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MARK THROWER MANAGING EDITOR

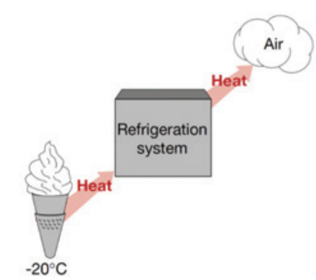
SERIES **16** | MODULE **02** | **REFRIGERATION**

Improve the efficiency of refrigeration systems

by David Hart, director, Energy Intelligent Solutions

Refrigeration systems are commonplace in many industrial and commercial installations, ranging from complex, bespoke systems operating at low temperatures in industry to more 'standard' solutions used for cooling commercial buildings and to generate chilled water. In the basic refrigeration process, shown in Fig. 1, heat is taken away from the substance to be cooled, and rejected at a higher temperature, generally to the surroundings at ambient temperature.

Fig. 1 - The basic refrigeration process

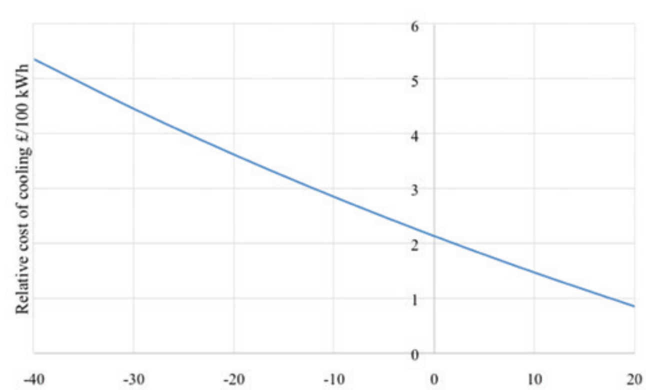


The cost of cooling depends significantly on the temperature required. It is much more expensive, and costly in energy and carbon emissions, to generate a chilled fluid at 10°C compared with one at, say, 6°C. This is illustrated in Fig. 2 which shows the approximate cost of providing 100kWh of cooling at various temperatures using a conventional vapour compression refrigeration system and assuming an electricity price of 10p/kWh.

The figure shows that a system operating at -30°C will need some three times the energy of one operating at 10°C. Perhaps more usefully, cooling to 6°C compared to 10°C increases energy costs by 18 per cent.

The exact costs and differences depend on the particular system and its operation, but the principle that energy costs increase by 2 to 4 per cent for each 1°C reduction in cold temperature is generally true. Often, therefore, an easy opportunity to improve the efficiency of existing systems is to raise the temperature of the cooled fluid to save energy. For example, raise the chilled water temperature set point and increase the cold store temperature by 1OC. This might be possible at times of lesser cooling demand or because the set point is already lower than it needs to be. For designers it is important to take account of the relationship between temperature

Fig. 2 - Variation in the cost of cooling with temperature for a conventional vapour compression refrigeration system and assuming an electricity price of 10 p/kWh

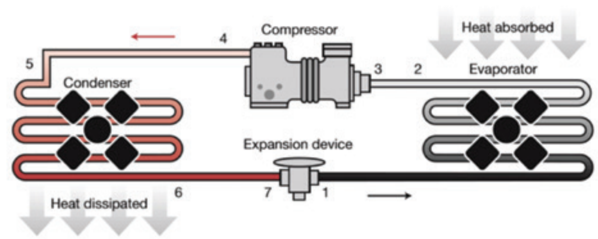


and energy efficiency.

Another significant improvement opportunity, and arguably the first to consider with refrigeration, is to reduce the demand for cooling. Cooling demands are many and various, but there are some more common efficiency improvement opportunities that can be considered. There is little point in installing an efficient refrigeration system if the cooling is not needed in the first place:

- use heat recovery where possible to cool process streams before using refrigeration systems. Where feasible, use alternative 'free' coolers such as air coolers or cooling towers, or fresh air in buildings;
- use control systems to avoid over-cooling products or space temperatures, or to avoid simultaneous heating and cooling in buildings;
- improve the insulation of pipes and surfaces, and keep cold store and chiller doors closed as far as possible. Use strip curtains to prevent heat losses, and use night blinds on chilled food display cabinets;
- where pumps are used to distribute chilled fluid, make sure the power use by these pumps is minimised, for example through using variable speed drive controls and control systems/valves that eliminate unnecessary bypass flows. Remember that a significant proportion of the energy used by the pump motor ends up as heat in the chilled fluid and this heat is an additional cooling demand for the refrigeration system; and
- where fans are used to distribute air such as cold store evaporator fans, make sure they are not overused by introducing controls that cut fans off when not required without compromising the distribution of air. Again, the energy used by these fans has to be removed by the refrigeration system. Where defrost systems are required, especially electric defrost, these should be controlled to avoid under and over defrost, both of which can significantly impair the performance of refrigeration systems, with over defrosting being a further addition to the system cooling demands

Fig. 3 – A vapour compression refrigeration system



In the same way that the colder the substance being cooled the more energy is required, it is also the case that the hotter the 'ambient', where the heat is rejected, the more energy is require

The common, conventional vapour compression refrigeration system is shown in Fig. 3. The system includes four key components: the compressor, the condenser, the evaporator and the expansion valve. There are variants on this basic cycle. The refrigerant enters the evaporator mainly as a low-pressure liquid and boils, in turn cooling the substance. The temperature of the refrigerant must be lower than the temperature of the substance being cooled for the heat to flow. The refrigerant gas leaving the evaporator is compressed and then enters the condenser where it is cooled by the ambient air or water. The refrigerant condenses, and the temperature of the refrigerant at this stage is higher than that of the fluid which is providing the cooling. Liquid leaves the condenser and then passes through the expansion valve where its pressure is lowered and the refrigerant cools, and the cycle is completed.

Evaporating temperature

The relationship between the temperature of the refrigerant as it boils/condenses and the refrigerant pressure is key. As pressure is lowered, the boiling temperature of the refrigerant lowers. Therefore, in the evaporator the refrigerant can boil, and remove heat, at a low temperature (and pressure) and in the condenser, the refrigerant can condense (and boil) at a higher temperature (and pressure) and reject heat to the condenser cooling fluid. These two temperatures are referred to as the evaporating temperature, Te, and the condensing temperature, Tc. The compressor and expansion valve divide the high and low-pressure sides of the system.

The general measure of the energy performance of a refrigeration system is the Coefficient of Performance, CoP. This is defined as the useful cooling divided by the power used by the compressor. A higher CoP means higher energy efficiency.

Fig. 4 illustrates the effect of changes in evaporating temperature, Te, and condensing temperature, Tc, on CoP. A higher evaporating temperature gives a higher COP, a lower condensing temperature gives a higher CoP. For each 1°C change in Te or Tc, the refrigeration system energy use increases by 2 to 4 per cent for the same amount of cooling.

A higher Te can be achieved by raising the temperature of the cooled fluid, as already discussed, but also by improving the performance of the evaporator, such that the evaporating temperature is closer to the temperature of the fluid being cooled. Practical measures for this include ensuring the expansion valve is set to avoid high superheating of the gas leaving the evaporator, having a larger evaporator, and avoiding fouling and blocking of the heat exchanger (for example dirt, oil or ice).

A lower Tc can be simple to achieve. Many refrigeration systems operate with control systems that keep the condensing pressure and condensing temperature higher. A sign of this is idling condenser fans in mild and colder weather. This may be due to the constraints of the expansion valve or compressor, or it may be just a chosen strategy. Avoiding this 'head pressure control' is generally feasible and very cost effective, often a quick win with significant benefits, or alternatively reducing the head pressure control set point can be easily implemented.

The approximate relationship between Te, Tc and CoP for a practical refrigeration system is given by the equation below:

CoP = 0.6* Te/(Tc-Te)

Where Tc and Te are in Kelvin, equivalent to °C + 273.

For example, for a system with a condensing temperature of 40°C and an evaporating temperature of -10°C:

CoP = 0.6*(263/50) = 3.16

This means that every 1kW of power input to the compressor will produce 3.16kW of useful cooling. Often, it is useful to include other power use associated with the system within the CoP calculation, for example the power use of the evaporator pumps, to give a system CoP which provides a more accurate overall picture of system performance.

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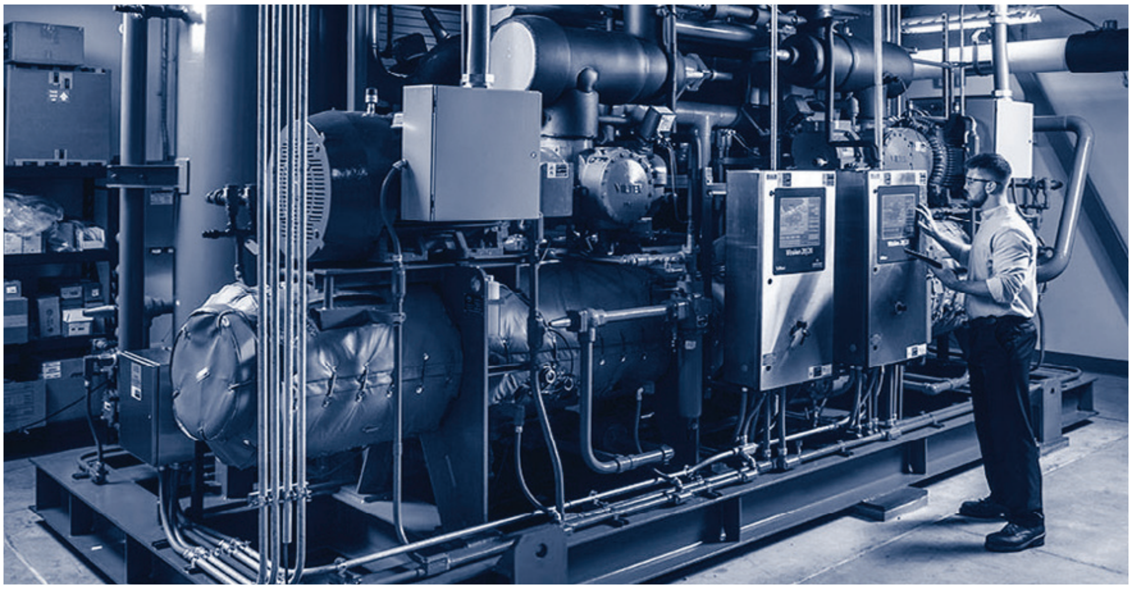


Opportunity to recover heat

The opportunity to recover waste heat from the condensers of refrigeration systems exists in many diverse sectors: in the (petro) chemical sector where there is concurrent heating and cooling, in food manufacture, in some offices, in data centres where there is adjacent heating demand, and in pubs and restaurants, for example. In this case, there can be a justification for raising the condensing temperature to make the heat more usable (higher temperature). The higher compressor power use is offset by the value of the waste heat. Heat recovery from refrigeration systems is incentivised in some cases by the UK Renewable Heat Incentive.

The performance of the compressor(s) is very significant in determining the overall energy use of the refrigeration system. The compressor(s) should be selected to give high efficiency levels under the operating conditions. These operating conditions should vary, for example as the ambient temperature and condensing temperature vary (assuming there is no head pressure control). The compressor should be efficient under all conditions.

Part load compressor operation is often an issue. At part load, many compressors operate poorly, for example screw compressors below 70 per cent with slide valve capacity control, centrifugal compressors with inlet guide vanes, or systems with hot gas bypass. Part load operation of these systems should generally be avoided. The effect is worsened if the energy use of fixed auxiliary equipment is taken into account – for example the evaporator or condenser pumps may still use full load power when at part load, so overall the energy use per unit of cooling achieved is high and CoP is low.

However, in some cases, for example compressors with variable speed control, part load compressor performance is not significantly affected by load, and in this case low load operation can be beneficial. At low loads, the heat duties on the condensers and evaporators are reduced with consequent improvements in evaporating and condensing temperatures, with the overall result that CoP is improved. Modern water chillers with variable speed compressor controls and electronic expansion valves can achieve very significantly improved CoP at low load. That said, the majority of existing refrigeration systems installed have poor part load performance still.

The vapour compression system is not the only option. For chilled water, absorption chillers are proven and cost effective where there is a cheap source of heat above around 80°C. For example, this could be process waste heat or from a combined heat and power plant. A CHP plant with absorption chiller that is fully utilised will achieve a rapid return on investment at current energy rates.

Further opportunities exist with some refrigeration systems: demand response – where systems are rapidly switched off (or turned up) in return for payments from National Grid to support the balancing of the electricity supply network, thermal storage/ice bank systems which allow management of power demand to avoid higher electricity charges, and more.

The effective management of refrigeration systems is important. It is common for faults to occur and be unnoticed because they do not affect the ability of the system to cool, but do increase energy use. Issues to look for are low refrigerant charge, air in condensers, incorrect set points (especially for compressor load, condensing temperature and evaporating temperature) and fouling of heat exchangers. Ongoing performance monitoring, for example ongoing measurement of CoP and comparison with expected values/targets, is essential.

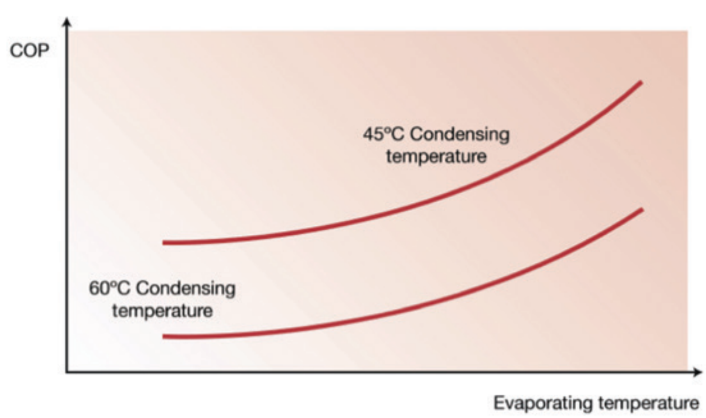
Over the years, the harmful effects of certain refrigerants have become apparent. These include not only issues of toxicity and flammability, but ozone depletion which was associated with the now banned CFC refrigerants, and more recently the Global Warming effects of modern HFC refrigerants.

Some of the most common refrigerants in use have very high Global Warming Potentials – 1 tonne of R404A released into the atmosphere, for example, has the equivalent effect to 3,992 tonnes of carbon dioxide released.

The F Gas Regulations came into force in 2014 and from 2015 a phase down of HFCs started in this country. By 2030, the amount of HFCs available will have reduced to 20 per cent of the 2009 to 2012 levels, and the first significant drop in availability has already happened. Operators of refrigeration systems need to be aware of these issues.

In summary, refrigeration systems offer many opportunities for improved performance, ranging from quick wins to capital investments. ■

Fig. 4 – Variation of CoP with evaporating and condensing temperature



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CPD 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. How much costlier in energy use is a refrigeration system operating at 0^{O}C compared with one operating at 10^{O}C?

☐ 3 times ☐ 1.4 times ☐ 1.2 times

2. If the ambient temperature is 26OC and the chilled water temperature 8OC, which statement about condensing and evaporating temperatures may be correct?

☐ Te is 3^{O}C and Tc is 35^{O}C
☐ Te is 11^{O}C and Tc is 24^{O}C
☐ Te is 3^{O}C and Tc is 24^{O}C

3. Why is CoP not always the best measure of performance?

☐ It does not include the effects of additional power use of auxiliaries and therefore can provide a misleading guide, for example at part load operation of systems
☐ It does not account for changes in ambient temperature
☐ It assumes the compressor is operating at full load

4. What is the approximate power use of a refrigeration system cooling a cold store to -20^{O}C when the ambient temperature is 30^{O}C? Assume that the condensing and evaporating temperatures are 10OC above and below the ambient and cold store temperatures and the cooling achieved is 100kW?

☐ 55 kW ☐ 33 kW ☐ 48 kW

5. What is often a simple solution to high condensing temperatures?

☐ Eliminate fouling and air in the condensers
☐ Reduce the head pressure set point
☐ Both the above

6. What are the potential solutions to achieving higher evaporating temperatures?

☐ Raise chilled substance set point, increase chilled water/air flow, reduce head pressure set point, increase expansion valve superheat setting, eliminate fouling, use larger evaporator
☐ Raise chilled substance set point, increase chilled water/air flow, reduce head pressure set point, reduce expansion valve superheat setting, eliminate fouling, use larger evaporator
☐ Raise chilled substance set point, increase chilled water/air flow, reduce expansion valve superheat setting, eliminate fouling, use larger evaporator

7. How much waste heat is generated, approximately, from a refrigeration system using 100kW of power in the compressor and operating with a CoP of 4?

☐ 500kW ☐ 125kW ☐ 75kW

8. Why is part load compressor performance not always inefficient?

☐ Variable speed compressor control improves efficiency
☐ Reduced duty on the condenser and evaporator results in altered Tc and Te and the benefits of this offset the losses associated with compressor efficiency and auxiliaries
☐ Part load operating gives higher CoP

9. What is a potential alternative to vapour compression refrigeration and when is it suitable?

☐ Free cooling, when the cooling fluid is cold enough
☐ Absorption chilling when there is a source of waste heat
☐ Absorption chilling plus CHP

10. What is the first thing to look for when considering refrigeration system energy savings?

☐ Reduce cooling demands
☐ CoP
☐ Head pressure controls

Please complete your details below in block capitals

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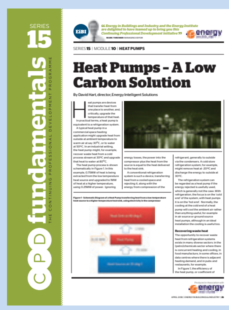

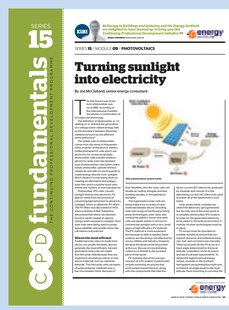

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