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Ejector technology – The next generation in transcritical CO_2

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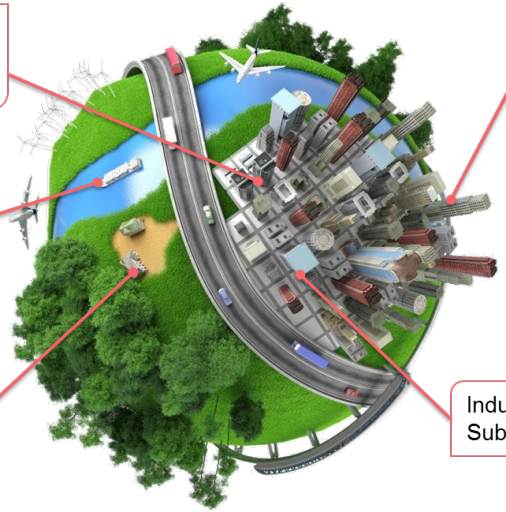
CO_2 Focus Applications

Food Retail
Subcritical and Transcritical applications

Transport Refrigeration
Subcritical applications

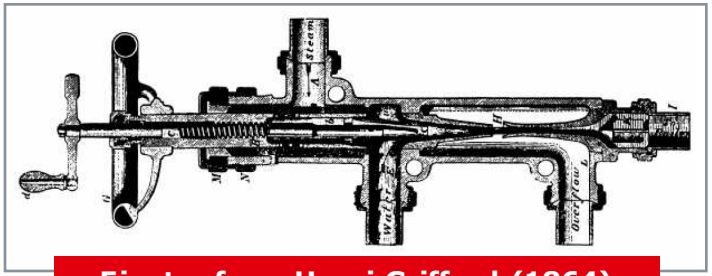
Heat Pumps
Transcritical applications



Server and Electronics Cooling
Subcritical and Transcritical applications

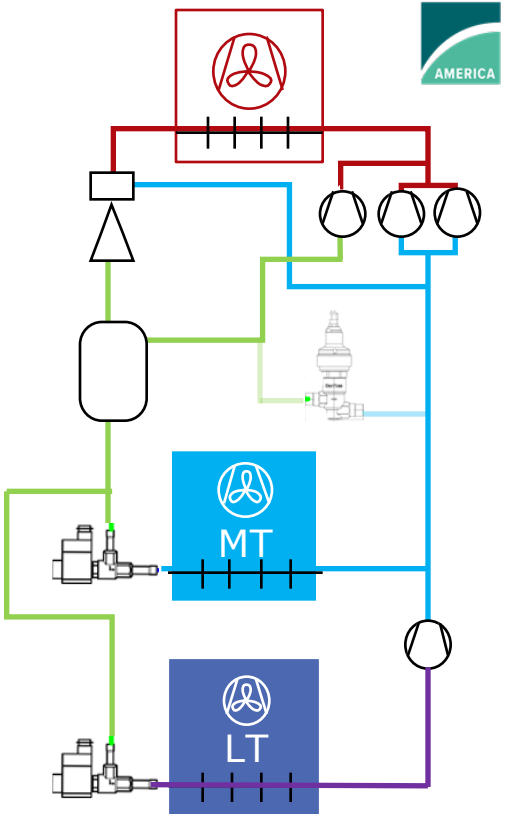
Industrial Refrigeration
Subcritical applications

Last Year
Gas Ejector System

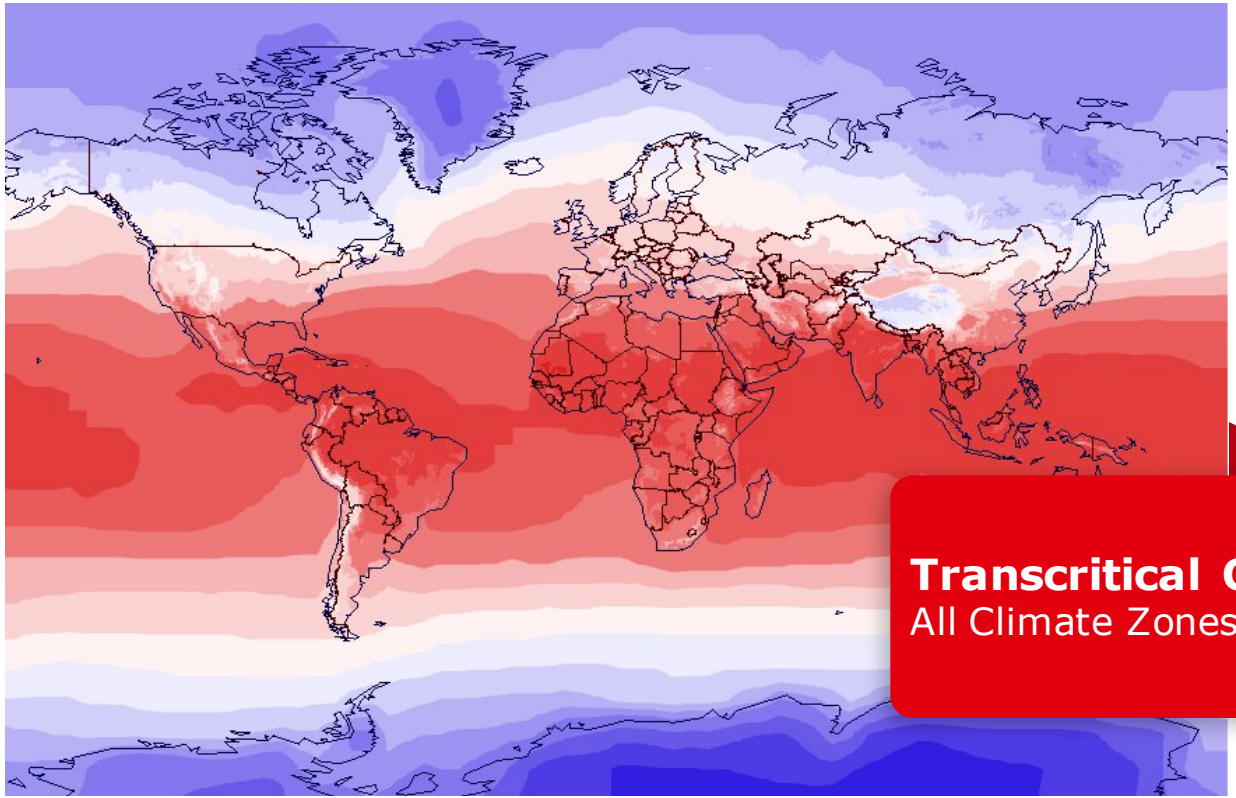


Ejector from Henri Griffard (1864)

- Ejectors move gas from MT suction to parallel compressor.
- First systems in operation since 2013 with good results.
- First system in operation with Danfoss Multi Ejector Jan 2015.
- 180+ Installations to date

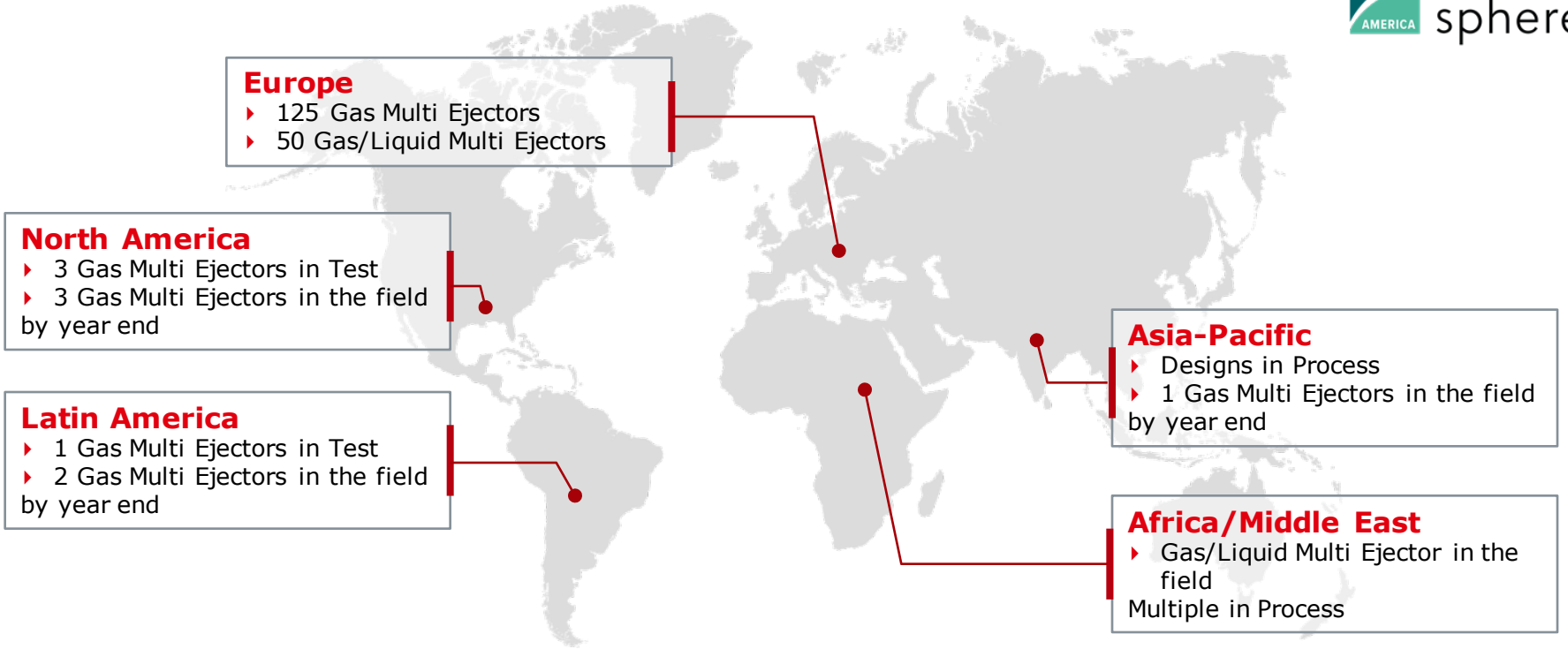


Removing Barriers To Transcritical Co2



Transcritical CO_2
All Climate Zones

Multi Ejector Global Deployments
March, 2017



Europe
- 125 Gas Multi Ejectors
- 50 Gas/Liquid Multi Ejectors

North America
- 3 Gas Multi Ejectors in Test
- 3 Gas Multi Ejectors in the field

by year end

Latin America
- 1 Gas Multi Ejectors in Test
- 2 Gas Multi Ejectors in the field

by year end

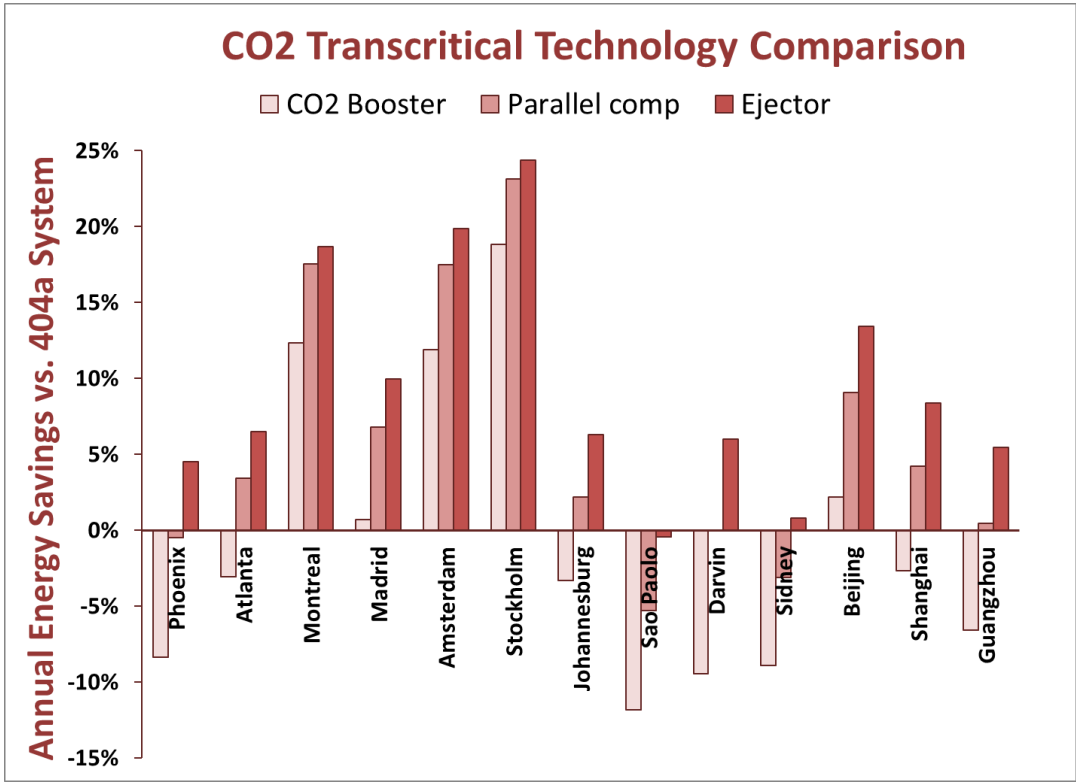
Asia-Pacific
- Designs in Process
- 1 Gas Multi Ejectors in the field

by year end

Africa/Middle East
- Gas/Liquid Multi Ejector in the field

Multiple in Process

CO2 Transcritical Technology
Development Continues



CO2 TRANSCRITICAL TECHNOLOGY
Development Continues

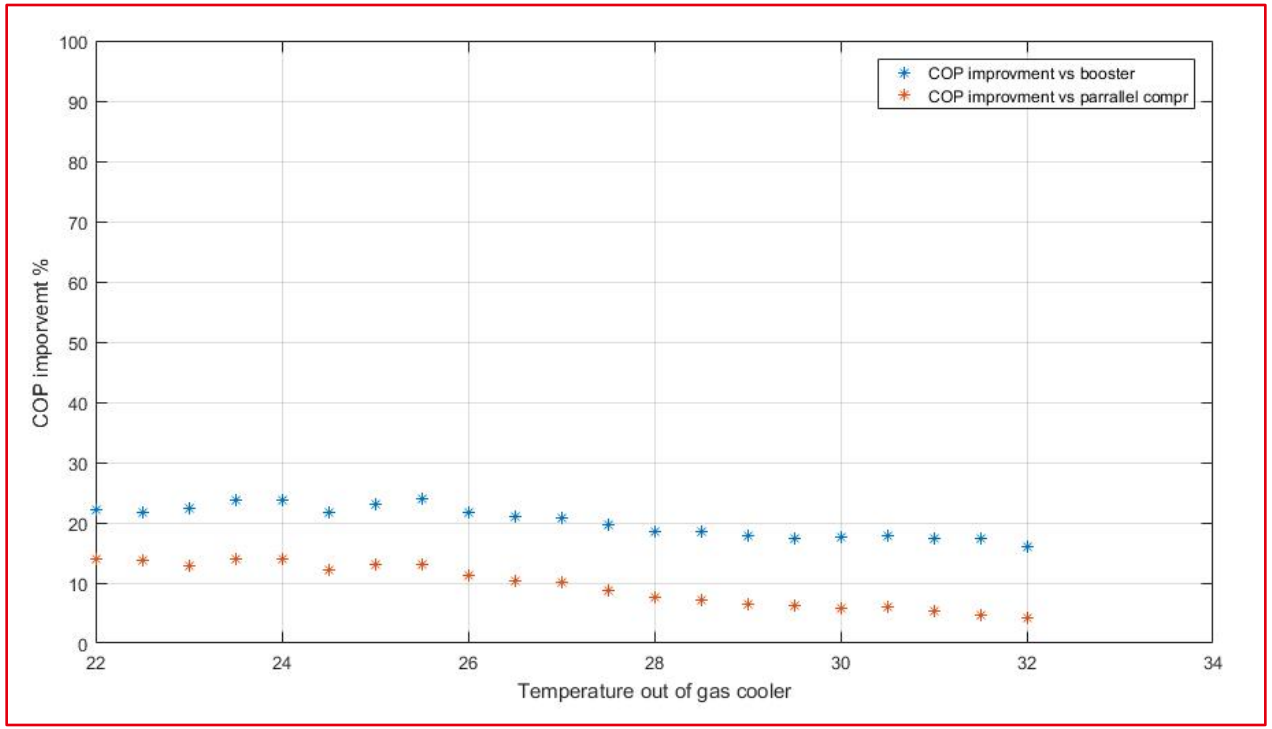
FIELD CASE STUDY
Johannesburg, South Africa

- **Compressors**
  - 2 Low Temp.
  - 3 Medium Temp.
  - 2 Parallel
- **Start-up:** Q2 2015
- 2 ejector blocks w/ 6 ejectors
- 200 kW MT + 22 kW LT

Test conditions:

- 4 days with ejector
- 3 day without ejector

High Pressure Lift Gas Ejector Performance Data



1 **Note:** System is still being fine tuned

2 Expect improvement when liquid ejector is included

Summary

System	Energy saving VS. R404a	Compressor capacity saving VS. Booster
Booster	-11%	0%
Parallel compression	7%	15%
Gas ejector	10%	18%
Liquid & gas ejector	22%	27%

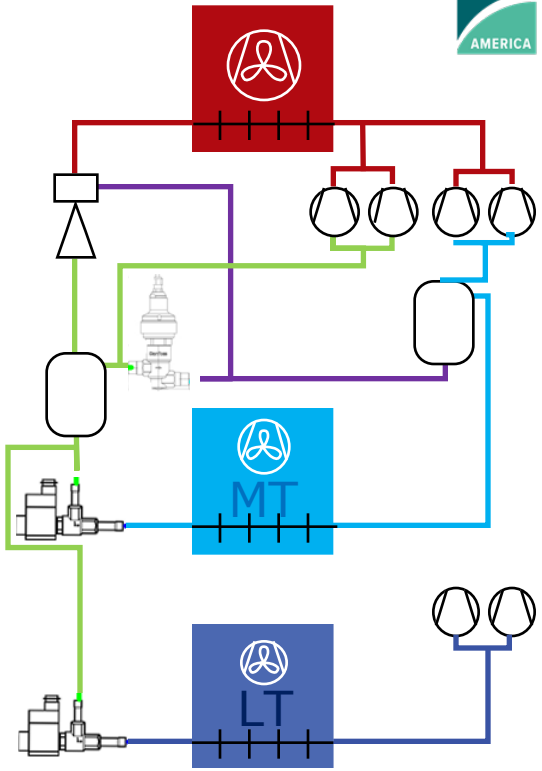
Comparison made @ 32 °C

1. Parallel compression is good step but may not be possible on small systems (<100kW)

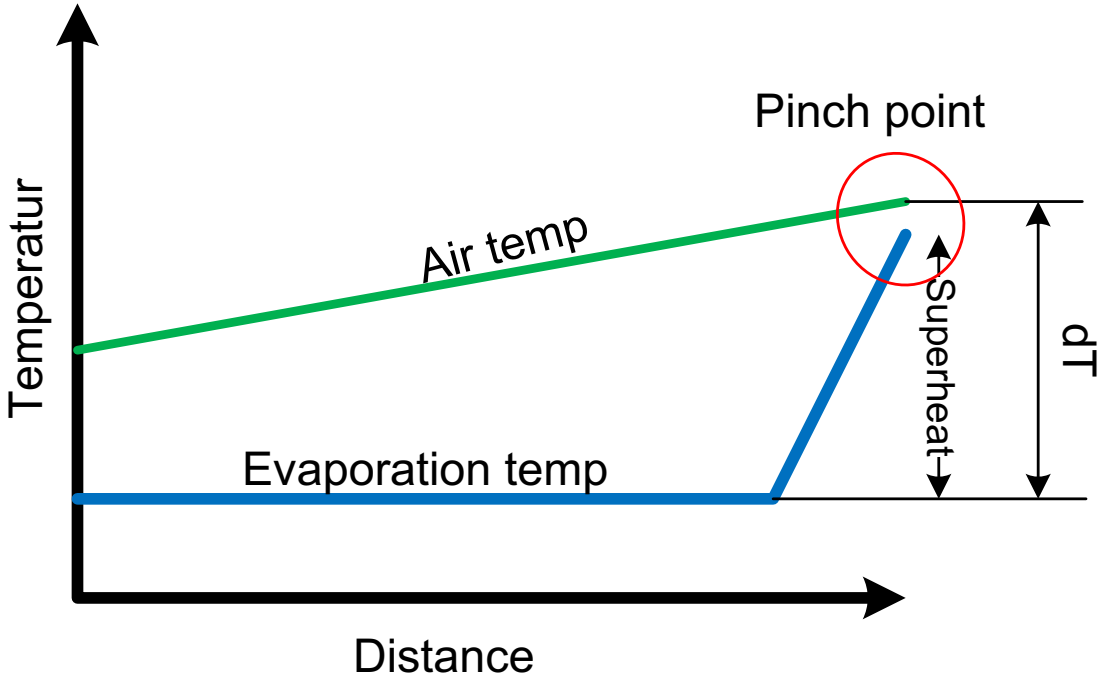
2. Demonstrated large energy saving in warm ambient with ejector technology – both gas and liquid

Liquid Ejector System
Flooded Evaporator

- Liquid ejector system allows the MT evaporator to be flooded.
- The saving from the higher suction pressure.
- Ejector is in this case substituting a pump
- Trials has been running since 2013 with good results.
- Evaporation temperature is in average raised by 5 K.
- The saving of the liquid ejector can be added to the saving of the gas ejector.

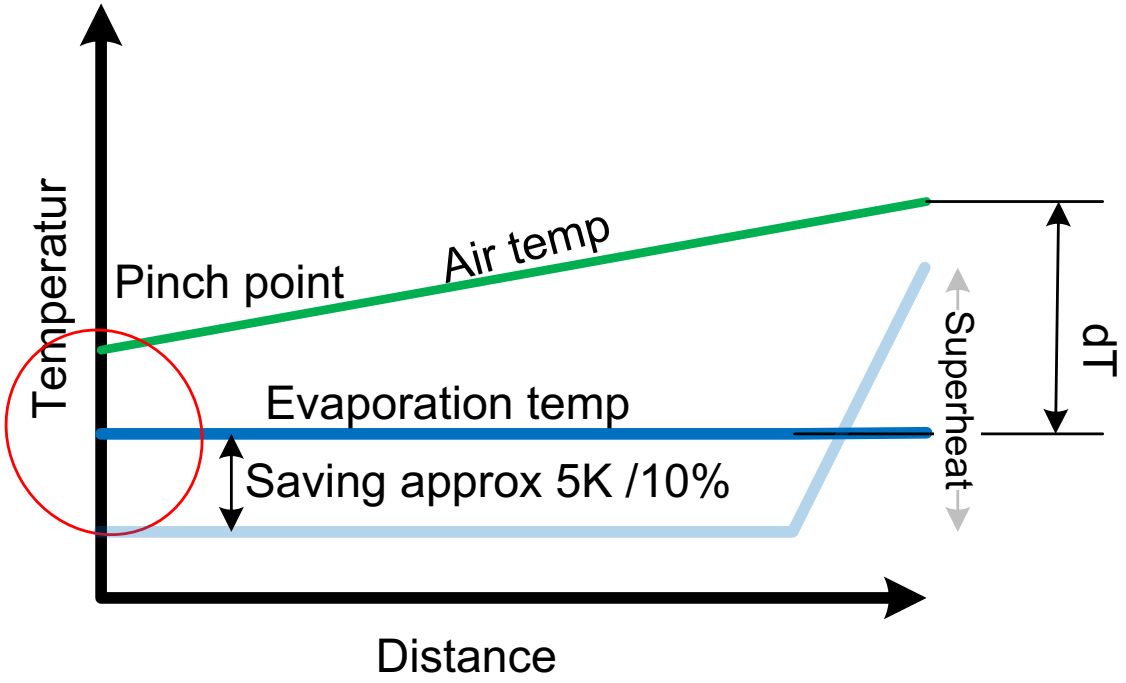


Typical Direct Expansion



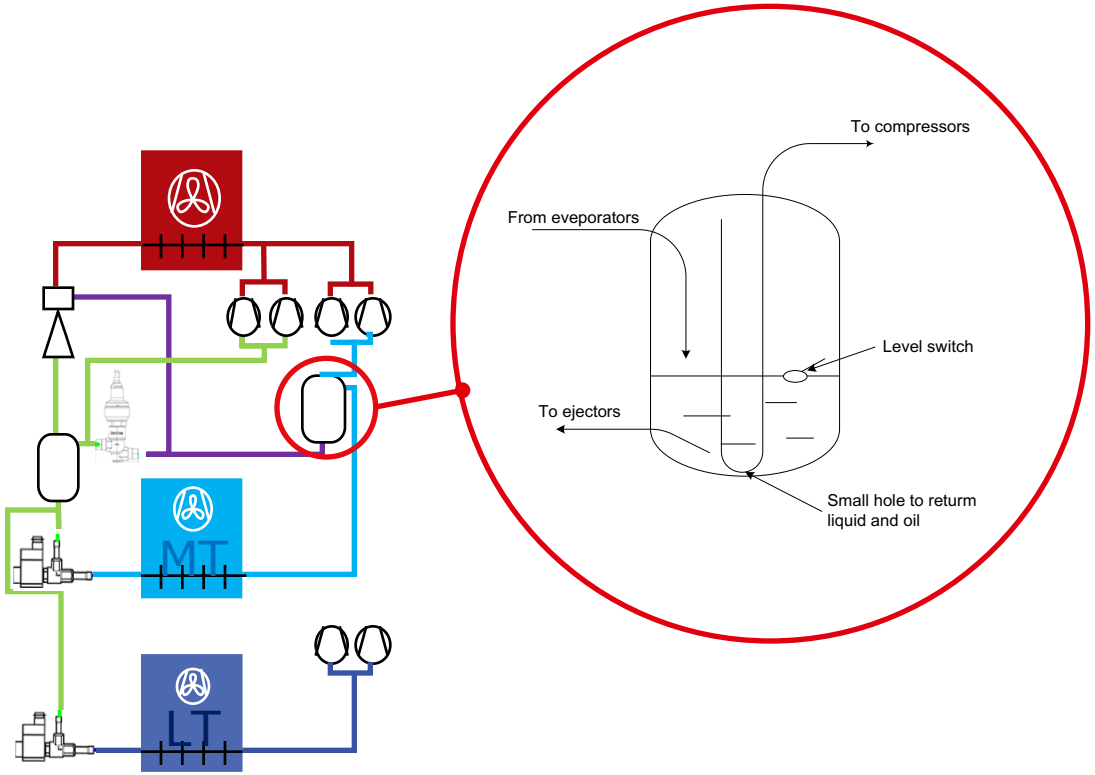
- Evaporation temperature controlled by the "pinch point" created by the required Superheat

Flooded Evaporator without PO Optimization



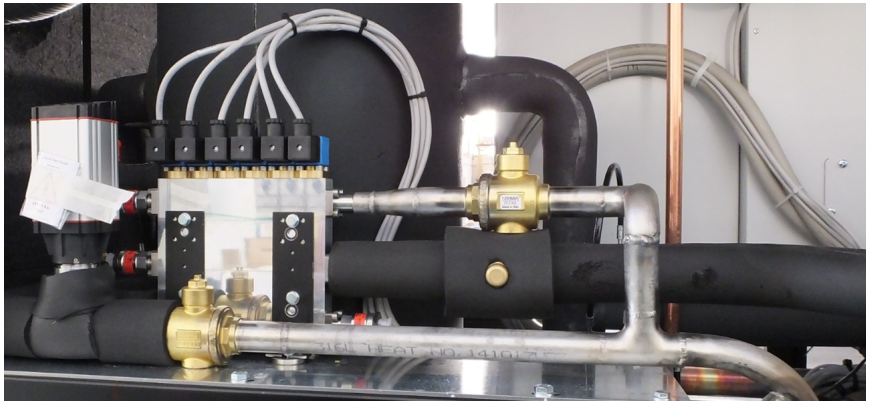
- Move the "pinch point" by eliminating the Superheat
- The evaporation temperature can be lifted
- Compressors?

Suction Accumulator



- Protect the compressors with a suction accumulator
- The liquid ejector provides a pump to lift pressure and move the liquid to the receiver
- As with the gas ejector, the work is provided by the expansion after the gas cooler

Early Liquid Ejector Performance Data



- Performance is Primarily dependent on two parameters:
  - Pressure lift from evaporator to receiver
  - Gas cooler pressure and temperature
- Other factors such as evaporation temperature and sub cooling out of the gas cooler also has some influence, but is it not very significant
- Capable to supply an entrainment ratio of min 15-20% at 5 bar lift and down to 5 °C inlet
- Availability projected to be in 2018

Multi Ejector Applications Experience
Lessons Learned

Ejector improves the stability of the system

- Control of parallel compressors can be tricky with a low volume of gas in the receiver, the additional suction gas from the ejector helps!
- Also this helps with compressor sizing parallel compressors

Opens up new ways of doing things.

Focus has been on larger supermarkets with parallel compression, but other solutions are in the pipeline:

- Solutions for smaller formats are emerging (3 installations running)
- Liquid ejector systems (+50 systems running)
- Heat recovery savings are expected (5 systems in operation)
- AC as an included feature maybe powered partly by ejectors (3 systems in operation)
- The focus has been on FR, but can also be applied to chillers and heat pumps (tests on heat pumps done in lab and chillers in progress)

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Thank you very much!