Fundamental

SERIES 9 MODULE 09

CURRENT THINKING ON...

Refrigeration

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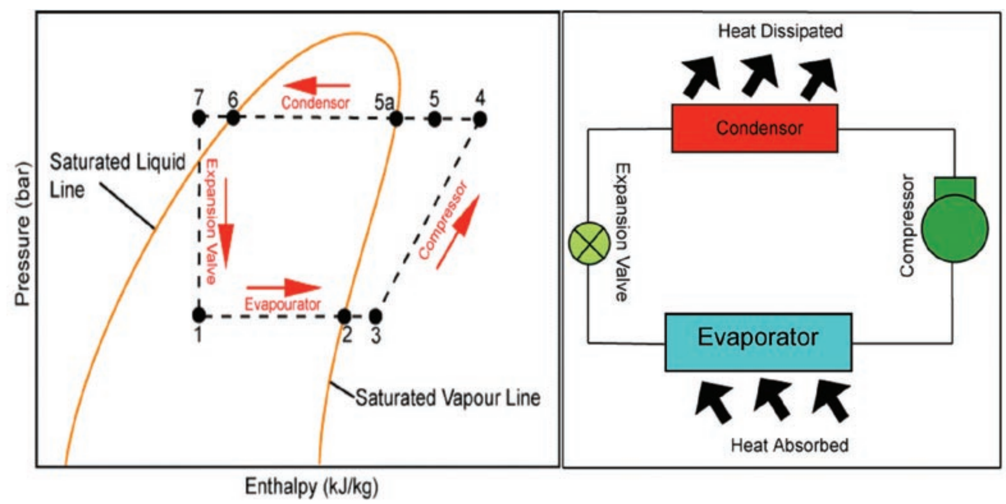
A refrigeration system transfers heat from a substance to be cooled to another or vice versa, i.e., to heat or cool a fluid, normally air or water. It is worth highlighting at this point that depending upon level, heat can be perceived as cold or warm. Most refrigeration systems utilise what is called the vapour compression cycle1. This is when heat is absorbed through a heat exchanger as the refrigerant evaporates. Heat is then rejected through another heat exchanger as the refrigerant condenses. There are other types of systems which can also obtain a cooling effect for example absorption cooling and steam injector.

Figure 1: Pressure-Enthalpy diagram for a typical refrigerant and basic schematic diagram of a refrigeration system.



Vapour compression cycle

Prior to understanding the cycle it would be useful to understand (or in many cases remind) some of the basic rules of Thermodynamics [2].

Rule 1: Heat flows naturally from hot to cold.

Rule 2: Energy (in the form of heat) is required to change a substance from a liquid to a gas (to boil or evaporate). When this happens the liquid absorbs large amounts of heat.

Rule 3: Energy is given out by a substance changing from a gas into a liquid (liquefying or condensing).

Rule 4: The boiling temperature and the condensing temperature change if the pressure changes.

A simple vapour compression cycle can be illustrated in the pressure/enthalpy diagram and the corresponding refrigeration circuit showing the main components, below in Fig. 1. The curve is called a saturation curve and shows:

- the refrigerant is just pure (saturated) liquid on the left part of the curve;
- it is a pure (saturated) vapour on the right part;
- the refrigerant is a saturated mixture of liquid and vapour inside the curve;
- it takes a lot of heat to evaporate liquid. A small amount of liquid circulating in a refrigerator can perform a large amount of cooling. This is one reason why the vapour compression cycle is widely used.

The refrigeration cycle is shown in Fig. 1, along with the basic components of a refrigeration system. Each system must have these basic components to complete the refrigeration cycle. These are explained in more detail later.

Each of the steps in the refrigeration cycle is shown on the pressure/enthalpy diagram :

1 - 2 Low-pressure liquid refrigerant in the evaporator absorbs heat energy from its surroundings (usually air or water), which fuels its change of state from a saturated liquid to a saturated vapour.

2 - 3 In practice, the slightly superheated refrigerant vapour picks up more heat energy from ambient air around pipework between the evaporator and the compressor. This should be minimised as it affects the efficiency of the system.

3 - 4 The superheated vapour enters the compressor where its pressure is raised. There will be a large increase in temperature, because some of the energy of the compression is transferred into the refrigerant purely as heat, thus raising its temperature (superheat).

4 - 5 The very hot vapour losses a small amount of heat to ambient air in the pipework between the compressor and condenser. This improves the efficiency of the system.

5 - 6 The high pressure superheated vapour flows into the condenser. The initial part of the cooling process (5-5a) de-superheats the vapour before it then turns back into saturated liquid (5a-6). The cooling for this process is usually achieved by using ambient air or water.

6 - 7 A further reduction in temperature may occur between the condenser and the expansion valve, so that the refrigerant liquid is sub-cooled as it enters the expansion valve. This improves the efficiency of the system.

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7 -1 The high pressure sub-cooled liquid passes through the expansion valve, which reduces its pressure and results in the temperature of the refrigerant going down. There is no energy loss or gain through the expansion valve.

The outlet of the expansion valve to the evaporator does not lie on the saturated liquid line. This is because at a lower temperature, the refrigerant cannot contain as much heat. This excess causes some of the refrigerant to evaporate (flash) in expanding.

Subcooling and superheating are usually desirable to ensure only liquid enters the expansion device. Superheating is recommended as a precaution against droplets of liquid being carried over into the compressor. [3]

Refrigeration cycle

These are the steps in the refrigeration cycle through the function of the main components:

1 - 2 The refrigerant absorbs a lot of heat in the evaporator. The evaporator contains refrigerant boiling at low pressure. As the refrigerant boils or evaporates it absorbs heat. This heat removed from the fluid surrounding the evaporator usually air, water or a secondary refrigerant.

2 - 3 Refrigerant vapour absorbs a little more heat in the suction line. The refrigerant absorbs heat from the ambient temperature air around the suction line between the evaporator and the compressor. This superheating should be minimised by insulation, to maintain its efficiency.

3 - 4 Refrigerant vapour is compressed in the compressor. The compressor takesrefrigerant vapour from the low pressure of the evaporator to the higher pressure of the condenser. During compression, the refrigerant vapour also heats up. Compressors are usually driven by an electric motor and are the main power users in refrigeration systems.

4 - 5 Refrigerant vapour loses some heat in the discharge line. The high-pressure refrigerant vapour flows from the compressor to the condenser, losing a small amount of heat energy to ambient air. This should be minimised to optimise efficiency.

5 - 6 Refrigerant loses a lot of heat in the condenser. The condenser contains the refrigerant which is changing from a superheated vapour into a liquid at high pressure. A lot of energy is released during this process which is either rejected to ambient air or cooling water.

6 - 7 Liquid refrigerant subcools in the liquid line. The liquid refrigerant flowing between the condenser and expansion device usually loses heat to ambient air. This subcooling is beneficial to the performance of the system since it increases the capacity without increasing the power input.

7 - 1 Refrigerant pressure is dropped in the expansion device. An expansion device maintains the pressure drop between the condenser and evaporator. The refrigerant saturation temperature also reduces as the pressure drops. The expansion device is sized to pass the required amount of refrigerant at the minimum likely pressure drop across the system.

Before exploring the components of a refrigeration cycle, it is important to look at some of the descriptions used when evaluating an efficient system.

System efficiency chain

The efficiency of a refrigeration system is expressed as the Coefficient Of System Performance (COSP)

$$\text{COP} = \frac{\text{Heat in (kW)}}{\text{Work in (kW)}}$$

The power input is that of the compressor and all other motors associated with the system such as fan motors, pumps and controls.

The efficiency of the compressor is expressed as the Coefficient of Performance.

$$\text{COSP} = \frac{\text{Capacity (kW)}}{\text{Power (kW)}}$$

This is the efficiency of the compressor and does not take into account the power of the other motors associated with the system such as fan motors, pumps and controls. Heat in, is calculated from the enthalpy values between points 1 and 2, or across the evaporator. Work in, is calculated from the enthalpy values between points 3 and 4, or the work done by the compressor.

The cooling effect of the evaporator is governed by:

- the difference in temperature between the medium being cooled and the evaporating refrigerant. The wider the temperature difference, the greater the rate of heat transfer;
- the size and design of the evaporator.

The compressor capacity is affected by:

- the compressor displacement, usually measured in cubic metres per second (m3/s);
- the difference between the evaporating and condensing temperature, known as the temperature lift. Similarly, the compression ratio with the pressure in the condenser and evaporator related to the temperatures;
- the properties of the refrigerant.

The condenser capacity is affected by:

- the temperature of the cooling air or water;
- the size and design of the condenser.

System components

The evaporator is the heat exchangers where refrigerant is evaporated while cooling the product, fluid, or body. For example the air in a cold room or water. The refrigerant enters the evaporator and boils off along the evaporator at the evaporating temperature. The aim of the process is for the liquid to turn to a saturated vapour, this occurs at the same temperature. Only when fully saturated will the temperature rise further.

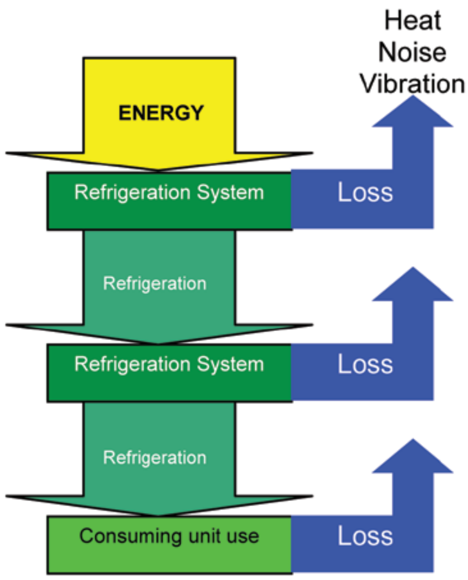
The evaporator temperature must be as high as possible to maintain evaporator efficiency. Using a large evaporator will achieve this but requires the heat transfer surface to be maintain. For example:

- in a direct expansion air cooler, the fin block should be kept clear of dirt and slime whilst adequately defrosted when necessary;
- the tubes in a shell in tube evaporator should be cleaned to prevent fouling and corrosion;
- the cooling medium flow should be maintained, pump or fan motors must work properly;
- oil should not be allowed to build up in the evaporator;
- the flow refrigerant through the evaporator should be correctly controlled to ensure full use of its capacity with minimum superheat.

The effectiveness of the evaporator depends on:

- evaporating temperature/ pressure;
- size/condition of evaporator;

Figure 2: System efficiency chain



• degree of superheat; and
• degree of subcooling.

The increase of 1°C in evaporating temperature will decrease the temperature lift by 1°C cutting running cost by 2-4 per cent.

The function of the compressor is to draw the low-pressure refrigerant vapour from the evaporator and compress it to a higher pressure. This enables the vapour to be condensed back into a liquid by the other heat exchanger (the condenser). Refrigeration compressors can be summed up as the way the increase in pressure is obtained. The type of these can be seen in figure 2, below. Reciprocating compressors are the most common types used today [3].

The efficiency of the different types of compressor can vary significantly and so it is necessary to match them to the application. In any comparison, all ancillary items should be taken into account. For applications with large loads or varying loads, several compressors are used to improve the efficiency by closer matching the load. This may also improve maintenance by reducing the number of starting and stopping. When considering the number of compressors you should:

• avoid the use of single, large compressors;
• select a combination of sizes (reduces the likelihood of part loaded compressors); and
• use a control strategy that minimises the operation of the compressors on part load when more than one is running.

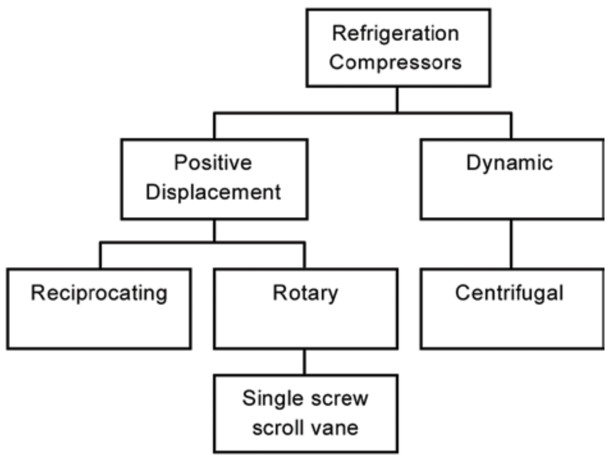
Effective compressor use

Compressors are most effective when:

• the temperature lift (compression ratio) is low;
• suction superheat is low; and
• cooling is adequate.

The condenser is the heat exchanger that converts refrigerant vapour to a liquid. Superheated refrigerant vapour enters the condenser, where it loses heat by passing close to the coolant fluid. The refrigerant vapour is first cooled to its saturation temperature at which point condensation begins. It is while it condenses to a liquid at constant temperature, latent heat is released. Only when fully condensed will the

Figure 3: Types of refrigeration compressors



temperature start to fall. In reality condensation occurs even in the superheated region and subcooling occurs in the condensation region. Three main types of refrigeration condensers are: air cooled, water cooled, and evaporative. Evaporative utilises both ambient air and the evaporation of water to remove heat.

Condenser efficiency

The more surface area a condenser has, the closer the condensing temperature is to the temperature of the coolant. For example:

• in an air cooler, the fin block should be kept clear of dirt and slime;
• in water-cooled condensers, the condenser tubes should not be fouled, corroded or have any scale build up.

The condenser should be set up to take advantage of any lower ambient air temperatures, i.e. in the winter or overnight. This will affect the pressure ratio causing a need to select the appropriate expansion device to cope with the change.

The effectiveness of the evaporator depends on:

• condensing temperature/ pressure;
• size/condition of evaporator;
• cooling medium;
• temperature of the cooling medium; and
• head pressure control.

A decrease of 1°C in condensing temperature will increase the temperature lift by 1°C cutting running cost by 2-4 per cent.

The expansion device reduces the pressure of the liquid refrigerant after the condenser so that evaporation takes place. There are four types of expansion device: capillary tubes and orifice plates; thermostatic, electronic or balanced port valves; float valves; hand expansion valve and level switch. Some types of expansion devices are capable of controlling the flow of the refrigerant to the benefit of varying the system capacity to meet demand; and, prevent liquid refrigerant leaving the evaporator and causing damage to compressor.

When capillary tube or orifice plates are used, the quantity is critical to the capacity and efficiency. If they become partially blocked or damaged this would affect the efficiency.

With thermostatic valves the superheat setting has a significant effect on efficiency, and reliability. If the superheat is too low, liquid refrigerant may return to the compressor, causing damage. If the superheat is too high, capacity and efficiency are reduced.

Thermostatic valves should be avoided for varying load as they do not control changes too well.

Other components and features that are important are: the control system; insulation; liquid receiver; oil separator; sight glass; liquid pressure amplifier, insulation; and, heat recovery.

Refrigerants

The use of refrigerants is changing, primarily with the phasing out of ozone depleting substances. Therefore, it is important to understand what refrigerant is being used and use the changing regulations to plan for investment in new or upgrading existing systems to be more efficient. COP and COSP for refrigeration systems have improved in recent years so it can be an opportunity for investment. The following is a short summary of the changes taking place:

• cannot use CFCs (R12, R50);
• no new HCFC systems (R22); HCFCs banned from 2010
• annual leak test when CFC/HCFC charge is greater than 3kg; and
• trend towards HCs and CO_2 (indirect and cascade system).

References and further reading

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SERIES 9 MODULE 09: QUESTIONS

Refrigeration

Please mark your answers on the sheet below by placing a cross in the box next to the correct answer. Only mark one box for each question. You may find it helpful to mark the answers in pencil first before filling in the final answers in ink. Once you have completed the answer sheet in ink, return it to the address below. Photocopies are acceptable.

1. What state is the refrigerant when entering the evaporator?

☐ Low Pressure Liquid ☐ Low Pressure Vapour
☐ High Pressure Liquid ☐ High Pressure Vapour

2. The temperature lift or compression ratio is the difference between?

☐ Compressor and Evaporator
☐ Evaporator and Condenser
☐ Expansion Device and Compressor
☐ Evaporator and Expansion Device

3. What component regulates the pressure drop between the condenser and evaporator?

☐ The compressor ☐ The condenser
☐ The evaporator ☐ The expansion valve

4. The coefficient of performance is the ratio of?

☐ The compressor work in and the heat dissipated
☐ The refrigeration capacity and compressor work in
☐ The heat dissipated and the heat absorbed
☐ The refrigeration capacity and the heat absorbed

5. Maintaining a high evaporation temperature will

☐ Help optimise the system efficiency
☐ Increase the level of control in the system
☐ Reduce the system efficiency
☐ Decrease the level of control in the system

6. For large systems with varying loads, what following compressor arrangement is recommended?

☐ A single large compressor with variable speed drive
☐ Duty and standby compressor and well controlled
☐ Multiple compressors with varying sizes and well controlled
☐ Multiple compressors with the same duty and well controlled

7. Minimising the temperature lift (compression ratio) will?

Reduce the work done by the compressor
Improve the heat transfer of the evaporator
Reduce the heat transfer of the evaporator
Increase the work done by the compressor

8. The effectiveness of the evaporator will improve?

☐ With the temperature of the cooling medium
☐ With the size of the compressor
☐ With the size of the condenser
☐ Reducing the heat transfer area

9. What type of process takes place in the expansion valve?

☐ Is a constant enthalpy process ☐ Is a constant heat input
☐ Is an increasing enthalpy process ☐ Is a heat dissipation process

10. The COP of a systems is calculated by Heat In divided by Work In. Referring to figure 1 graph, what are the two points that would be used to calculate the Heat in?

☐ enthalpy values between points 3 and 4
☐ enthalpy values between points 1 and 2
☐ enthalpy values between points 4 and 7
☐ enthalpy values between points 1 and 3