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CO_2: NO LONGER SUN-BAKED!

Various technologies are helping to make CO_2 possible in warm ambient climate situations.

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Upon its rediscovery as a refrigerant during the 1990s, CO_2 was not considered suited to warm climates – and this idea that it is a refrigerant only for cold countries has never really left the minds of many in the HVAC&R industry.

"For a long time, the greatest challenge for CO_2 [transcritical] refrigeration systems has been efficiency in warmer climates," according to the '*Technical report on energy efficiency in HFC-free supermarket refrigeration*', published by the Environmental Investigation Agency (EIA) and shecco, publisher of this magazine, and funded by the Kigali Cooling Efficiency Program (KCEP).

This warm ambient climate issue is commonly defined as the 'CO_2 equator' – the previously accepted geographical limit for cost-effective and efficient performance of CO_2 systems in all food retail store formats.

Compared to other refrigerants, the thermodynamic properties of CO_2 are quite different, as acknowledged in a 2004 paper by Professor Petter Neskå of the Norwegian University of Science and Technology (NTNU), Trondheim.

"Experience from testing and modelling of CO_2 refrigeration and air-conditioning systems shows that cooling COP [coefficient of performance] is more sensitive to ambient temperature variation than with conventional refrigerants," Neskå explains.

"This typically leads to the situation [...] where the CO_2 system is superior at moderate and low ambient temperature, and slightly inferior at very high temperature."

This critical point of CO_2 – 31.10°C – means that at high ambient temperatures, it exists as a supercritical fluid (without distinct liquid and gas phases), and more energy is required in the vapour compression cycle.

Yet despite this efficiency challenge, CO_2 has been moving increasingly south to warm ambient temperature countries where it was not thought possible a few years ago, like Australia (see '*One Man's Vision*', *Accelerate Australia & NZ*, winter 2018), China (see '*Chinese retail's first transcritical CO_2 system*', *Accelerate China*, April 2018), Indonesia, India (see '*Innovators take to Gustav Lorentzen stage*', *Accelerate Europe*, autumn 2018), Jordan (see '*Sun shines on CO_2 in Jordan*', page 26) and Mexico (see '*Casa Ley takes a swing at transcritical*', *Accelerate America*, September 2018).

"To overcome such challenges, experts in the field developed and introduced certain types of processes and components, which managed to overcome the so-called CO_2 equator," the EIA/shecco report says.

These technologies, familiar to CO_2 enthusiasts, include parallel compressors, liquid ejectors, adiabatic cooling and mechanical sub-cooling.

Saving with parallel compression

Parallel compressors enhance the performance of conventional CO_2 transcritical refrigeration systems by recovering the energy loss.

In simple terms, parallel compression recovers the flash gas (the refrigerant in gas form produced spontaneously when the condensed liquid is subjected to boiling) lost in a CO_2 transcritical cycle by using the compressors to compress some or all of the vapour generated by the liquid receiver from an intermediate pressure to a higher one, according to *Gullo et al.* in a 2016 paper: '*Energy and environmental performance assessment of R744 booster supermarket refrigeration systems operating in warm climates*.'

They recover the flash gas by re-directing it through an internal heat exchanger and then to the separate parallel compressor or compressors. "Adding parallel compression delivers 6-8% savings for the operation of the transcritical system," notes the '*Technical report on energy efficiency in HFC-free supermarket refrigeration*'.

Since the development of this parallel compression technology, many end users, such as Jordan's Al-Salam military supermarket, Makro in South Africa, Selgros Cash and Carry in Romania (see '*Scaling new heights in Romania*', *Accelerate Europe*, autumn 2016), Migros in Switzerland (see '*In Migros's DNA*', *Accelerate Europe*, summer 2018), Iper in Italy, and Carrefour in Spain (see '*Crossing the CO_2 equator: Carrefour leads the march south*', *Accelerate Europe*, summer 2016) have used it in warm ambient climates to achieve energy efficiency with CO_2, according to the report.

Geeking out on ejectors

Added to this, the development of the ejector has been hailed as a key achievement that is bringing CO_2 to warm ambient climates.

The devices can improve the efficiency of refrigeration systems by up to 20, 30 or in some cases 40% (see '*Ejectors: To efficiency, and beyond*', *Accelerate Europe*, winter 2016).

How do they work? The diagram overleaf depicts the energy lost during the refrigeration cycle as heat is transferred between the condenser, expansion valve and evaporator. Introducing an ejector into this space can improve compressor efficiency by recovering energy that is normally lost during the vapour compression cycle.

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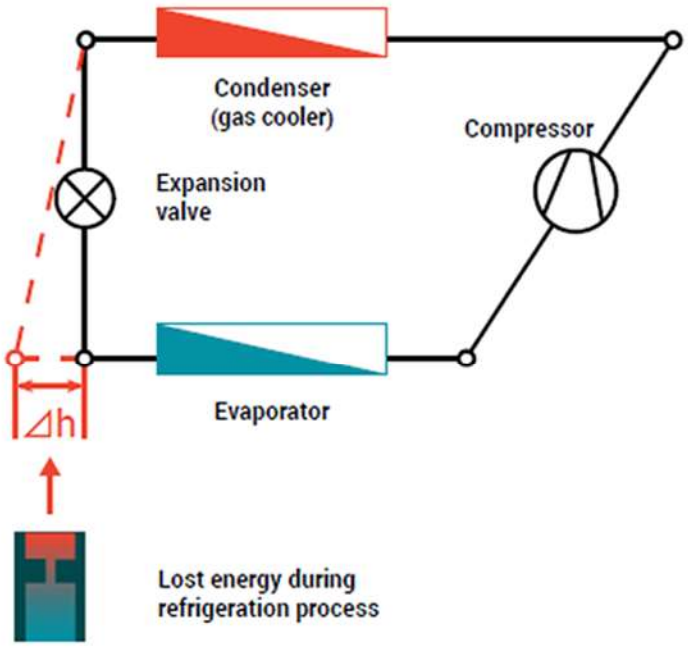
Energy lost during refrigeration cycle



Source: Presentation by Masahiro Takatsu, DENSO, ATMOsphere Asia 2016

The ejector achieves this by increasing the compressor's intake pressure. Sounds complicated, right? The essential point is that ejectors yield significant long-term cost benefits to end users.

Many leading OEMs have had success with ejectors in the field – including enEX, Carrier/CAREL, Danfoss, Compact Kältetechnik and Würm – in a variety of different climates.

"We started trialling ejectors in 2014/2015 and released our first ejectors to the general market earlier this year, but we already have over 300 ejectors in the market," Danfoss' Hans Ole Matthiesen told *Accelerate Europe* at Chillventa 2018 in Nuremberg, Germany.

Danfoss primarily sells vapour multi-ejectors (which are made of blocs of around six ejectors stacked in rows), but they have also now launched a liquid ejector. "We were taking our time to bring the liquid ejector to market. I think it's very important to make sure the systems are simple [...]. We've been testing liquid ejectors for two years," Matthiesen adds.

Liquid ejectors, comprising an expansion valve system, use the energy of the high-pressure gas to lift liquid from the suction accumulator.

Carrier/CAREL's electronic modulating ejector (EmJ), launched in a joint venture in 2016, has also been a success. "This is not [...] a novelty in the refrigeration industry," Diego Malimpensa, CAREL's business unit manager – retail solutions, argued at Chillventa. But he did point out that more work needs to be done to make it a "standard" technology.

The EmJ's fundamental feature is the continuous modulation ensured by the ejector, which via dedicated control algorithms allows the system to continuously adapt to a refrigeration system's typical variations in operating conditions. The EmJ now comes in various sizes suitable for small stores and large stores, as well as industrial refrigeration systems with CO_2.

Ejectors and parallel compression also can mean the systems end up paying for themselves, as demonstrated by the efficiency of the Jordan CO_2 supermarket. Industry experts quoted in another shecco report entitled '*F-Gas Regulation: Shaking up the HVAC&R industry*' from 2016 (see page 28 of the report) argued that the cost of ejectors is a non-issue – insisting that adding ejectors and parallel compression increases the price of a system by 10% at most.

Data from Danish CO_2 rack manufacturer Advansor reveals the strong relationship between increased efficiency of CO_2 systems and falling component prices (see table, page 75, *Accelerate Europe*, winter 2016).

Ejectors are proving popular despite price challenges. A study, supported by the Swiss Federal Office of Energy (SFOE) and published in December 2017 by the German magazine *Kälte Klima Aktuell*, reports that, "according to estimates, several hundred [CO_2] ejector systems are currently in use, the majority of which are in Europe".

Migros, the largest retailer in Switzerland, in December 2017 counted 60 stores fitted with CO_2 refrigeration technology using ejectors and said it planned to add 30 more every year.

"Today, ejectors are integrated into the planning of cooling technology as standard for the renovation and new construction of Migros stores whenever they are economical," said Daniel Duss, head of construction and technology at Migros Cooperative in Lucerne.

Coop, Switzerland's second-largest retail chain, also has opted to use ejectors, according to the study. "Refrigeration needs in food markets account for about half of the electricity consumption, which is why the ejector makes a significant contribution to the reduction of energy consumption," said Thomas Häring, head of energy and technology at Coop.

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CAREL/Carrier's EmJ modulating ejector. Ejectors help to improve efficiency in warm climates.

Opening up the bag of tricks

Apart from ejectors and parallel compression, there are other tools in the HVAC&R technician's box to increase the efficiency of CO_2 in warm climates.

At ATMOsphere Europe 2018, organised by shecco – publisher of this magazine – at Lago di Garda, Italy on 19-21 November, there was a session dedicated to precisely this question.

Epta's Refrigeration Systems Sales & Marketing Manager Francesco Mastrapasqua presented the Italian firm's FTE (full transcritical efficiency) concept, which works by flooding the evaporators to eliminate superheat. "The FTE system is leading to annual energy savings of around 10% in warm countries like Malta, Italy, and Portugal," said Mastrapasqua.

"FTE could use parallel compression, but we want to promote it as a simple system," he said, explaining that it was developed to take account of, "the situation in developing countries where the knowledge about CO_2 is not that advanced".

Mastrapasqua said that in one case study in Malta, the ROI on the system was just 1.5 years.

The FTE was also the subject of a site visit to the Italmark supermarket in Brescia. Alvise Case, energy manager at Epta, said that the system had been running for two years. "It is leading to significant energy savings when compared with conventional installations in the same area," Case said.

LU-VE is also developing technologies that help to improve efficiency in warm climates. "We have been pioneers of CO_2 transcritical installations in Europe since the early 2000s, and in 2018 we were proud to install the first CO_2 transcritical systems in India and Jordan," said LU-VE Marketing Manager Livio Perrotta at ATMO Europe 2018.

The Emeritus, a solution developed with the Polytechnic University of Milan, involves adiabatic precooling with a spray function. In this way, the system exploits the synergy between two effects: adiabatic humidification and the evaporation of water on the coil. Thanks to a sophisticated control system, the Emeritus boasts efficient performance in different climatic conditions.

The group is now "pushing to install it in southern Italy," said Perrotta. "The results of a simulation for a store in Trapani (Sicily) show that the Emeritus would lead to 9% energy savings in a year, thanks to the increased efficiency of the system and the reduction in outlet temperature," he said.

Perrotta stressed the importance of training. "Not all installers are familiar with CO_2," he said.

Other manufacturers of heat exchangers such as Modine, Güntner, Evapco, Alfa Laval, and Baltimore Aircoil Company (BAC) also offer CO_2 adiabatic systems in Europe.

Giovanni Gonzato, sales and applications engineer at Frascold, showed the results of simulations done for a CO_2 transcritical system using the firm's CapaFlex capacity control system. "It was developed in a partnership with the University of Padua," said Gonzato.

"Thanks to the innovative stepless capacity control – without the use of a variable frequency driver – the CapaFlex configuration is more efficient than conventional systems in high ambient temperatures," Gonzato said.

"Sometimes we do not need to look at the needs in terms of energy efficiency only, but also in economic terms," he said, showing how CapaFlex would lead to lower installation and maintenance costs. "We are running more simulations to support and validate this application to understand how to better use it," he said.

Other technology ideas were also being explored to increase the efficiency of CO_2 refrigeration systems, like

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controls such as Eliwell's DOMINO solution, which has been used across Europe including in Italy, Belgium, Switzerland and Spain as well as in China. Bitzer, meanwhile, recently launched a sub-cooling unit during Chillventa 2018 (see '*Natural refrigerants aim high at Chillventa*', *Acclerate Europe*, winter 2018).

The DOMINO was used in China's second transcritical CO_2-based refrigeration system, at a CSF Market opened in Beijing in July 2018.

The control system from Eliwell and Dorin compressors in a Panasonic CO_2 transcritical rack help the system to cope with the high temperatures experienced in the Chinese city (July 2018 temperatures in Beijing hovered at 39°C).

Adiós to 'CO_2 equator'

CO_2 has seen impressive market success in warm ambient temperatures in Europe. 16,000+ CO_2 transcritical systems have been installed in supermarkets in Europe with the help of the various technologies cited above, according to data from sheccoBase, the market development arm of *Accelerate* publisher shecco.

"CO_2 has demonstrated efficiency and security: Goodbye to the psychological barrier of the 'CO_2 equator'!" said Julio Minguillón of Carrier during ATMOsphere Ibérica, organised by shecco in Madrid on 18 September (see '*NatRefs advancing in Spain and Portugal*', *Accelerate Europe*, winter 2018).

"Carrier has installed more than 7,500 transcritical CO_2 systems in Europe, and 94 systems in the Iberian Peninsula, for 16 different clients," Minguillón said.

Boundary conditions like the warm climate of southern Europe had long been seen as a barrier to wider adoption of CO_2, limiting the efficiency of these systems.

Diego Ortega from Epta showed during his presentation the field results of the Full Transcritical Efficiency solution to boost the efficiency of CO_2 transcritical systems. Ortega presented the results obtained in a CO_2-based commercial refrigeration installation of 139.5 kW (-10°C) on the medium-temperature side and 34 kW (-35°C) on the low-temperature side in Bologna, Italy.

"The FTE solution has proven higher efficiency compared to a traditional system, even in warm ambient climates," said Ortega.

With all these technologies being employed in different configurations, it's 'adiós' to the CO_2 equator!

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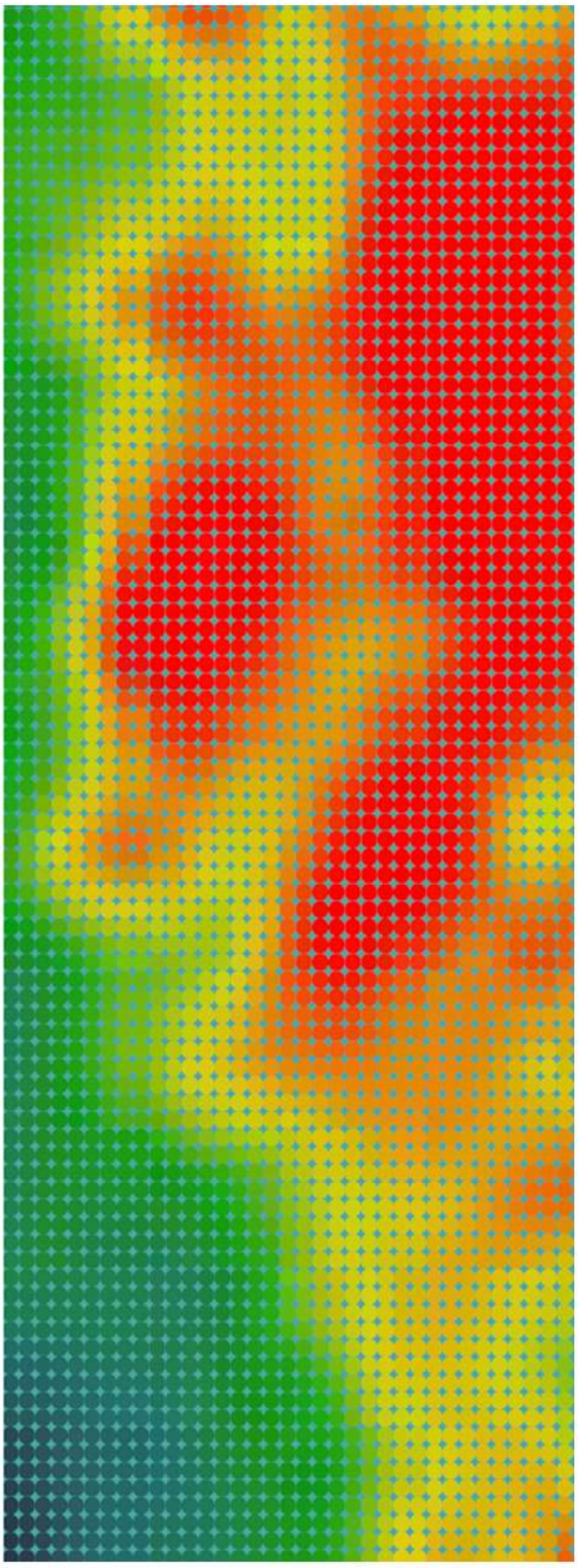

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