SERIES 13

CPD fundamentals

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MARK THROWER MANAGING EDITOR

SERIES **13** | MODULE **05** | **REFRIGERATION**

Understanding today’s refrigeration systems

George R Norrie, director, Scotia Energy Ltd

Refrigeration is a general term used to describe the effect of using mechanical, chemical and thermal systems to move heat from one location to another to effect cooling in the original location. The opposite of a refrigeration system is a heat pump whereby the heat is moved from one location to provide additional heat in the second location. Where there is a refrigeration system, there is also a heat pump capability and vice versa. The capability is not always utilised but it is fundamental to how the refrigeration/heat pump cycle works.

If you move energy from one place to another it must increase the energy in one area and reduce the energy in another.

Refrigeration systems account for some 15 per cent of the UK’s energy use and is growing. Much of this is used in air conditioning systems. Other large users are supermarkets, cold storage, hospitality and food processing.

This article is designed to introduce readers to some of the refrigeration and heat pump technologies and their applications.

Various refrigeration and heat pump systems exist and new technologies are being implemented continually across the world as part of the search for more carbon friendly heating and cooling solutions.

The basic rules of thermodynamics relating to refrigeration are:

• heat naturally flows from a hotter to a colder state.

• energy is required to change a refrigerant chemicals state from a cooler to a hotter condition;

• energy is released in the form of heat when the refrigerant vapour condenses to a liquid.

• energy is absorbed in the form of heat when the refrigerant liquid evaporates to a vapour.

• the condensing and boiling point of a refrigerant changes depending on the system pressure.

There are two main types of practical refrigeration and heat pump systems used throughout the world at present.

These are the vapour compression cycle and the absorption cooling cycle.

The vapour compression cycle is the most common method of refrigeration. It is used in almost all refrigeration applications and accounts for almost 90 per cent of all refrigeration systems.

The basic vapour compression cycle is based on the fact that some unique chemicals called refrigerants can be pressurised and depressurised to change the state of the chemical from liquid to gas. This allows it to increase in temperature and decrease in temperature as it is compressed as a hot gas and expanded to a cold liquid. The temperature and pressure that these chemicals change state is the operating range of the refrigeration system.

This unique ability allows the refrigerant chemical to be heated by adding heat input from the evaporator when a liquid at low temperature and pressure until it changes state to a vapour whereby it absorbs heat form the heating source which could be ambient air or water. Once the liquid has absorbed enough heat it will change to a vapour in a gaseous state and can be compressed to a higher pressure and temperature normally using a compressor. Once the vapour has been compressed it is at a higher temperature and pressure which can be fed to a heat exchanger called a condenser allowing it to lose heat from the hot vapour to the fluid on the other side of the heat exchanger which is at a lower temperature. As the heat is lost from the vapour the vapour cools down and starts to condense. Once the maximum heat is lost from the vapour as it condenses it is then expanded back down to the original pressure using an expansion valve or similar device, whereby the high pressure liquid is dropped to a liquid at low pressure and temperature and fed back to the evaporator where the cycle can be repeated.

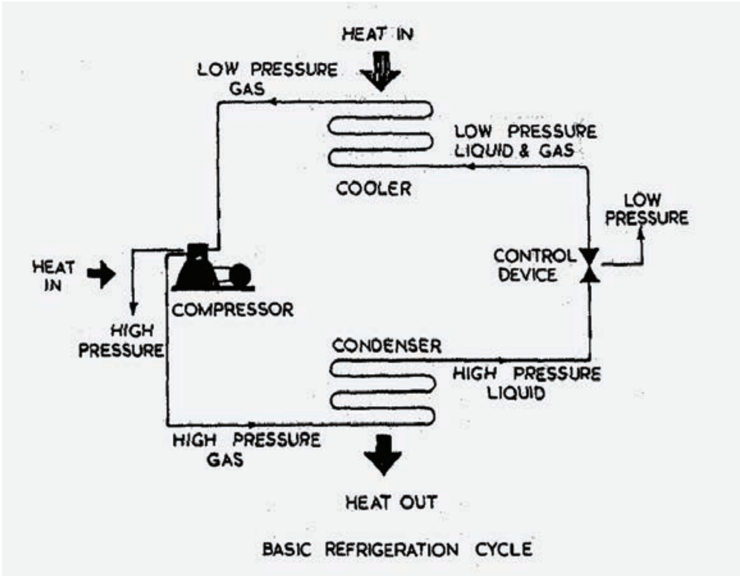
The cycle requires energy input from the compressor to make the system work. Typically the heat moved is some 2 to 6 times the compressor energy input. One kW of compressor power can move some 2kW to 6kW of heat from a colder to

Produced in Association with energy institute hotter area or vice versa.

Refrigeration is a very efficient method to move heat either from a cooler to a hotter location allowing refrigeration of the cooler location or heating of the hotter location.

Various gaseous vapours and gases can be used for the refrigeration cycle. The main requirements are that the chemicals change state from liquid to gas at temperatures close to those that you want to refrigerate to.

The implementation of the new part L building regulations, carbon reduction commitment and F Gas regulations (EC) No 842/2006 will require that we all take a closer look at heat pumps and refrigeration system design and operation to minimise energy consumption and allow operators to meet there energy and carbon reduction targets and associated legislation.



Vapour Compression Refrigeration Systems

The key to optimum efficiency in specifying and using refrigeration systems is the choosing the right system and equipment. In all but the most specialist of applications such as CHP and high temperature heat recovery the vapour compression cycle will be the most appropriate.

This system is made up of a number of key components. The main ones are:

- refrigerant
- compressor
- evaporator
- condenser
- expansion valve

The refrigerant is is the most important element in the system. This makes the cycle work and it is essential that it is specified correctly. There are many different refrigerants. A refrigeration system will be designed to operate with a specific refrigerant and it will only work correctly with this refrigerant or one with very similar characteristics.

In common refrigeration systems with a temperature range of +5C to -30C a number of synthetic fluorinated gases (HFC's) have been developed which are in almost all small commercial and domestic refrigerators. Refrigerators normally work at +5C and freezers at -28C.

Ammonia is still the gas of choice for large low temperature commercial applications such as food processing and large cold stores. Helium is used for cryogenic refrigeration systems at up to -272C. Air can be used as a refrigerant but only at very low temperatures around -181C. (CFCs) Chlorofluorocarbons and (HCFCs) Hydro chlorofluorocarbons were the main refrigerants used until 2000. They were very aggressive ozone depleting gases have been banned for use in refrigeration systems since 2010.

In 2006 the F Gas regulations (EC) No 842/2006 came into force. These regulations were meant to optimise the use of the very harmful HFC greenhouse gas refrigerants by imposing regular inspection and leak testing of systems and recording of any refrigerant losses. Although the regulations exist, enforcement seems to be a low priority for the local government. This has resulted in the regulations being ignored in many organisations. The loss of 1kg of HFC-23 into the atmosphere is equivalent to 14,760kg of CO_2.

The compressor is the heart of a vapour compression refrigeration system. It provides the energy input to the refrigerant to increase its pressure during the vapour stage. It uses almost all the energy input to the refrigeration system.

The low pressure vapour is drawn into the compressor suction and compressed to a higher pressure before being sent to the condenser where it loses heat and condenses to a saturated liquid at high pressure.

Numerous types of compressor are available but generally reciprocating and screw compressors are the most common. The compressor is chosen based on the refrigerant being used and the size of the load. Single stage compressors are used in domestic and small commercial installations and multistage, multi pack or screw compressors are used in large commercial installations.

Oil free compressors are available but where oil lubricated compressors are used the refrigerant has to be filtered to ensure that there is no contamination from the oil. A filter dryer is also fitted to most systems before the expansion valve prior after the refrigerant sump to remove any water from the refrigerant during operation and a sight gas is usually installed prior to the dryer to allow visual inspection of the refrigerant. If any bubbles are present, this usually indicates a shortage of refrigerant, blocked filter dryer or undersized condenser.

Refrigeration compressors operate most efficiently if:

- the compression ratio is minimised;
- suction superheat is minimised; and
- the compressor is adequately cooled.

Some variable speed compressor systems are available where by the compressor speed is increased or decreased to meet the required cooling load making significant energy savings. These compressors are expensive to purchase and are generally only found on commercial installations at present.

The evaporator is a heat exchanger which is connected in the circuit to allow the heat from the area to be cooled to be absorbed by the refrigerant. The refrigerant is a cold liquid when it enters the evaporator after the expansion valve and it evaporates to a vapour as it absorbs the heat from the refrigerated area.

There are many different types of evaporator but most are liquid to air heat exchangers normally with electrically operated fans blowing the air from the refrigerated space over the heat exchanger to increase heat exchanger performance. Refrigerant to water evaporators are used in chilled water systems. In many ground source heat pump systems the evaporator heat exchanger is buried in the ground.

Evaporator performance depends on:

Correct operating evaporating temperature and pressure

The size and heat exchange properties of the evaporator i.e. Is it made from copper or aluminium etc. Is it fan assisted if air to liquid.

Is it well maintained and defrosted regularly if air to liquid.

The actual temperature of the refrigerated load is maintained near the evaporator design conditions.

The degree of useful superheat is maximised by ensuring that the refrigerated load temperature is a few degrees higher than the evaporator temperature.

Ensure transfer pipe work between the evaporator and the refrigerant liquid sump outside the refrigerated space is minimised and well insulated to prevent unwanted heat loss from the pipe to its surroundings or 'useless superheating'.

Minimise evaporator fan running time using temperature control to switch off fans when the cooled area is down to temperature in air to liquid systems.

Ensure that the cooled chilled water or space temperature is controlled tightly and not over cooled.

The condenser is a heat exchanger which is connected in the circuit to allow the heat from the hot refrigerant after the compression cycle to be cooled and be absorbed by the colder condenser heat transfer medium. Normally this medium is either ambient air or cooling water. The refrigerant is a hot gas when it enters the condenser and it condenses back to liquid as it loses heat to the condenser cooling medium.

There are many different types of condenser but there are 2 basic types generally in use: liquid to liquid (refrigerant to water) or refrigerant liquid to air heat exchangers. In the case of liquid to air condensers the cooling is normally assisted with electrically operated fans blowing the ambient air over the heat exchanger to increase the condenser heat exchanger performance. These fans add to the energy input to the cycle and must be controlled to maximise efficiency.

The condenser can be any kind of heat exchanger and many designs have been developed for different applications with differing operational efficiencies and associated cost.

Condenser performance depends on:

Correct operating condensing temperature and pressure

The size and heat exchange properties of the condenser i.e. Is it made from copper or aluminium etc. Is it fan assisted if air to water.

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Ensure that the condenser eat transfer surfaces are well maintained and cleaned regularly.

The degree of useful sub-cooling is maximised by ensuring that the cooling medium temperature is maintained a few degrees lower than the condenser temperature.

Minimise condenser fan running time using temperature control to switch off fans when they are not required.

Ensure that liquid to air condensers are located in a cool area and not subjected to direct sun heat gains.

Ensure that the head pressure is controlled to maximise efficiency

The expansion valve

The expansion valve is located after the condenser and the refrigerant sump. It is used to expand the cool vapour at high pressure down to a cold liquid at low pressure. The low pressure or head pressure is normally preset depending on the refrigerant gas condensing pressure and temperature. Some smart automatic expansion valves are now available which alter the head pressure depending on demand to minimise energy use. These are efficient but expensive and are generally only used on the larger commercial systems.

Vapour Compression Refrigeration System efficiency

Comparing different system energy use is important to evaluate performance against alternative technologies and systems and to identify any reduction in system performance over time

The vapour compression refrigeration cycle is based on the reversed carnot heat engine cycle. This cycle has a theoretical maximum efficiency which is very high but must be under 100% as some energy is required to drive the cycle using a compressor.

The Carnot cycle efficiency is described as:

Efficiency = work output/work input.

As we are dealing with moving energy in the form of heat rather than actual work another method of gauging performance is used.

In the case of refrigeration systems the COP (coefficient of performance) is normally used to describe performance.

The COP = useful heat transferred/ energy input

The useful heat transferred in a refrigeration system is the heat moved from the evaporator to the condenser. The work input is normally the compressor energy input.

From a pressure enthalpy diagram this is normally

COP = (h3-h2)/(h2-h1) see fig below

Where auxiliary fans or equipment are used this energy can be added to correct the COP giving the COSP.

COSP = Refrigeration effect produced/ total energy used. or

COSP = (h3-h2) / ((compressor power) + (fan power) + (defrost power etc))

The COP and COSP can vary during time depending on loading and ambient conditions. This can produce large reductions in efficiency. Ideally the COP should be calculated and logged continually using M&T software. This allows the user to see how best to operate the system and the effect of poor operation and loading on efficiency.

Another method of looking at refrigeration efficiency is looking at the actual useful output compared to the energy input.

For example a food processer may freeze a number of items per hour.

The key ratio might be:

Number of items per hour frozen / refrigeration energy input. (items frozen / kWh)

This graph would show how the refrigeration system coped with operational changes over time.

Efficiency Improvements

The key to optimum efficiency in specifying and using refrigeration systems is selecting the appropriate equipment and refrigerant for the required operating temperature range.

Different refrigerant chemicals and systems are available for different operating temperatures, cooling loads and conditions. Select the correct system and appropriate refrigerant.

Design the system with the lowest temperature difference possible and do not greatly over or under size. A 1oC increase in temperature lift between cooling location and heating location temperatures equates to a 2% to 4% increase in energy input.

Minimise the cooling load by ensuring that the refrigeration system and refrigerated load is well insulated and that it is well sealed preventing outside air heat in-leak where possible.

Minimise any electrical heat gains in the refrigerated area such as lights or motors. Ensure that all auxiliary loads are switched off and only used when necessary.

Ensure that all the heat exchanger surfaces are clean and ice free. Instigate automatic de-frosting systems to keep evaporator surfaces ice free.

Locate the condenser in a cool area with no direct sunlight or heat gains.

Ensure that there is good air circulation at refrigerated air cooled rooms and cabinets

Insulate all liquid refrigerant pipe work

Check refrigerant levels regularly and seal leaks. Low refrigerant can increase energy input by up to 15%. refrigerants are also very aggressive greenhouse gases.

Fit good controls to optimise operating times and minimise energy.

Vapour Absorption Cooling

The vapour absorption cooling cycle is a chemically driven cycle rather than a mechanically driven one. It has very few moving parts and relies on thermal and chemical reactions to drive the system.

Vapour absorption refrigeration systems are similar to vapour compression systems in that they have a condenser, evaporator and expansion or throttle valve. They differ in that the main compressor energy input is replaced by heat. They are typically much more expensive to purchase than vapour compression systems and are only suitable for large heat recovery systems where the heat is required for cooling purposes.

There is a small liquid refrigerant circulating pump and the refrigerant is normally either ammonia or a lithium bromine solution which are both hazardous toxic chemicals and need special care when operating or handling. Vapour absorption systems are normally used in large fixed load applications such as heat recovery as they are not good under part load.

They are normally less efficient than vapour compression systems but are applicable where constant waste heat is available for recovery which can be used for refrigeration. Vapour absorption chillers normally provide chilled water from the evaporator at temperatures suitable for air conditioning systems.

In the vapour absorption cycle heat is supplied as hot water or steam at the desorber. The heat is absorbed by the refrigerant in the desorber or generator and the hot vapour produced is passed to the condenser where it is condensed and heat is rejected to cooling water.

The refrigerant is passed through an expansion or throttle valve at low temperature and pressure to the evaporator where the cold vapour gains heat from the chilled water load.

The warmed vapour from the evaporator is then passed to the absorber where cooling water cools the refrigerant and it is mixed with the poor solution from the desorber and pumped back to the desorber via a solution heat exchanger which preheats the rich solution. At the desorber the cycle repeats. The heat is rejected at the condenser and the cooling is absorbed from the evaporator similar to vapour compression system.

Vapour Absorption Refrigeration Efficiency

In absorption refrigeration systems the COP (coefficient of performance) is defined as:

COP = the energy input / useful cooling energy

COP = (Tevap x (Tgen-Tcond)) /(Tgen x (Tcond- Tevap))

The COP for absorption refrigeration systems is normally lower than similar sized vapour compression systems at 1.5 to 3 but they are useful for large systems where continuous waste heat is available for recovery.

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ENTRY FORM

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.

QUESTIONS

1. What is a refrigeration system?
- ☐ A system which creates cold
- ☐ A system which moves heat from a colder to a hotter location.
- ☐ A system which makes ice
- ☐ A system which cools a room

2. The F gas regulations are meant to:
- ☐ improve maintenance and inspection of refrigeration systems to reduce refrigerant leaks and refrigerant losses
- ☐ to meet EU regulations
- ☐ to stop icing of plant
- ☐ to optimise energy use

3. In vapour compression refrigeration systems the COP is short for:
- ☐ cold outside place
- ☐ coefficient of pressure
- ☐ coefficient of performance
- ☐ cold in pipes

4. In vapour compression refrigeration systems the COP is defined as
- ☐ energy input x compressor power
- ☐ useful heat transferred x energy input
- ☐ useful heat transferred/energy input
- ☐ energy input/useful heat transferred

5. The loss of 1kg of HFC-23 into the atmosphere is equivalent to
- ☐ 200 kg of CO2
- ☐ 1,000 kg of CO2
- ☐ 1,476 kg of CO2
- ☐ 14,760 kg of CO2

6. A condenser in a refrigeration system is used to:
- ☐ export heat from the hot high pressure vapour
- ☐ absorb heat from the atmosphere
- ☐ condense the low pressure vapour
- ☐ evaporate the high pressure vapour

7. An expansion valve is used in a refrigeration system to:
- ☐ compress the hot refrigerant
- ☐ supply heat to the atmosphere
- ☐ allow the high pressure vapour to expand to low pressure and temperature
- ☐ allow the cold gas to expand to a higher presure

8. An Absorption chiller is best used on:
- ☐ intermittently loaded refrigeration loads
- ☐ small refrigeration systems
- ☐ low temperature systems
- ☐ large fixed load waste heat recovery systems

9. Vapour absorption refrigeration systems normally use hazardous refrigerants these are:
- ☐ water
- ☐ ammonia or lithium bromide solution
- ☐ CO2
- ☐ helium

10. Dryers are used in refrigeration systems to:
- ☐ remove water from the refrigerant
- ☐ produce dry ice
- ☐ increase system pressure
- ☐ remove grease from the system

Please complete your details below in block capitals

Name .... (Mr. Mrs, Ms) ....

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Completed answers should be mailed to:

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