEV a stuffing box is provided between pushpins and the valve body so that evaporator inlet pressure is not communicated to the bottom of bellows. Figure 5-6 shows a TEV with an external equalizer arrangement with pressure tapping.

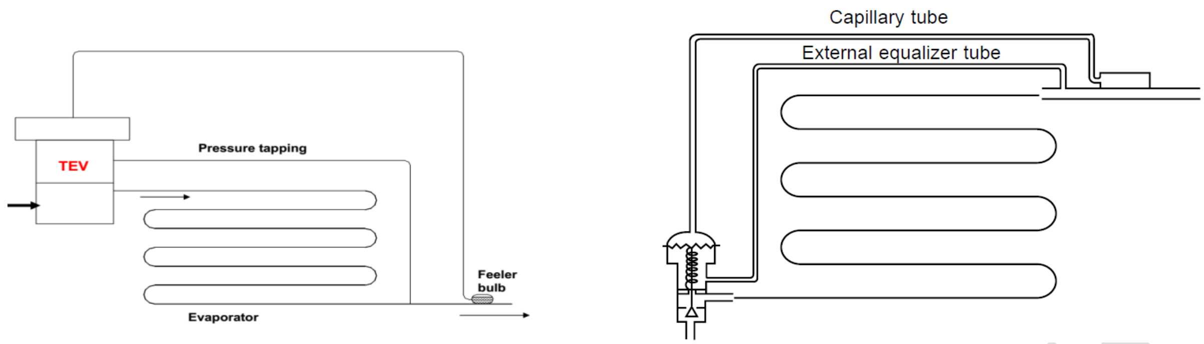

Fig. 5-6 A Thermostatic Expansion Valve with an external equalizer

In other word, in any case a large evaporator pressure drop leads to a lower COP; hence a number of parallel paths or circuits are provided in the evaporator. The refrigerant is fed to these paths by a single TEV fitted with a distributor. In such a case, it is recommended that external pressure equalizer be used and care taken to ensure that all the paths are symmetric and have the same length.

5-6-3 Advantages, disadvantages and applications of TEV:

The advantages of TEV compared to other types of expansion devices are:

1- It provides excellent control of refrigeration capacity as the supply of refrigerant to the evaporator matches the demand
2- It ensures that the evaporator operates efficiently by preventing starving under high load conditions
3- It protects the compressor from slugging by ensuring a minimum degree of superheat under all conditions of load, if properly selected.

However, compared to capillary tubes and AEVs, ***a TEV is more expensive and proper precautions should be taken at the installation.*** For example, *the feeler bulb must always be in good thermal contact with the refrigerant tube. The feeler bulb should preferably be insulated to reduce the influence of the ambient air. The bulb should be mounted such that the liquid is always in contact with the refrigerant tubing for proper control.*

The use of TEV depends upon degree of superheat. Hence, in applications where a close approach between the fluid to be cooled and evaporator temperature is desired, ***TEV cannot be used since very small extent of superheating is available for operation.***

TEVs are normally selected from manufacturers' catalogs. The selection is based on the refrigeration capacity, type of the working fluid, operating temperature range etc.

5-7 Electronic Expansion Valve, EEV:

Called also **thermal electric expansion valve** in which the schematic diagram of an electronic expansion valve is shown in Fig.5-7. As shown in the figure, an electronic expansion valve ***consists of an orifice and a needle in front it***. The needle moves up and down in response to magnitude of current in the heating element. A small resistance allows more current to flow through the heater of the expansion valve, as a result the valve opens wider. ***A small negative coefficient thermistor is used if superheat control is desired.*** The thermistor is placed in series with the heater of the expansion valve.

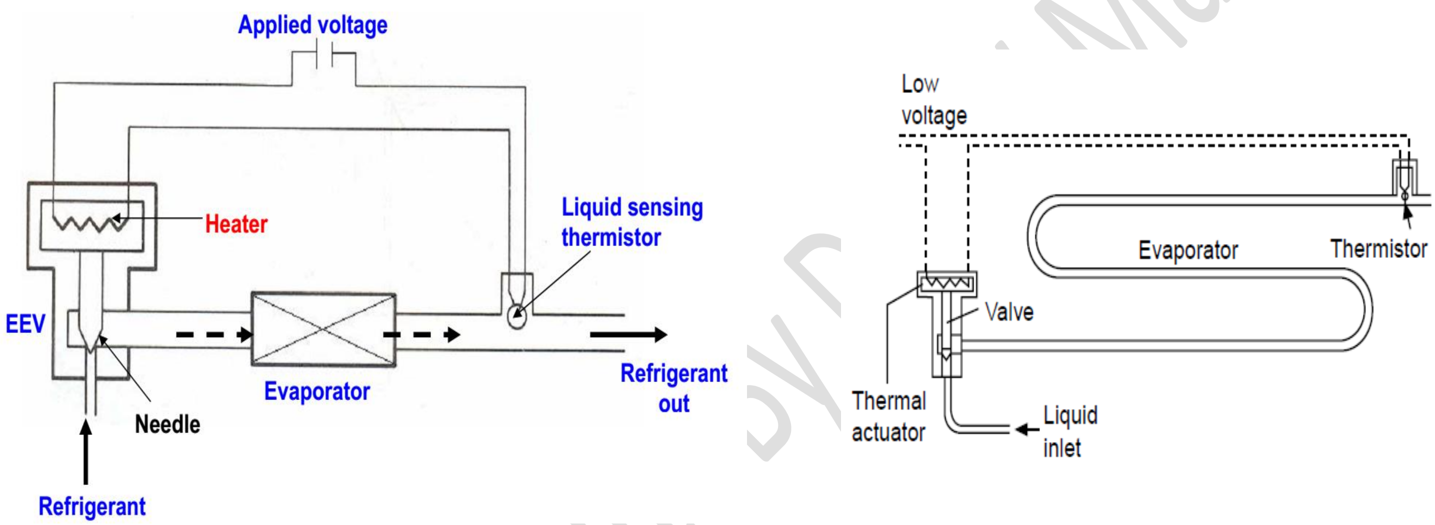

Fig.5-7 Schematic of an electronic expansion valve

The heater current depends upon the thermistor resistance that depends upon the refrigerant condition. Exposure of thermistor to superheated vapor permits thermistor to self-heat thereby lowering its resistance and increasing the heater current. This opens the valve wider and increases the mass flow rate of refrigerant. This process continues until the vapor becomes saturated and some liquid refrigerant droplets appear. The liquid refrigerant will cool the thermistor and increase its resistance. Hence in presence of liquid droplets the thermistor offers a large resistance, which allows a small current to flow through the heater making the valve opening narrower. ***The control of this valve is independent of refrigerant and refrigerant pressure;*** hence it works in reverse flow direction also. It is convenient to use it in year-round-air-conditioning systems, which serve as heat pumps in winter with reverse flow. In another version of it the heater is

replaced by stepper motor, which opens and closes the valve with a great precision giving a proportional control in response to temperature sensed by an element.
Electronic expansion valves are now widely used on small automatic systems, mainly as the refrigerant flow control device (evaporating or condensing) in an integrated control circuit.

Part2: Auxiliary Devices

Figure 5-8 shows an excellent diagram of a practical vapor-compression refrigeration system with all control devices.

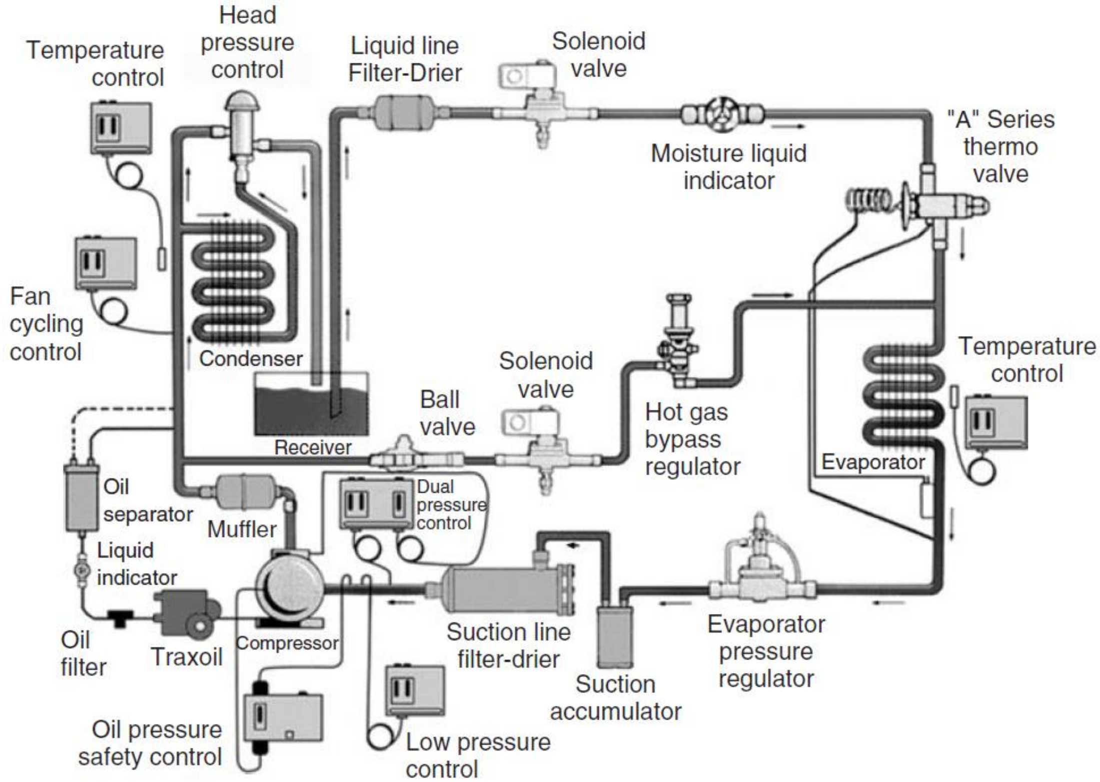

Figure 5-8 A practical vapor-compression refrigeration system with all control de*vices*.

1-Accumulators.
2-Receivers.
3-Oil Separators.
4-Strainers.
5-Driers.
6-Check Valves.
7-Solenoid Valves.

8-**<u>Defrost Control:</u>**

A defrost controller with timer operates various control valves and fan relays to quickly and efficiently remove frost and ice accumulation from evaporator surfaces. There are four easy-to-set defrost steps:

- Pump out.
- Hot gas.
- Equalize, and
- Fan delay.

This controller uses reliable, solid-state electronics with a precision quartz time clock and time interval adjusting slide knobs to sequentially operate through the four steps for smooth defrosting.

Each step is clearly indicated by a bright light emitting diode (LED) during operation. Terminals for optional sensor defrost initiation and terminations are provided. A 24-hour quartz time clock facilitates simple setting in 15-minute increments of defrosts start times. A 7-day quartz time clock for weekly scheduling is also available. All time clocks have 72-hour battery backup in case of short-term power failure. Because of its time-adjustable four-step defrost operation, this controller is suitable for almost every defrost application including top and bottom feed unit coolers, blast freezer evaporators, ice makers, etc.

<u>Questions and Answers</u>

1- What are the functions of expansion device, in refrigeration systems?
2- List the types of refrigerant expansion devices?
3- What are the factors that cause pressure drop in the capillary tube?
4- Define the following: Capillary Tube, Automatic Expansion Valve, Thermostatic Expansion Valve?
5- Draw a schematic diagram of the following:
   a- Automatic Expansion Valve?
   b- Thermostatic Expansion Valve?
   c- Electronic expansion valve?
6- What are the advantages of TEV in comparison with other types?
7- Rationalize the following:
   - TEV is most effective for dry evaporators in preventing the slugging of the compressors?
   - AEV maintains a constant temperature in the evaporator?
   - Sometime TEV is called TEV with cross charge?
   - Sometime TEV is called TEV with external equalizer**?** .
   - TEV valve always establishes balanced flow condition between compressor and itself?
   - The use of a high pressure control in refrigeration system?
8- Answer the following sentences by Yes or No, then correct the Wrong one:
   - Capillary is expansion device which used in refrigeration of ***variable*** opening type.
   - For ***TEV*** the adjustment spring is usually set such that during off-cycle, valve is closed.
   - A ***TEV*** also known as a constant pressure expansion valve.
   - ***AEV*** consists of a feeler bulb that is attached to the evaporator exit tube so that it senses the temperature at the exit of evaporator.
   - In ***AEV***, *t*he heater current depends upon the thermistor resistance that depends upon the refrigerant condition.
   - The control of EEV is ***d***ependent of refrigerant and refrigerant pressure.