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Experimental Investigation and Performance Comparison of a Transcritical CO_2 Unit

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Emerson Commercial & Residential Solutions

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Agenda

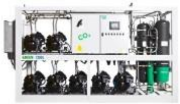
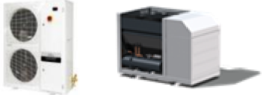
- Introduction
- Background Information
- Challenges
- Experimental Set-Up
- Experimental Results
- Conclusions

Market Trends & Drivers

- Increasing demand for low GWP Solutions
  - F-Gas Regulation
  - Tax and subsidy schemes
  - ErP Lot1 sets minimum seasonal efficiency standards
  - 10/15% lower for systems with GWP < 150

- Technology Trends
  - Capacity Modulations by Inverter
  - EC Fans
  - Advanced Controls and Communication
  - Heat Recovery
  - Electronic protection & diagnostics
  - Remote monitoring

Co-Existence Of Several Architecture/Refrigerants Combinations are Expected In The Future, Depending On Store Format

Store Type & Surface Area (m²)	Trend Architecture & Refrigerant After 2022
Hypermarket & Large Supermarkets >2500 m²	**Centralized : Booster CO2 / *Cascade IDX HFO/CO2?*** 
Supermarkets 1000 to 2500 m²	**Centralized : Booster CO2 / *Cascade IDX HFO/CO2?***  **Distributed HFO or CO2** 
Small Supermarkets & Hard Discounts 600 to 1000 m²	**Centralized: Booster CO2, Indirect Systems R290 & *Rack HFO?***  **Distributed HFO or CO2**  **Integrated Display Cases R290** 
Express Shops & C-Stores & City Stores <120 to 600 m²	**Distributed HFO/CO2**  **Multiple Units HFO**  **Integrated Display Cases R290 / Plug-Ins** 
Food Service / Cold Rooms	**Remote HFO/CO2**  **Multiple Units HFO**  Eura **Ceiling HFO / R290**  **MonoBlock HFO / R290** 

Development of a CO_2 Refrigeration Unit

This paper discusses an experimental study regarding a range of CO_2 units developed by Emerson, designation, OME-4MTL.

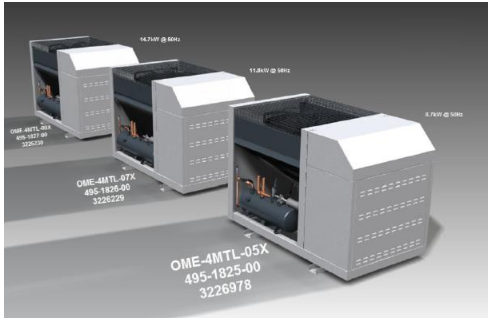
- This investigation was completed in parallel with the product development phase
- The aim was to investigate different technologies and potential improvements with respect to CO_2 refrigeration systems.
- The final unit design incorporates the by-pass cycle as will be discussed in more detail in the coming slides.
- The study was beneficial in understanding what is possible in terms of delivered capacity and performance and developing control algorithms for better system regulation.

The aims and target outcomes of this work:

- To experimentally and numerically investigate potential refrigeration cycles to improve system performance.
- To understand the practical implementation of a Medium Temperature CO_2 refrigeration unit.
- To better understand the limitations and challenges of using CO_2 as a working fluid.
- To target higher ambient temperature regions to widen the potential penetration of these units.
- To develop selection and performance tools for further development.

Background Information

Multiple CO_2 advanced cycles have been theoretically evaluated using the OME-4MTL range as a baseline:



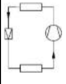
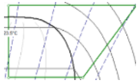
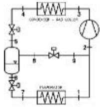
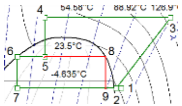
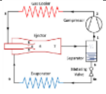
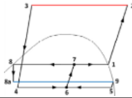
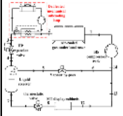
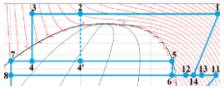
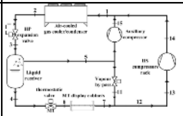
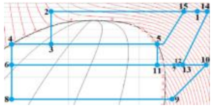
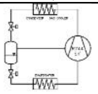
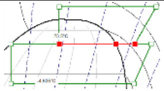
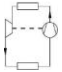
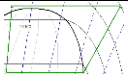
- Flash gas by-pass cycle (w & w/o internal heat exchanger)
- Multi-ejector cycle (w & w/o internal heat exchanger)
- Mechanical sub-cooling Cycle
- Parallel compression cycle
- EVI cycle
- Expander cycle

The most advantageous cycles with respect to cost, technology availability and application within a unit where selected to target two main improvements:

- Increase the ambient temperature operating range and therefore increase the potential target market for these units
- Increase the performance of the system.

All cycles where evaluated through modelling and calculation and those selected where also assembled and tested.

Cycle Comparions

#	Schematic	p-h diagram	Performance									
			COP at Tamb / increase to basic								SCOP	
			10°C		20 °C		25°C		35°C		Strasbourg	
1	 basic cycle		**3.70**	0%	**2.22**	0%	**2.29**	0%	**1.42**	0%	**3.01**	0%
2	 Flash-gas bypass		**3.70**	0%	**2.22**	0%	**2.29**	0%	**1.40**	-1%	**3.01**	0%
4	 multi-ejector		**4.04**	9%	**2.51**	13%	**2.57**	12%	**1.64**	16%	**3.34**	11%
6	 mechanical subcooling		**3.77**	2%	**2.51**	13%	**2.55**	12%	**1.71**	21%	**3.21**	7%
7	 parallel compression		**3.70**	0%	**2.22**	0%	**2.67**	17%	**1.79**	26%	**3.08**	2%
8	 EVI		**4.13**	11%	**3.12**	41%	**2.95**	29%	**2.02**	42%	**3.67**	22%
9	 expander		**4.13**	11%	**2.63**	19%	**2.66**	16%	**1.75**	24%	**3.44**	14%

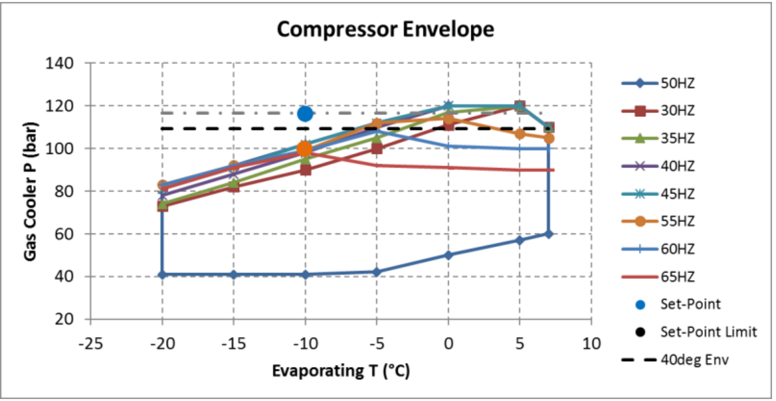
- Snap-shot from modelled system comparison…

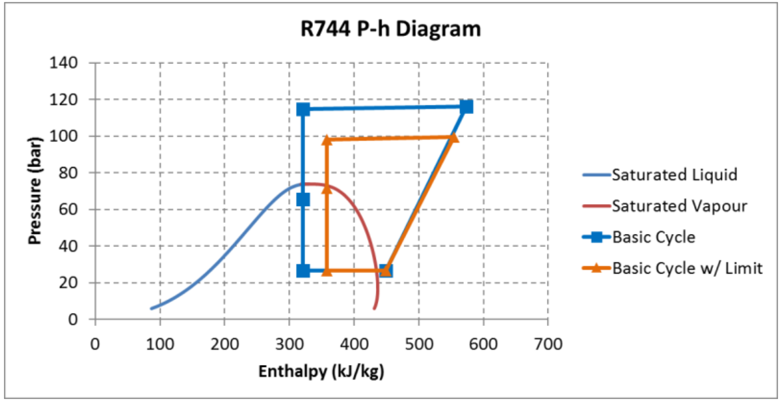
  – **Top performers include:**
  - EVI cycle / 2-Stage compression **+22%**
  - Expander cycle **+14%**
  - Multi-ejector cycle **+11%**
  - Mechanical sub-cooling cycle **+7%**

  – **Factors limiting selection:**
  - Maintain the unit footprint; there's not a lot of space for additional components.
  - Minimise complexity.
  - Minimise cost.
  - Use available technologies.

Challenges

Compressor/Unit Envelope





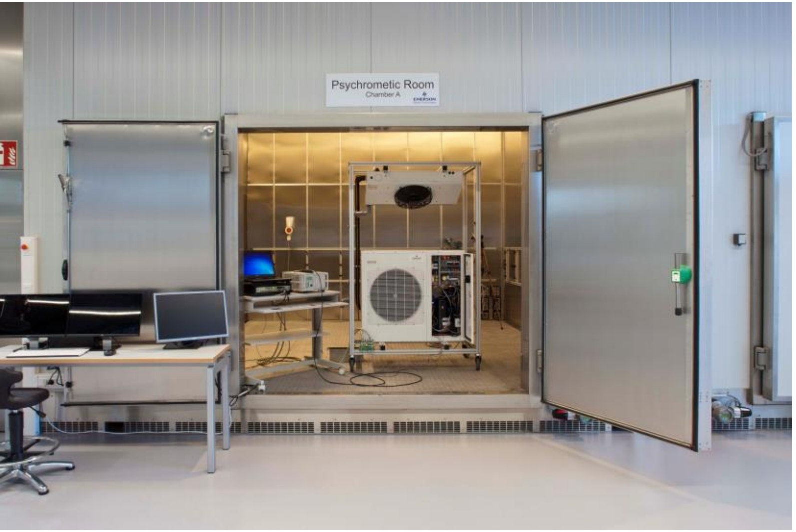
Limitations of the compressor envelope can prevent achieving the optimum gas-cooler pressure which results in a degradation of delivered capacity and performance.

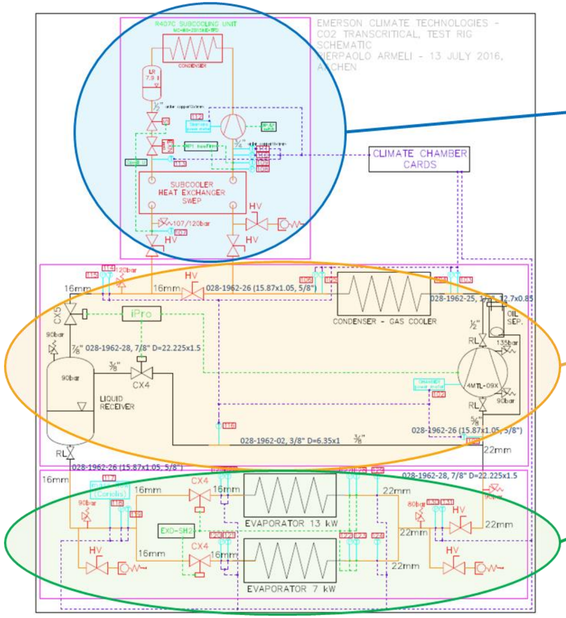
Flash Tank/Liquid Receiver PS

- The design PS of the liquid receiver/flash-tank is 90bar.
- At high ambient, for the conventional cycle, with no control over the flash-tank pressure, the safety limit of 85bar can be reached.
- At this point the controller stops the system.
- This occurred at approximately 36°C ambient.

Experimental Set-Up

Aachen Solution Centre Test Facility



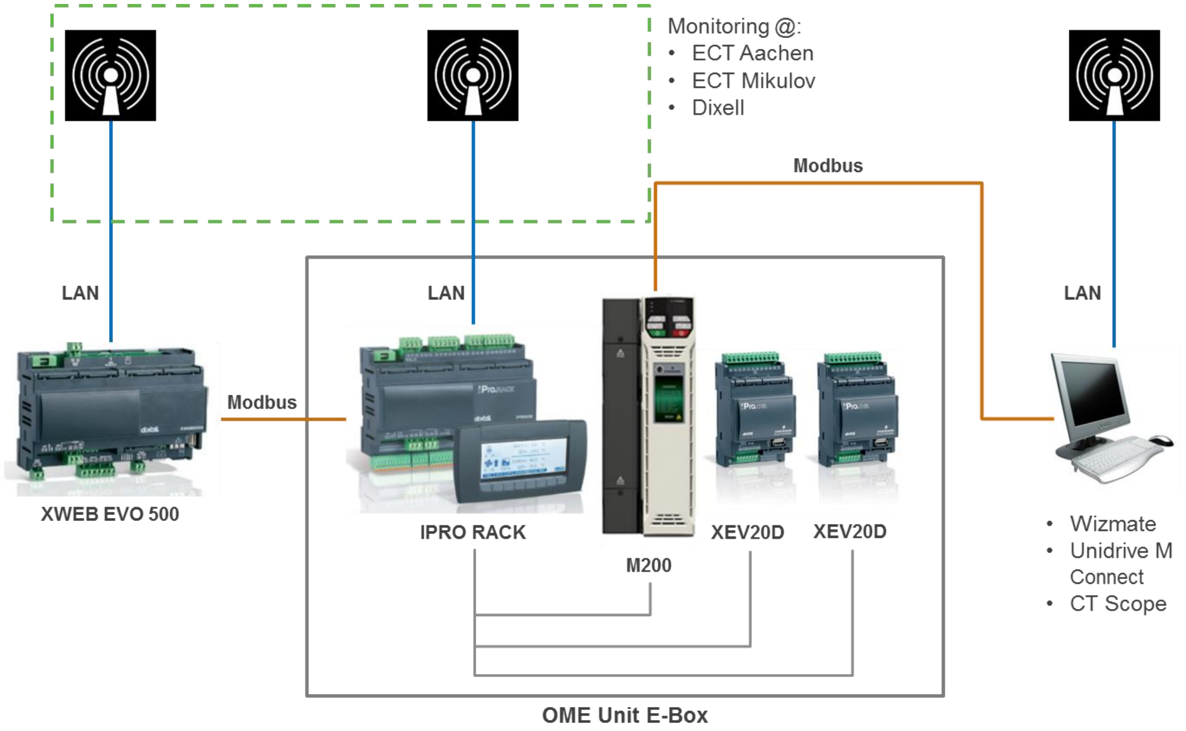


Sub-Cooling Unit
Chamber A

OME-4MTL Unit
Chamber A


Evaporators
Chamber B

Experimental Set-Up

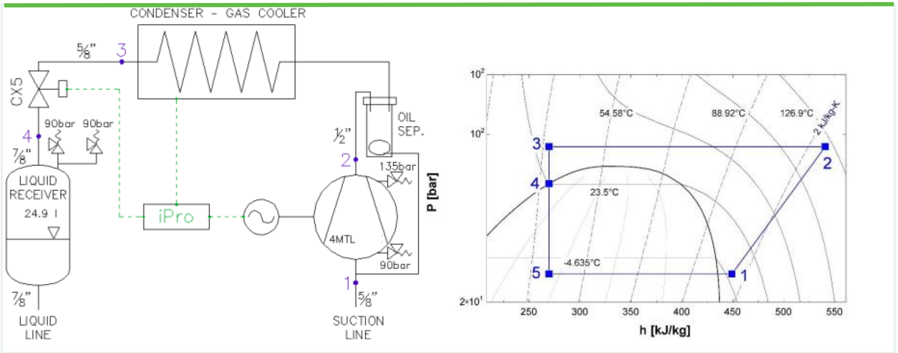


Control and Monitoring

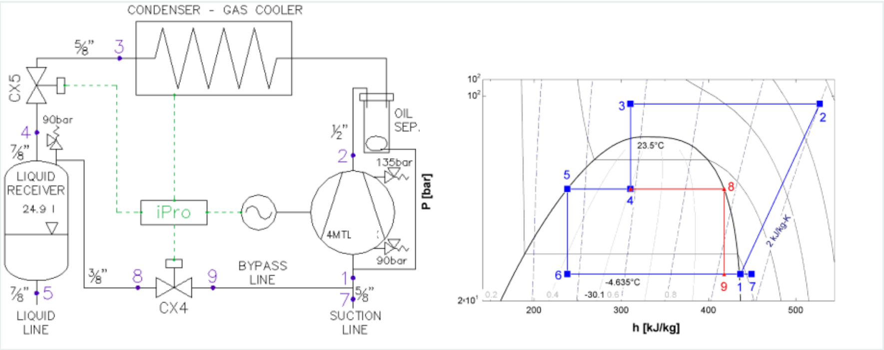
- The unit is controlled by a Dixell Ipro controller and is monitored directly by the XWEB EVO.
- The valves, HPV and BPV are driven by the XEV20D valve drivers.
- The compressor speed is controlled by the CT M200 drive and controlled and monitored by the Unidrive M connect and CT Scope software.
- The system is fully monitored using National Instruments hardware and software.
- All was connected on-line for remote monitoring and control.

Experimental Set-Up

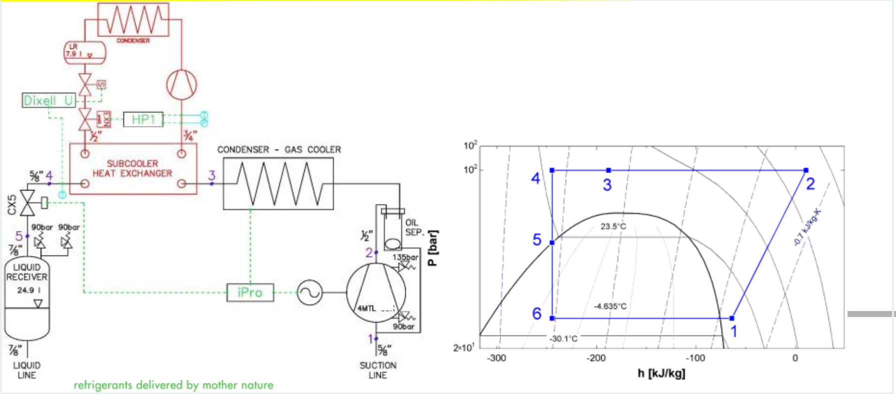
Conventional Cycle



By-Pass Cycle



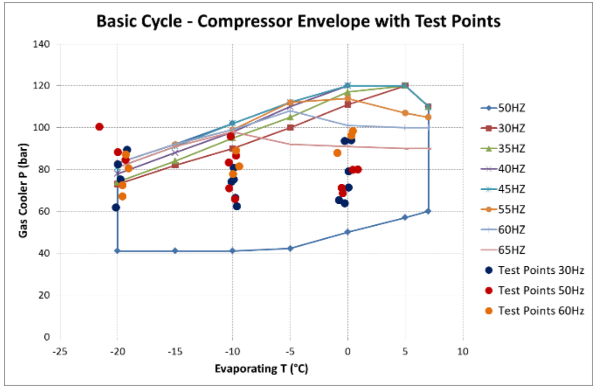
Mechanical Sub-Cooling Cycle



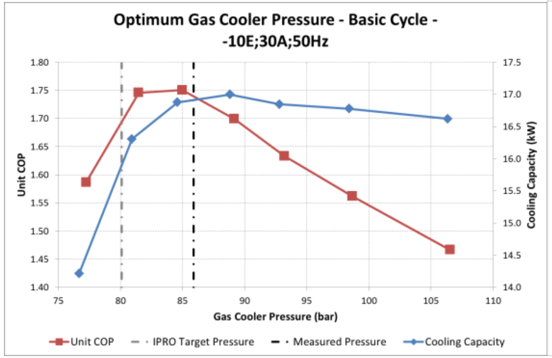
Cycle Description

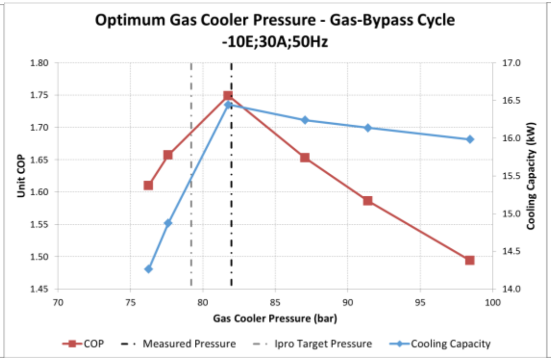
- Conventional Cycle – Vapour compression cycle w/ HP valve
- By-Pass Cycle – with the addition of by-pass piping and BP valve between the flash-tank and compressor suction.
- Mechanical Sub-Cooling Cycle – with additional dedicated refrigeration unit with brazed plate evaporator installed at the gas-cooler outlet.

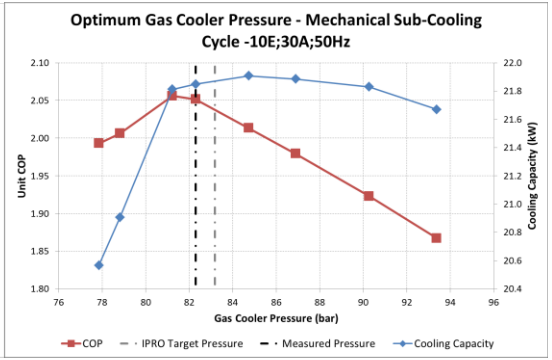
Experimental Results
Test Points and Optimum Gas Cooler Pressure



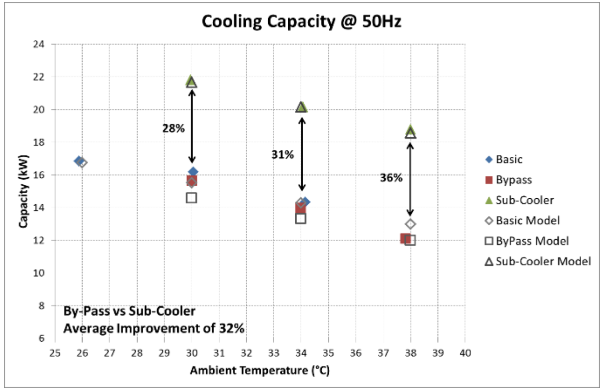
- Approximately 36 points where tested across the envelope at 3 evaporating temperatures, -20, -10 and 0°C at 30, 50 and 60Hz.
- These tests where repeated for each cycle.
- Tests where completed to evaluate the optimum pressure for each cycle
  - The graphs below, show the optimum pressure control from the Ipro controller.
  - In each case it is reasonable to conclude that the algorithm within the controller is suitable for each cycle.

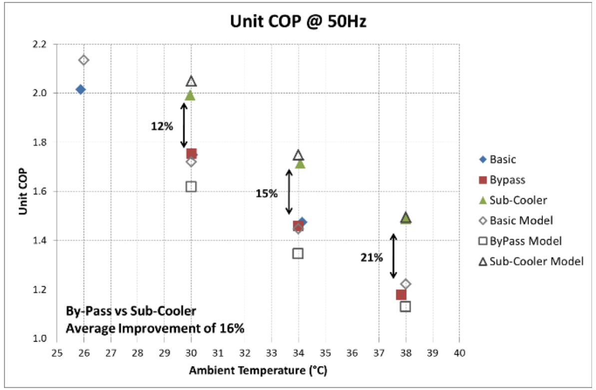


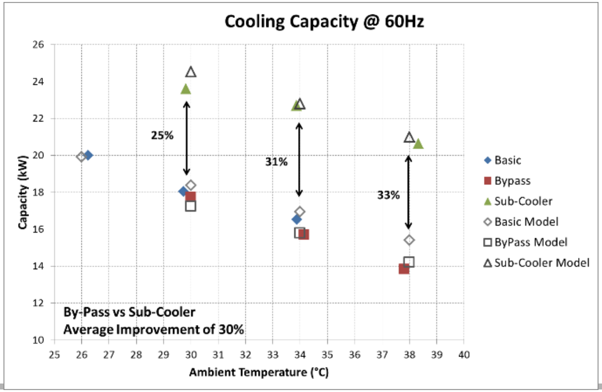


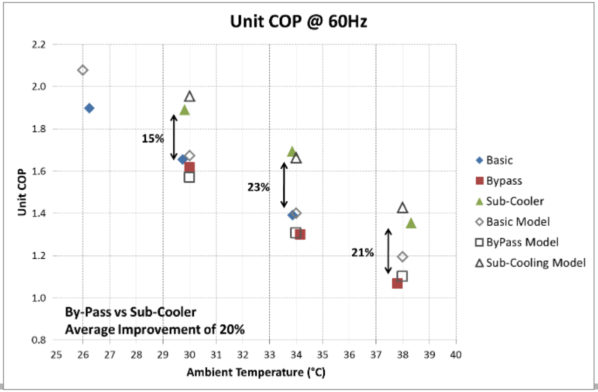


Experimental Results
Cooling Capacity and COP comparison





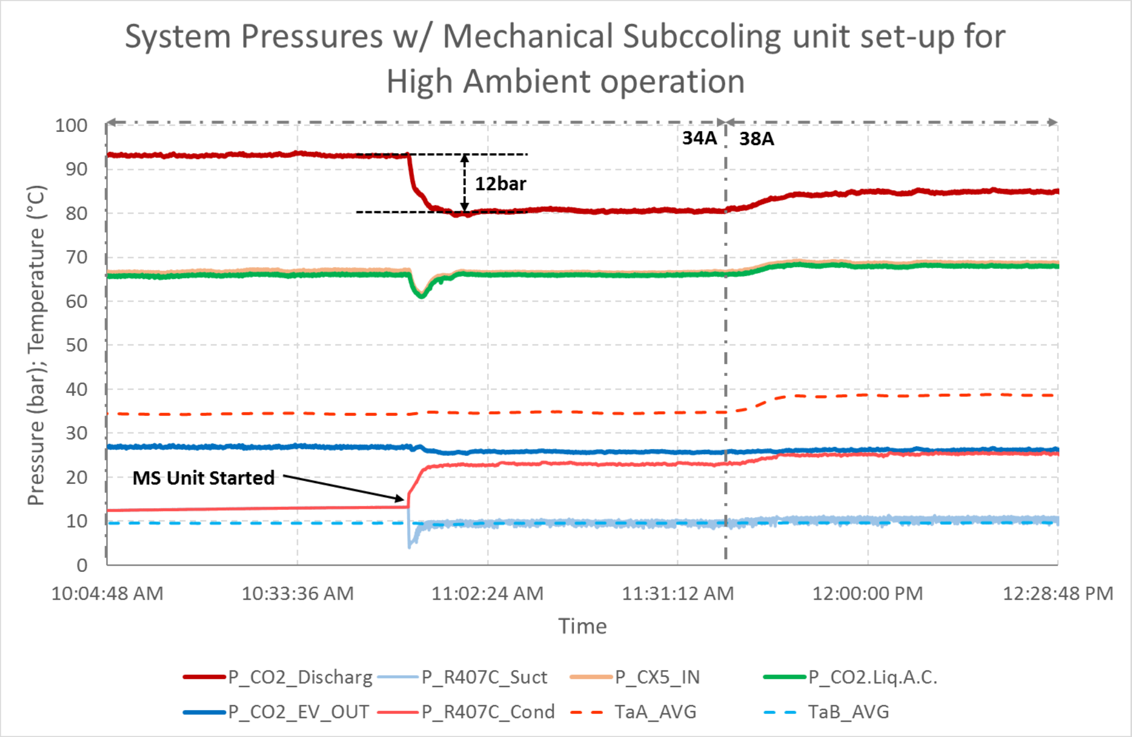




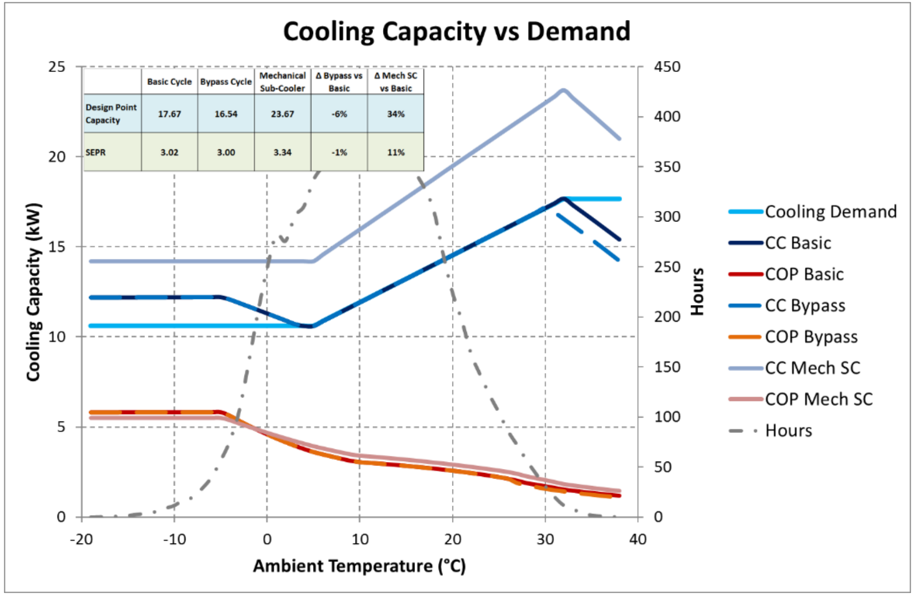
- There is a small reduction in cooling capacity for the bypass cycle with respect to the basic cycle in the region of 3%.
- There is a large increase in cooling capacity for the sub-cooling cycle with respect to the basic cycle in the region of 30%.
- There is a small reduction in the COP for the bypass cycle with respect to the basic cycle in the region of 1%.
- There is a large increase in COP for the sub-cooling cycle with respect to the basic cycle in the region of 18%.

Experimental Results
Mechanical sub-cooling unit set-up for high ambient operation

- The gas-cooler regulating temperature sensor was re-positioned to after the sub-cooling plate heat exchanger.
- Significant advantages achievable with respect to Gas Cooler pressure; reduced by 12bar @ 34°C ambient. This allows the system to operate at higher ambient temperatures, extending the compressor envelope.
- The flash-tank pressure can still cause a limitation with respect to the ambient temperature achievable.
- The GC pressure reduction provides a DLT reduction of 16K; again this allows to achieve higher ambient operation by extending the compressor envelope.
- There is a low gain in terms of capacity and COP, +7.33% & +2%, respectively. To improve, the gas cooler pressure algorithm needs to be optimised for mechanical sub-cooler w/ T sensor after the MS. By increasing the GC pressure, the gas cooler and mechanical sub-cooling unit can become more effective.



Experimental Results
SEPR Evaluation



Ambient Temperature (°C)	Compressor Frequency (Hz)	Evaporating Temperature (°C)	Intermediate Pressure (bar)	Cooling Capacity (kW)	COP
32	60	-10	35	15.69	1.39
25	45	-10	35	13.84	1.88
15	29	-10	35	11.49	2.90
5	25	-10	35	12.50	4.28

- The seasonal performance (SEPR) was modelled and compared with test results.
- The conventional/basic cycle delivers an SEPR of 3.02, the by-pass cycle a value of 3.00, a loss of 1%
- The mechanical sub-cooling delivers a value of 3.34, a performance boost of 11% when compared with the conventional cycle.
- The capacity delta for each cycle at the design point (-10E/32A/60Hz) are also displayed, 17.67kW for the conventional cycle, 16.54kW for the by-pass cycle (a reduction of 6%) and 23.67kW for the mechanical sub-cooling cycle (a capacity boost of 34%).
- Test data is shown in the table for the by-pass cycle.
- The SEPR from the test data was calculated at 2.97 and is therefore within 1% of the calculated value.

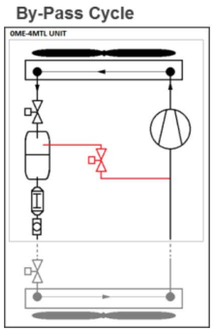
Experimental Results
By-Pass Cycle

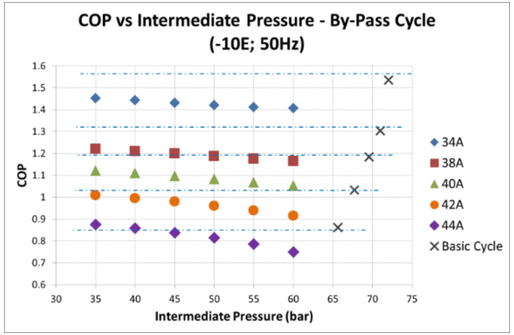
Why the by-pass cycle?

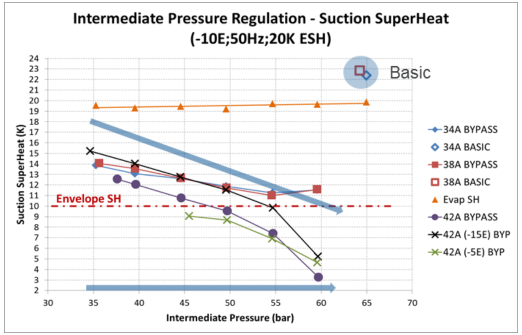
- It provides a 1% reduction in seasonal performance.
- It provides a 6% reduction in capacity at the design point (-10E/32A/60Hz)

Practically however:

- It operates at higher ambient temperatures; in excess of 42°C vs 35°C
- It allows full control over the liquid receiver pressure and therefore liquid line pressure.
- In this case the system can be assembled with standard copper and use lower pressure cooling furniture.
- The installation is less complex and less technically challenging.
- Low cost simple cycle.







Conclusions

- Each configuration, a conventional cycle, by-pass cycle and mechanical sub-cooling cycle have been tested and modelled for performance evaluation and comparison.
- With respect to the conventional cycle, the by-pass presented a loss in terms of delivered capacity and COP in the region of 3% and 1%, respectively.
- The mechanical sub-cooling cycle presented a capacity and COP improvement of 30% and 18%, respectively.
- Models where generated to develop selection and analysis tools which will be incorporated within the Emerson Select software. These have been validated and used to calculate the seasonal performance of these units operating under each cycle configuration. The SEPR of the by-pass cycle was calculated from test data and compared with the model with the results being within 1% of each other.
- The by-pass cycle provides further advantages with respect to practical application and extending the target temperature region range.

eurammon is always available as a sparring partner for questions on refrigeration with natural refrigerants.

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