Practical aspects of low superheat control - experimental test of a CO_2 system

CO_2 +

Chillventa 17OCT18

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Agenda

- Background
- Application
- Superheat control
- Refrigeration system design
- Results
- Conclusions

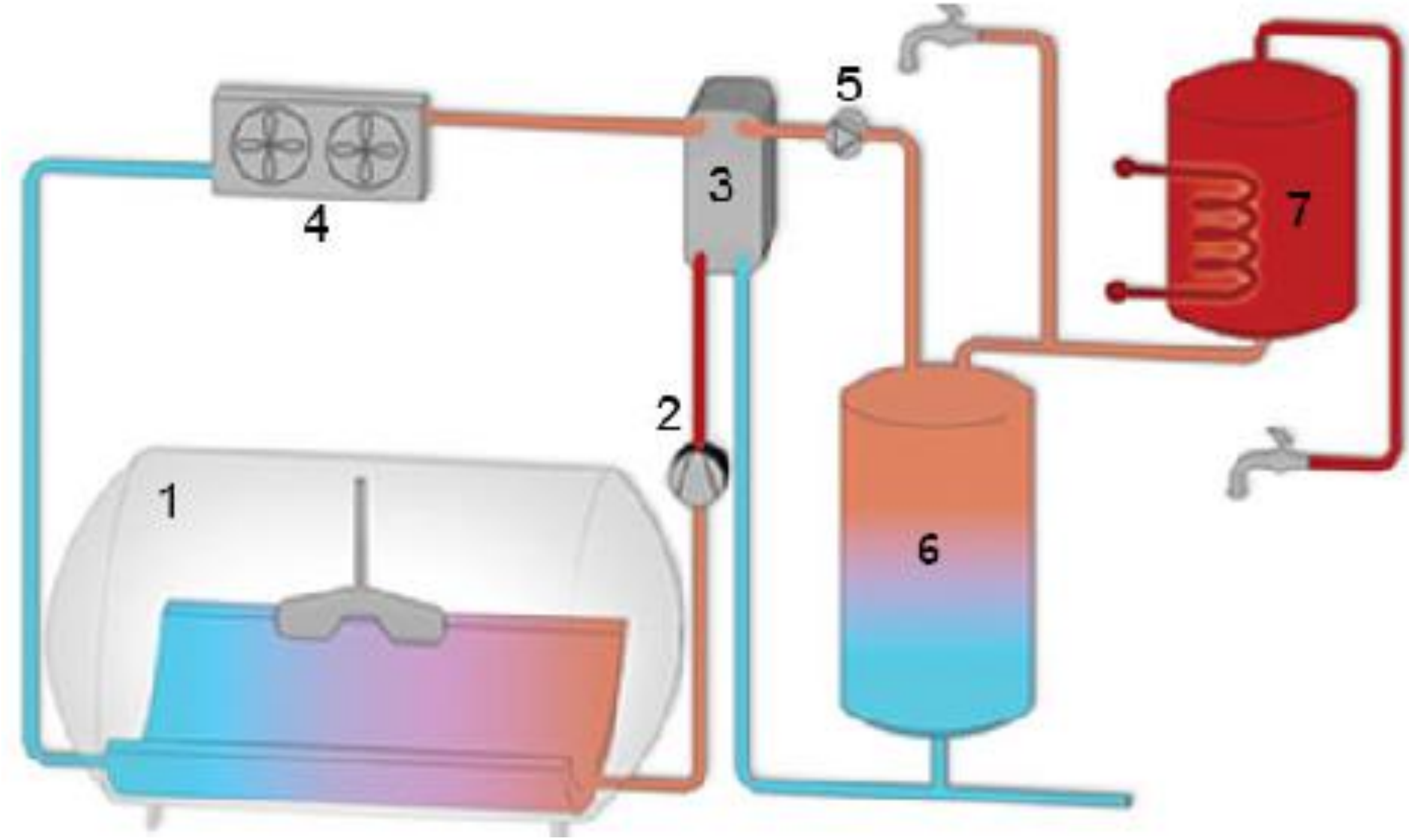
Background/Scope

- Develop a direct refrigeration system for farm based milk cooling comprising:
  - CO_2 refrigeration system
  - Heat recovery function (> 75°C)
  - Evaporator w/ design pressure (> 80 bar)
  - Controls (combined cooling & heating)

Milk production & cooling

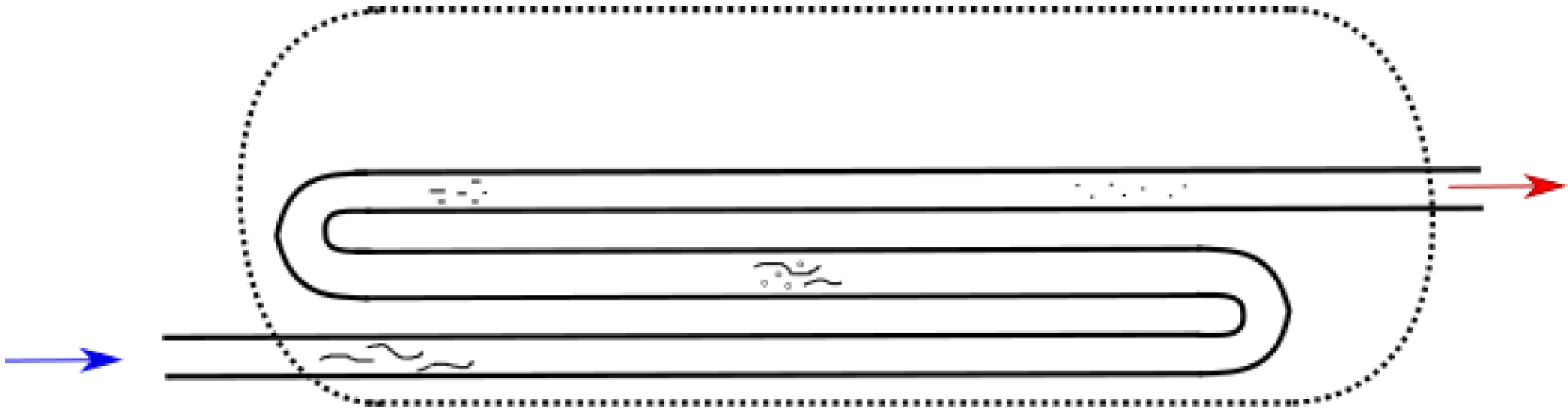
- Milking robot and milk cooling tank
  - Robot milking provides an even flow of milk to the tank

Refrigeration system + heat recovery



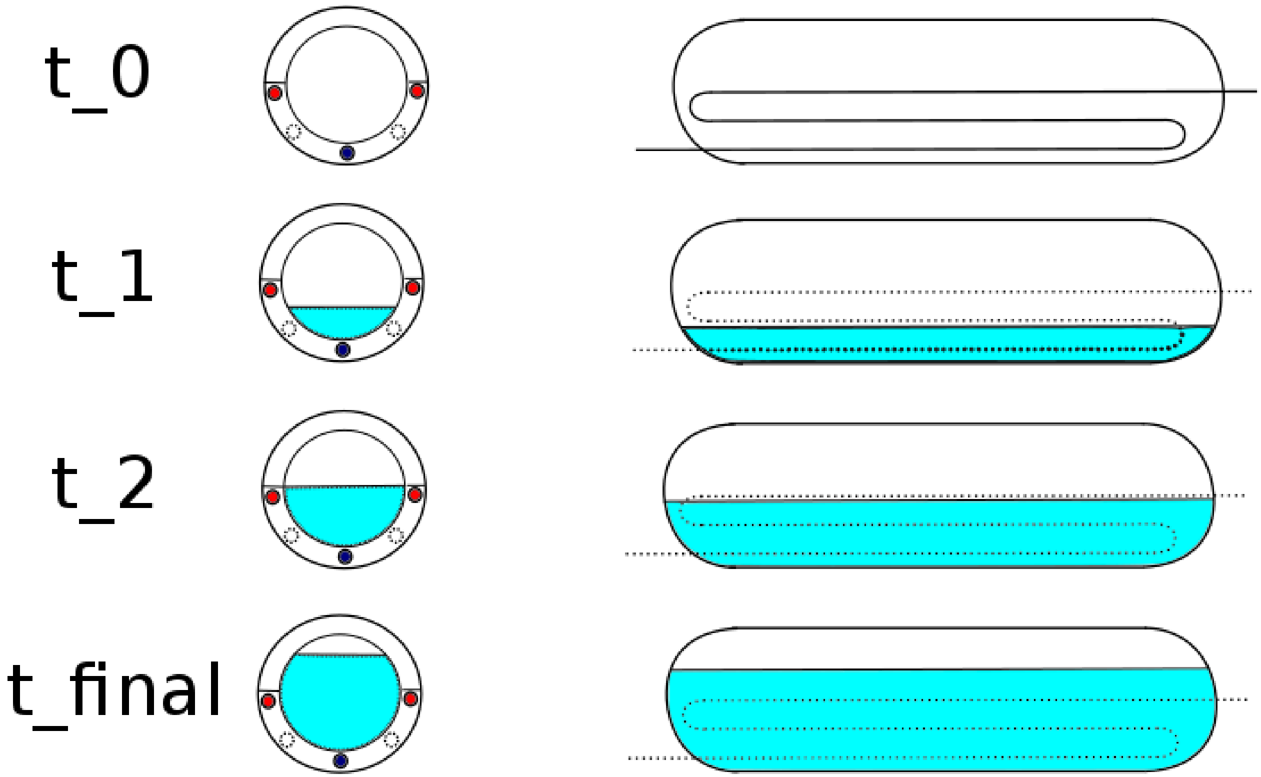
- Evaporator integrated in the milk tank

Evaporator feed – principal function



- Direct refrigeration system and tank with integrated evaporator!
  - Fed from the bottom

Tank filling process – 48 hours



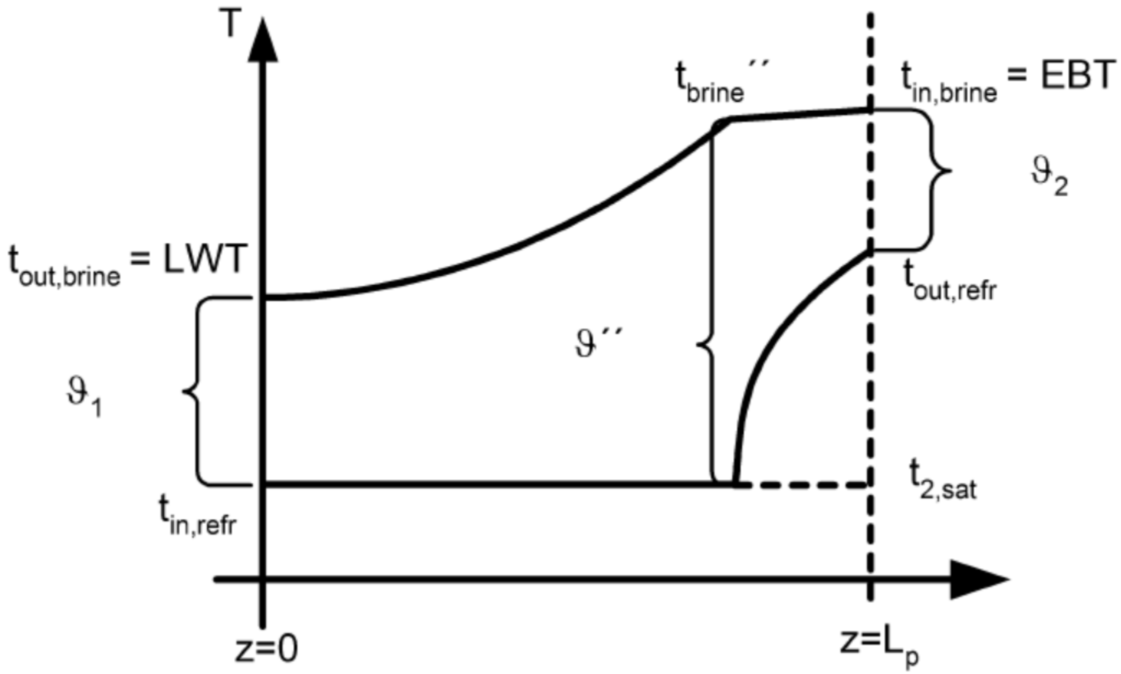
- The milk tank is filled up during 48 hours
  - Offers control challenges – a part of the evaporator is ”not active”

Application requirements

- Natural refrigerant – CO_2
- Robust system design and function
- Integrated evaporator (direct system)
  - Minimum stand still pressure 80 bar

- Evaporator design challenges
  - Pressure rating
  - Size
  - Cost
  - Oil return
  - Charge
  - Pressure drop
  - Manufacturing
  - ………

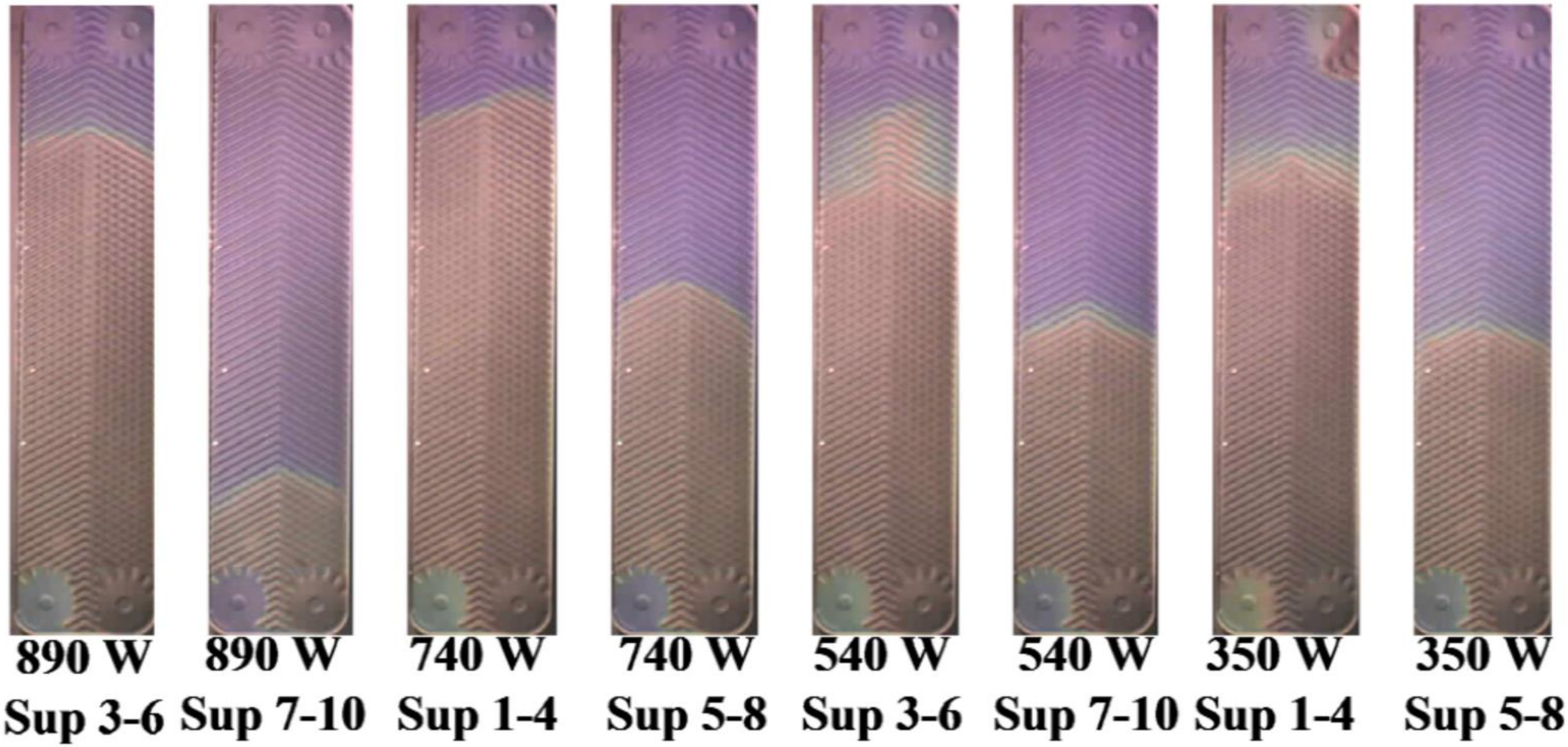
Why low superheat?



*J. Claesson, KTH, 2004

- Temperature profile in an evaporator*
  - Two regions – boiling and superheat
  - Less superheat – lower temperature difference
- Milk cooling:
  - Evaporation temperature – ”not to freeze the milk”: > -2°C
    - Max superheat: ~5K (milk temperature: +4°C)

Boiling vs. Superheat region (area)



*J. Claesson, KTH, 2004

- A significant area is used for superheat*
- ”Waste of surface/material”

How to achieve low/no superheat

- Traditional DX:
  - Compact/short evaporator
  - Improved refrigerant distribution
  - Good control
  - 3-5 K superheat possible but difficult
  - Typical superheat > 5 K
- Flooded evaporator (liquid overfeed) = no superheat
  - More common in large refrigeration systems
  - Liquid to be separated after the evaporator
    - Requires vessels and/or more components
  - Difficult to control the overfeed
  - Increases the charge

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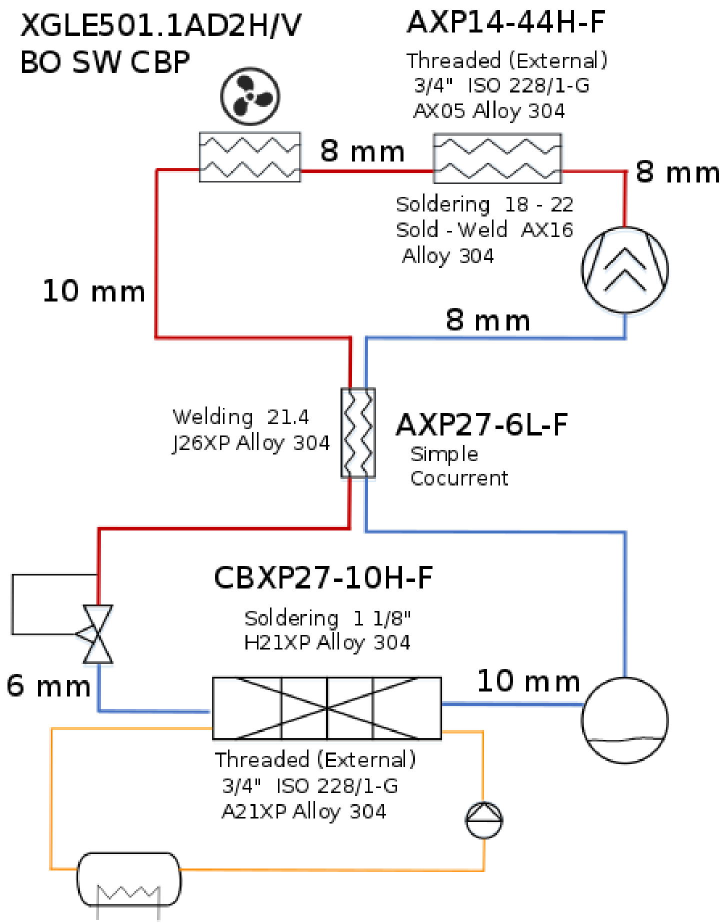
Test system design



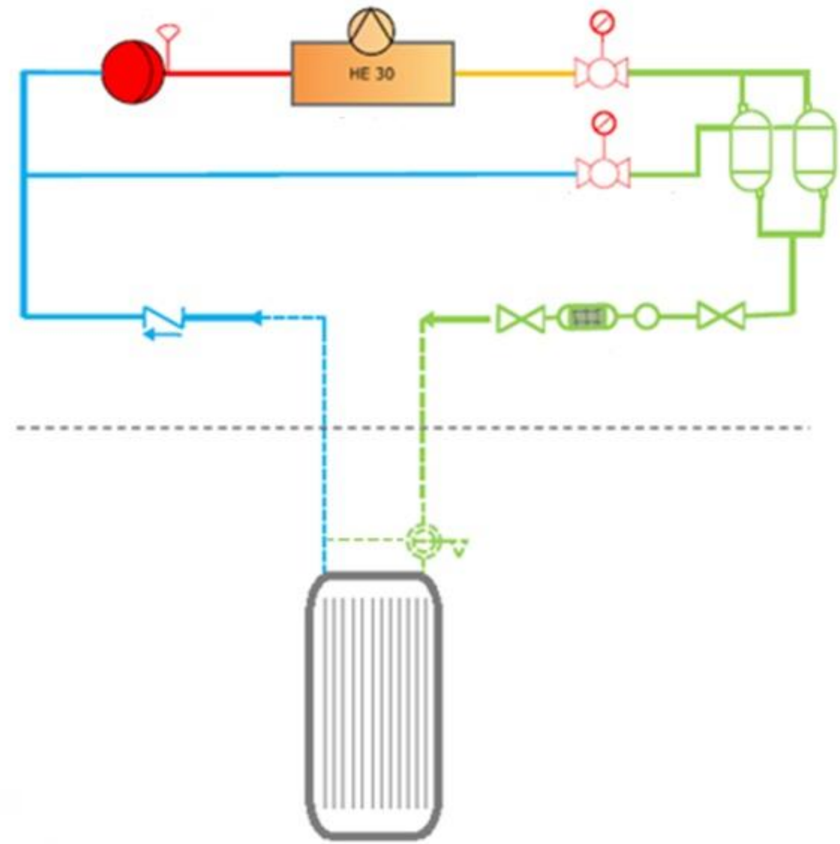
- Small scale CO2-system
- Prototype system tested w/ heat recovery

Phase 1 prototype conclusions

- Large charge variations between the high and low pressure side
  - Heat recovery control is challenging
- Expansion in one stage is difficult to manage over a wide range of pressure ratios
  - Expansion valve design is critical
- Liquid separation after the evaporator is challenging with CO_2
  - Small difference in liquid and vapour density
- High requirements on internal HEX to superheat or ”knock out” liquid
  - Liquid carry over and temperature difference varies

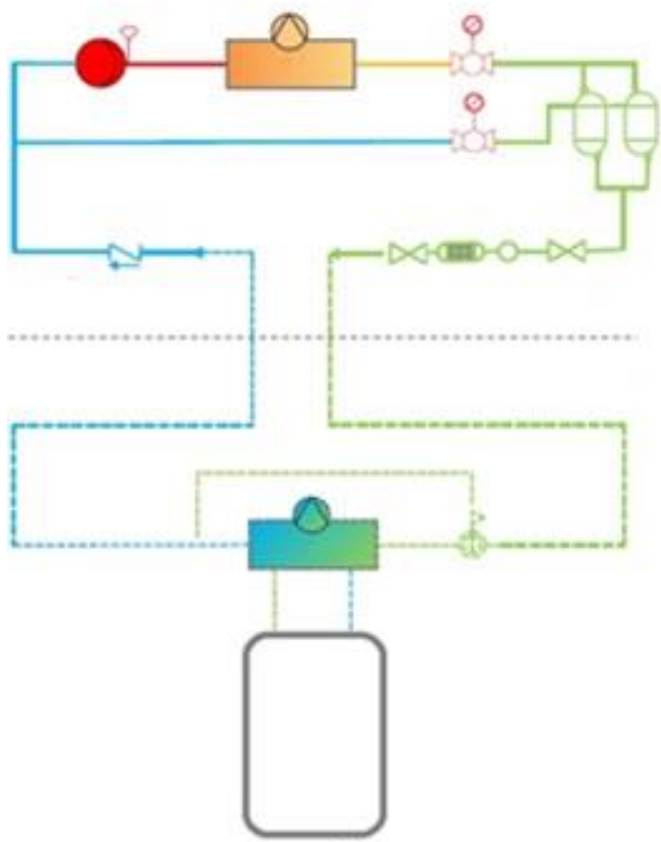
- <u>At this time (2016) – cost effective CO_2 condensing units became commercially available!</u>

Phase 2 goal: condensing unit <u>direct system</u>



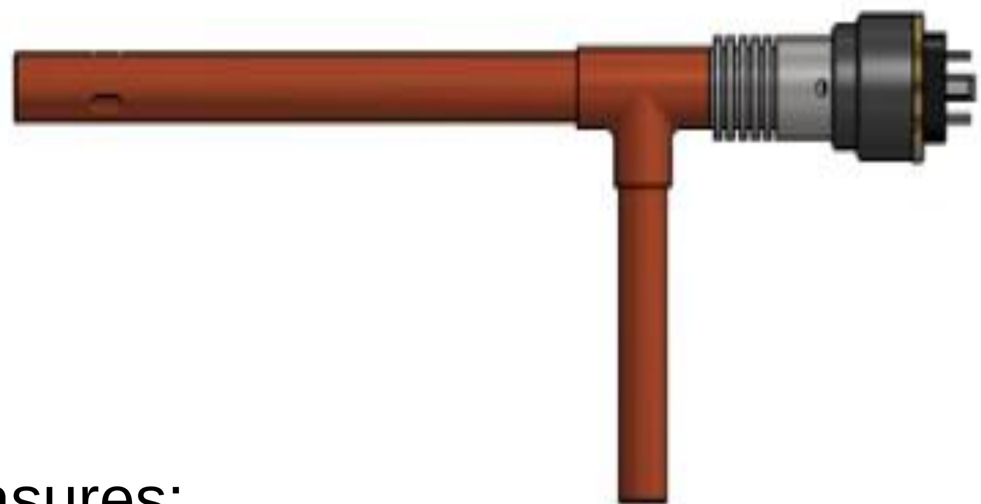
- Adapted condensing unit
  - Heat recovery function
- Integrated evaporator
  - Superheat control!

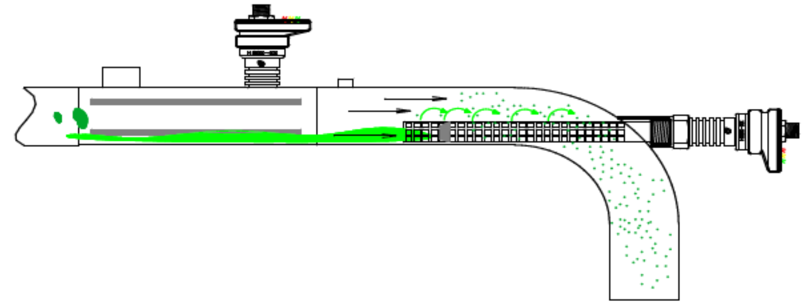
Phase 2: condensing unit + indirect system



- Expansion in two steps
- Better refrigerant control @ heat recovery
- …..but superheat control required….!

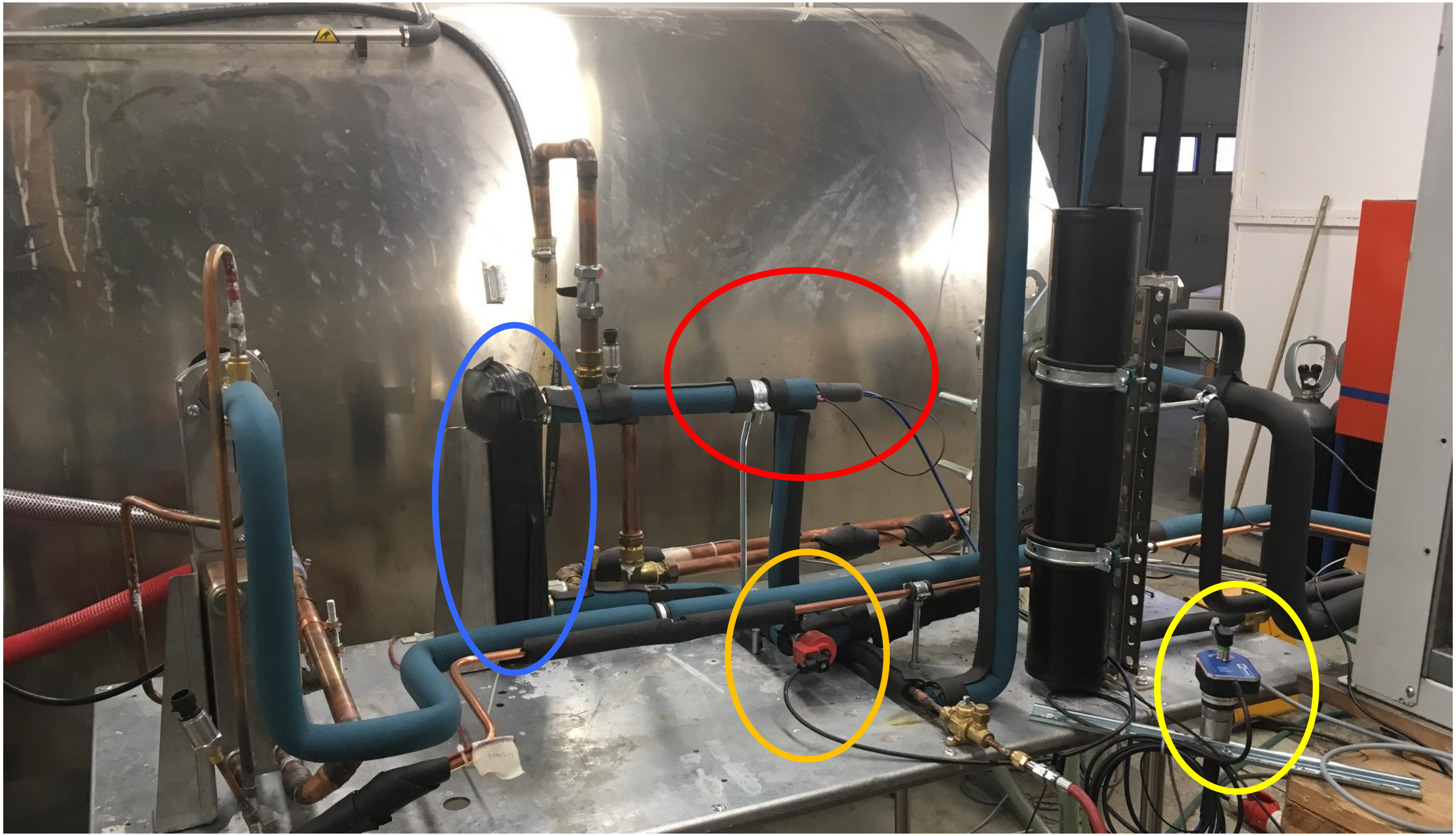
The HBX-sensor



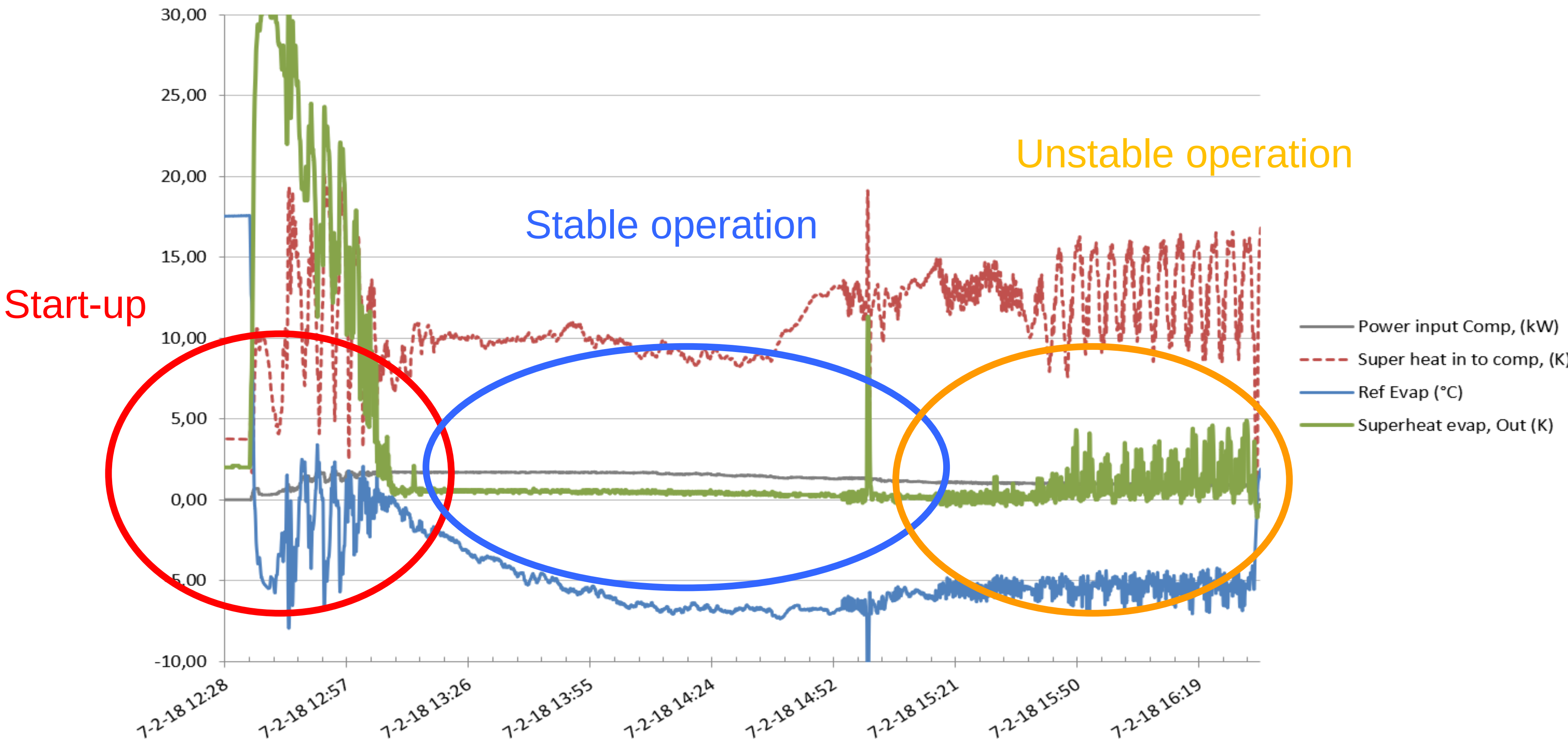


- Measures:
  - the vapour quality @ the evaporator outlet, and…
  - …controls the expansion valve..
  - ..to allow a vapour quality close to 1 (or just below)….
  - …consequently (ideally)… 0K superheat!

Test system with HBX-sensor

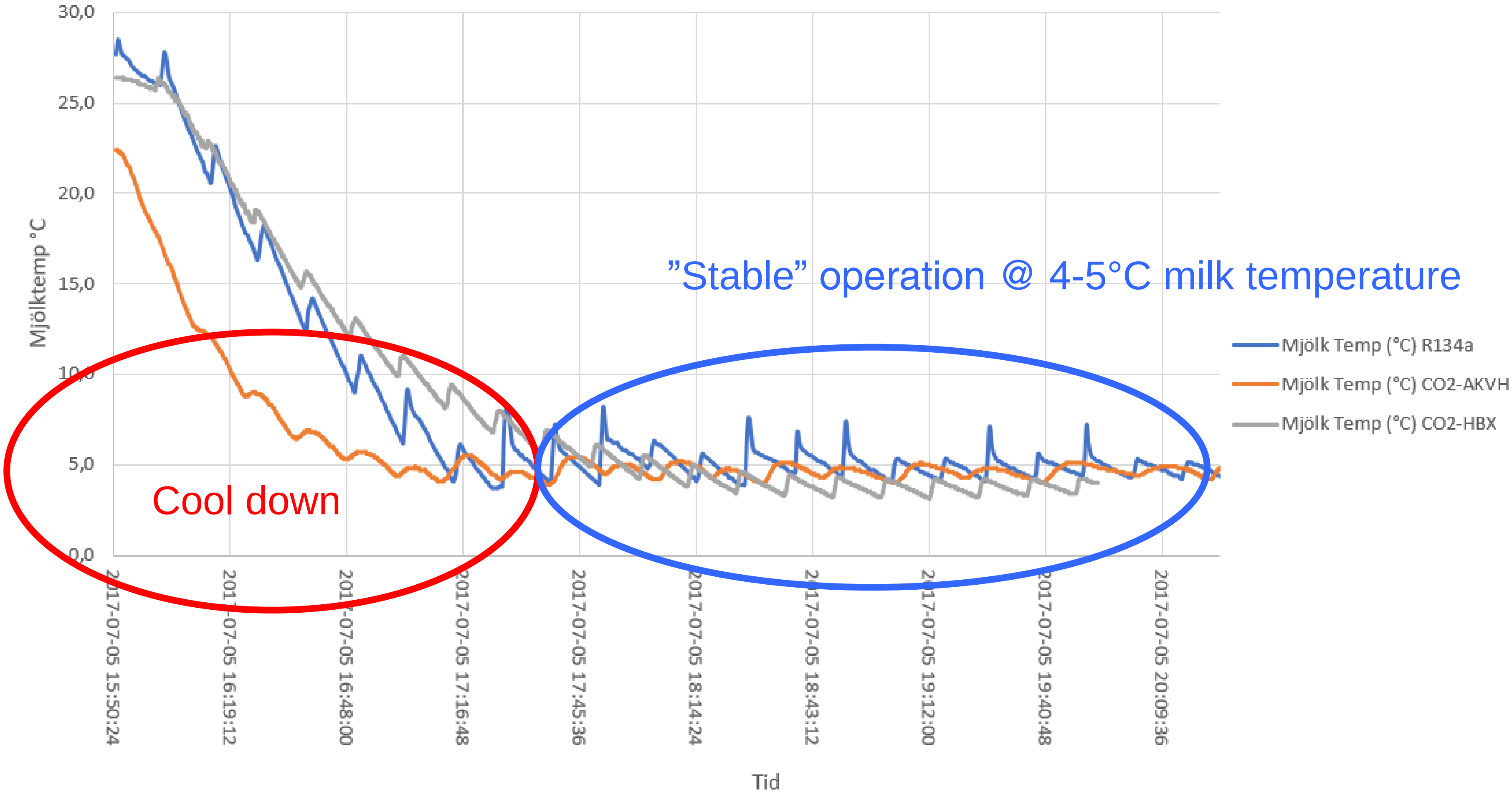


Test results



- 0 K superheat control was achieved!

Test results



- ”Longer term” control was achieved as well
- The comparisons were not conclusive at the time for testing

Summary

- The HBX-sensor represents a very interesting evaporator control concept!
- 0K superheat is possible and achieved
- Potential operation with “controlled” liquid overfeed is possible
  - Reduces the charge in the system
- Ideally no liquid separator is necessary
  - Saves cost
- Superheat is achieved in an Internal Heat Exchanger (IHEX)
- Reduces the required evaporator size (surface)
  - A key parameter in this application

Thank you for your attention!

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