Case study – Delivery of a scalable HFC-free and gas fuel-free warm climate supermarket

By Dario Ferlin, M.AIRAH, Woolworths refrigeration and sustainable innovations engineer

ABSTRACT

In the past decade the Australian commercial refrigeration and air conditioning industry has been mired by uncertainty surrounding synthetic greenhouse gas regulation. However, the ratification by the Australian government of the COP21 Paris agreement and the adoption of an 85% HFC phase-down strategy by 2036 announced by the Federal Minister for the Environment in June 2016 has provided the Australian industry with some urgently needed direction.

The Australian commercial refrigeration and air conditioning industry is unique in that it is far removed from the natural refrigerants fermenting pot that is Europe, and just two retailers command about 80% of the retail grocery pie. Furthermore, the existing technician base has some upskilling challenges, which need to be addressed before meeting the demands of an HFC phase-down market environment.

It is therefore incumbent on the leading grocery retailers to become agents for innovation as well as drivers of a skills step-change with local technology partners, who will be delivering the refrigeration and air conditioning systems of the future.

REFRIGERATION INNOVATION

As a supermarket business, Woolworths has been active in the refrigeration innovation space. In 2006 the retailer took the first uncertain steps away from commonplace R404a systems by opening its first cascade R134a/CO_2 store (Bankstown, NSW). At last count more than 250 cascade R134a/CO_2 stores have been launched.

However, the prospect of an HFC-free industry on the horizon has provided the impetus for a new cycle of innovation towards low-HFC and HFC-free refrigeration and air conditioning systems. To that end, between 2017–2018 the initiative has been taken to pilot two promising technologies. Specifically, low-HFC waterloop stores at Collins Square Melbourne, Caulfield North, North Sydney and The Oasis (Gold Coast); and HFC-free transcritical CO_2 systems at Colebee (Sydney), Wadalba (Wollongong) and Prestons (Sydney).

Prestons is by far the most ambitious of the initiatives, and a significant milestone for the supermarket chain; it represents the third generation of transcritical CO_2 solutions. At each iteration the technology boundary has been pushed. At Prestons, the 2,800m² trading area store has virtually eliminated synthetic refrigerants and natural-gas-fired boilers by providing refrigeration, space cooling and space heating via two parallel integrated transcritical CO_2 systems.

At the core of the strategy is an investment in the Australian refrigeration industry. It's an investment that will generate momentum, spark imaginations and develop the local skillset, which will be needed to design, build, commission and maintain these new technologies for the next 20-plus years and therefore sustain the innovation beyond the store opening date.

RISING TO THE CHALLENGE OF COP21

The problem with HFCs

If we consider that an average Australian car emits 200g/km[1] and travels around 15,500km per year[2] the annual direct emissions footprint is around 3,100kg of CO_2.

Now consider that 1kg of HFC R404a refrigerant has a global warming potential equivalent to 3,920kg of CO_2.[3] If a medium-size supermarket refrigeration system with 1,200kg of R404a loses a modest 10% of its charge to atmosphere per year via system leaks, this equates to the same CO_2 footprint as 152 average Australian cars (note this footprint does not consider the additional indirect emissions by drawing on fossil-fuel-sourced energy to run the refrigeration system).

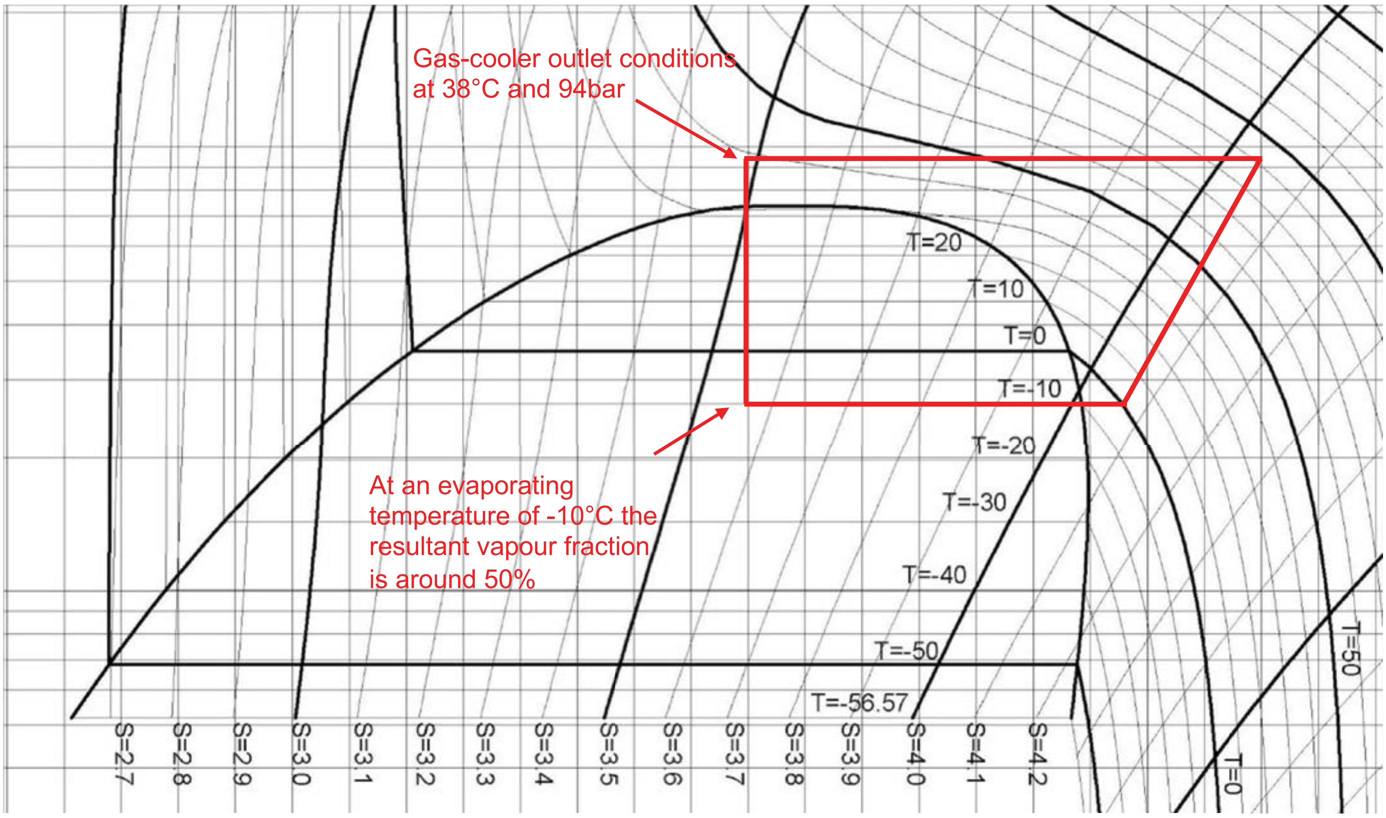

Fig. 1: Vapour fraction in a warm-climate transcritical system.

It therefore stands to reason that the COP21 agreement included an HFC phase-down proposal as part of the response to the threat of climate change.

Low-GWP alternatives to HFCs

HFCs make for excellent refrigerants. They are generally non-toxic, non-flammable and have operating pressures and physical properties that are very well suited to commercial refrigeration applications. Low-GWP alternatives to HFCs may share some of the physical properties of HFCs but are generally toxic and/or flammable.

Retail environments are particularly sensitive to risk. Often, the perception of risk is enough to discourage retailers from considering alternatives to common-practice solutions. However, CO_2 is an example of a low-GWP refrigerant that poses no real or perceived risk to the retail environment.

CO_2 presents challenges surrounding its physical properties. Above about 23°C (dry bulb) ambient conditions CO_2 stops behaving as a traditional HFC refrigerant and enters the transcritical zone. This is essentially defined as a state where one cannot distinguish between gas phase and liquid phase (i.e., a very dense gas). Hence condensation (or phase change), which is a characteristic of conventional refrigeration systems, is not possible.

HFC-free transcritical CO_2 systems

Transcritical CO_2 systems are not new. The first commercial refrigeration (i.e., supermarket) systems were installed in Europe close to 20 years ago, and by last count there are now over 14,000 installations.[4] The challenge with transcritical systems is implicit in the very name: when a system is running in transcritical mode it is no longer able to condense the compressor discharge gas into useful liquid. To obtain useful liquid, the discharge fluid from the gas-cooler (i.e., the heat exchanger shedding the heat of rejection) the refrigerant flow must first be throttled via a “high-pressure valve”. The throttling process creates useful liquid refrigerant and a proportion of “non-useful” vapour (i.e., “flash gas”).

The diagram in Fig. 1 illustrates this process for a transcritical cycle operating in a 35°C ambient environment. A typical 3K approach temperature (without adiabatic assistance) would yield a gas-cooler outlet temperature of 38°C. Furthermore, several published studies[5] point to an ideal gas-cooler pressure of 94bar at these temperatures. For a system operating with a -10°C evaporator pressure the proportion of non-useful vapour is around 50% of the system mass flow.

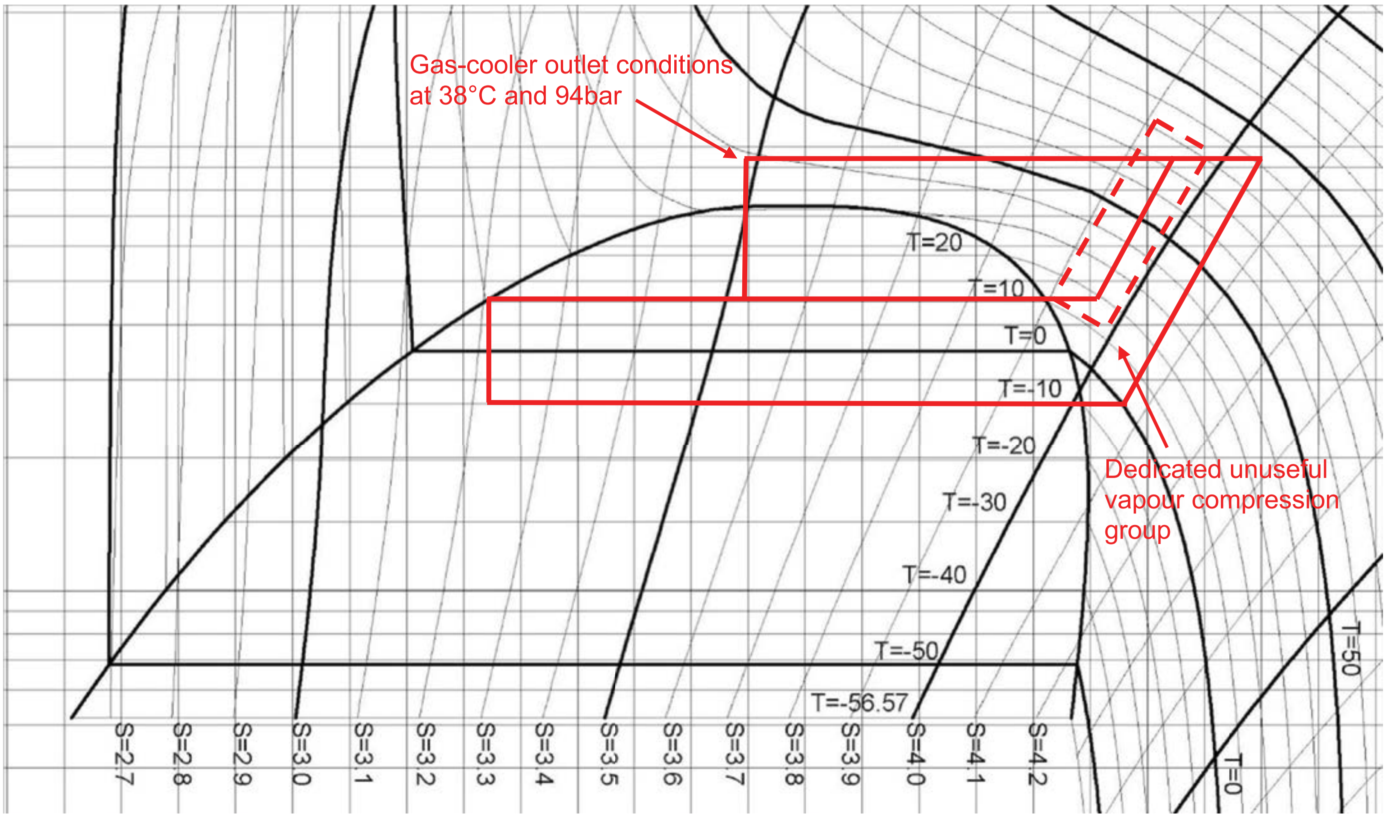

Fig. 2: Parallel compression.

The proportion of unuseful vapour increases as the outlet temperature of the gas-cooler increases. In other words, the higher the outside ambient temperature the more unuseful vapour is produced. This vapour cannot be simply disposed of; vapour compression systems are closed-circuit systems. Hence the vapour must be re-compressed and passed through the gas-cooler again (at the expense of energy) but to no refrigeration effect.

In essence, transcritical systems become energy-intensive and deliver a reduced refrigeration effect at high ambient conditions. Hence the low take-up of these systems in warm climates. However, in low ambient environments, these systems are particularly efficient and very effective. Additionally, the high-discharge temperatures allow for significant potential for heat recovery for space heating and sanitary hot water purposes. Hence the high take-up in colder climates.

The transcritical CO_2 equator

The refrigeration industry has coined the term "transcritical CO_2 equator" to define a geographic line in both hemispheres of the world that defines the threshold beyond which climates are considered too warm for transcritical CO_2 systems to be viable. Innovation is, however, gradually closing the gap between these threshold lines and unlocking opportunities for what were once considered unlikely markets such as Australia.

These innovations primarily centre around efficient management of non-useful vapour. Fig. 2 shows a modified cycle where the throttling process is undertaken to an intermediate pressure of around 35bar.

Useful liquid refrigerant is supplied to the showcases and coolrooms at this pressure, and the vapour is re-compressed by a dedicated compression group. This compression group is commonly referred to as "parallel compression" and works on a pressure differential from 35bar to 94bar. In the original cycle the non-useful vapour was re-compressed by the compressors operating at -10°C evaporator pressure (for CO_2 this equates to 25bar), hence working with a pressure differential from 25bar to 94bar. The benefit of parallel compression with reduced compression ratio is immediately apparent and results in reduced energy consumption.

Furthermore, the parallel compressors become redundant and cycle off at lower ambient temperatures when the system is operating in a conventional "sub-critical" cycle.

Opportunity unlocked by parallel compressors takes the form of space cooling for air conditioning purposes. At 35bar the liquid CO_2 stored in the liquid receiver is at around 1°C. The pool of "cold" liquid can be utilised as a direct or indirect cooling fluid in an air-handling unit. Any resultant vapour produced by evaporation may then be re-compressed by the parallel compressors at a relatively high suction pressure of 35bar.

A more recent innovation that is gaining industry traction in the management of non-useful vapour is the "ejector" (refer Fig. 3). Ejectors use the Venturi effect of a converging-diverging nozzle to create a low-pressure zone that draws in and entrains a suction fluid. After passing through the throat of the ejector, the mixed fluid expands, and the velocity is reduced, which results in recompressing the mixed fluids.

In a transcritical CO_2 system there is an ample supply of high-pressure fluid which can be used as the motive fluid in an ejector. In fact, ejectors have been successfully used not only in lieu of parallel compressors (at no energy cost) but also in lieu of liquid refrigerant pumps to enable safe operation of evaporator liquid overfeed and therefore driving system efficiency.

CONCLUSIONS

The prospect of an Australian refrigeration and air conditioning industry whose supply of HFC refrigerants will begin dwindling as of 2020 is very real and will quickly drive up the price point of installing and maintaining HFC systems. There are therefore real business drivers as well as the often-stated environmental drivers for retailers to start seriously considering low-HFC and HFC-free systems.

Transcritical CO_2 refrigeration systems with integration with mechanical services provide retailers opportunity for delivering HFC-free and natural gas-free solutions.

These non-conventional systems have already been successfully implemented in the Australian market. However, their non-conventional nature presents challenges to the local industry, which has had little or no exposure to these developing technologies. The onus is therefore on the local industry to invest in these non-conventional systems and above all invest in developing the human resources to meet the technological challenges of COP21.

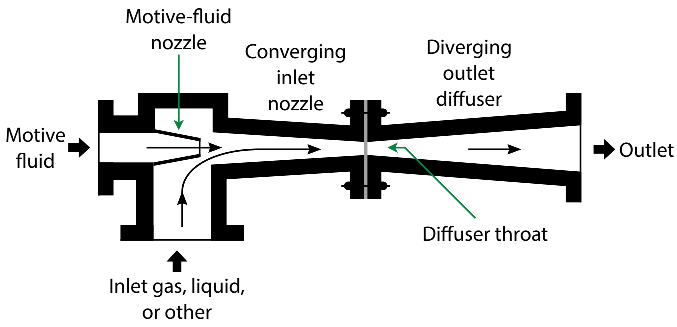

Fig. 3: Ejector

The Prestons-integrated HVAC&R transcritical CO_2 system was launched in December 2018 and successfully navigated the January 2019 heat wave in Sydney without incident. In early February 2019 a peak of 48°C ambient was recorded on the gas-cooler deck yet the system that serves 34kW of frozen produce load, 205kW of chilled produce load, 325kW of space cooling and 154kW of space heating delivered compliant temperature performance to all connected loads.

Significantly, with the deliberate purpose of driving the Australian commercial refrigeration industry towards a sustained uptake of natural refrigerants, the Prestons scope of works, design briefs, specifications, controls platform design, training and rack manufacturing were undertaken locally. It's a testament to what is possible and scalable in Australia today.

NOMENCLATURE

COP21 – 21st Conference of the Parties of the UNFCCC (United Nations Framework Convention on Climate Change) in Paris

HFC – Hydrofluorocarbons are organic compounds commonly used as refrigerants in air conditioning and refrigeration systems

GWP – Global warming potential

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ABOUT THE AUTHOR

Boasting an Honours degree in Mechanical Engineering from the University of Melbourne, Dario Ferlin entered the refrigeration industry in 2001 as a compressor rack design engineer for EPTA (Italy). There he collaborated in the first transcritical CO_2 projects being piloted in Europe. In 2004, he worked for EPTA as an applications engineer in the export department and oversaw turn-key projects for key supermarket accounts in developing countries. In 2009, Ferlin relocated to Sydney to work for Woolworths as a refrigeration engineer focusing on developing the showcase and refrigeration plant specifications. More recently he has served in the role of innovations engineer.