Onboard CO2 plate freezing with cold thermal energy storage

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Agenda

01 **Background**

02 **Method and materials**

03 **Numerical freezing**

04 **Results**

05 **Cold thermal energy storage (CTES)**

06 **Summary and conclusion**

Background

- Ammonia and CO_2 is a popular choise, however **CO_2** has the advantage of **lower evaporating temperature**
- Higher temperature difference decreases system COP, but results in **faster freezing rates**
- **Cold energy storages** is proven to be beneficial in residential refrigeration. Does is also apply for the freezing industry?

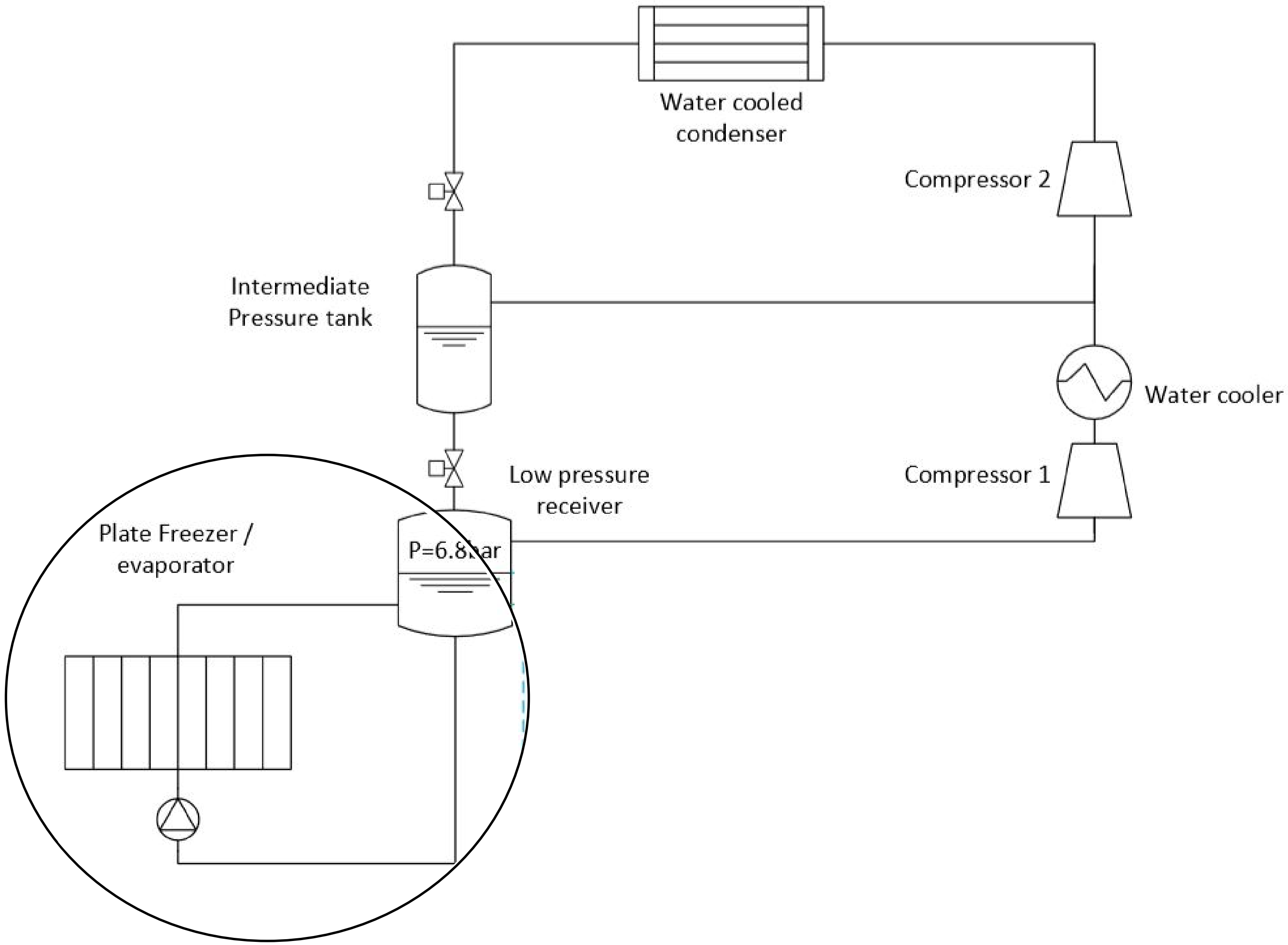
Problem statement

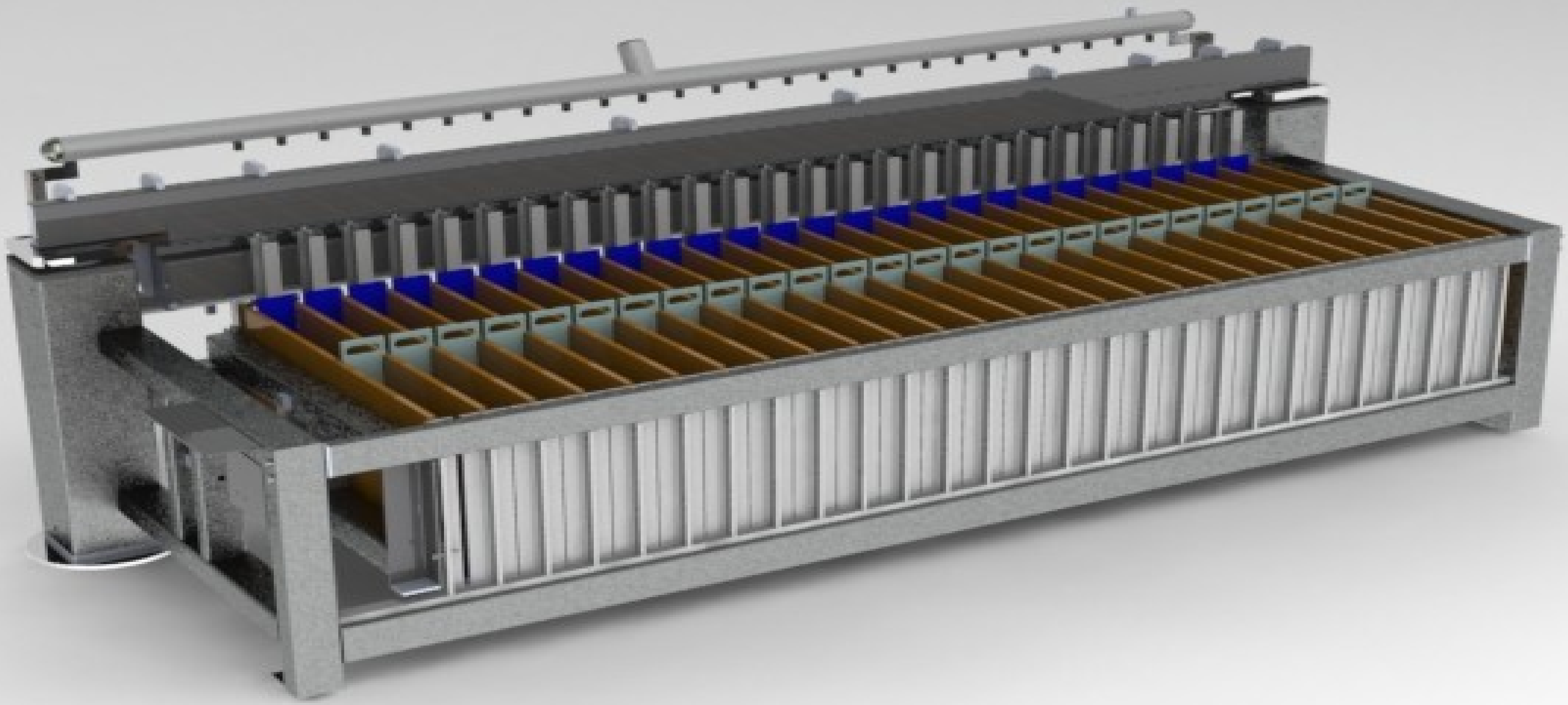
How are freezing systems influenced by lower evaporating temperatures, down to -50^{o}C?

Can they be improved by implementing CTES?

Method

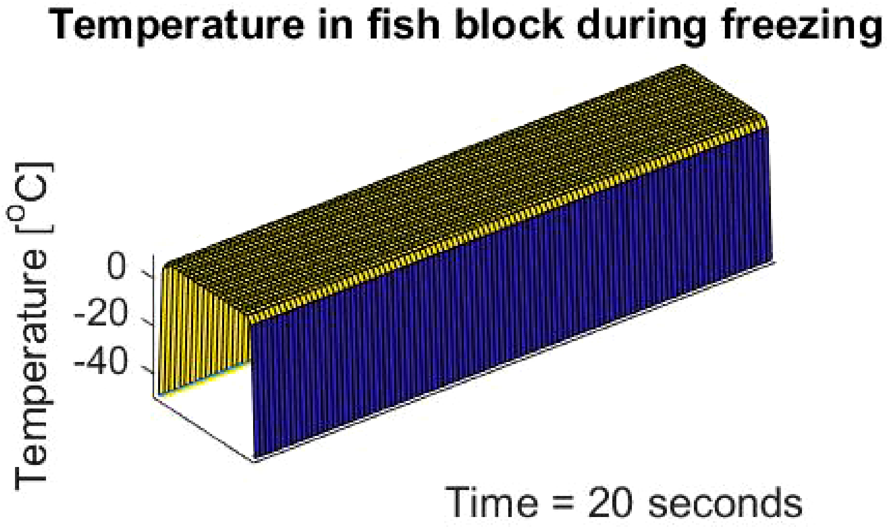
- Develop numerical freezing models
- Validate the model
- Develop refrigeration system model
- Define and calculate KPIs:
  - Specific energy use $\left[\frac{kJ}{kg\ fish}\right]$
  - Freezer capacity $\left[\frac{kg\ fisk}{day}\right]$
- How are the KPIs influenced by CTES?

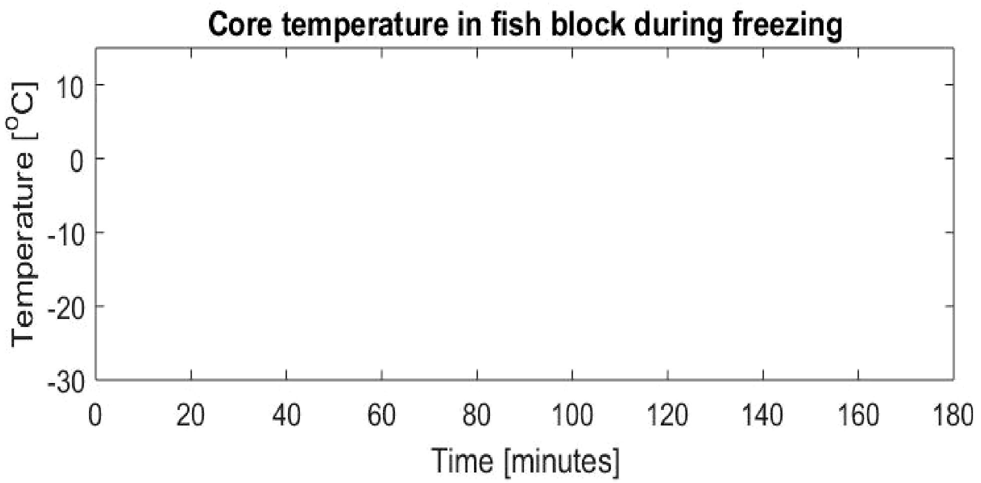

Water cooled condenser
Compressor 2
Intermediate Pressure tank
Water cooler
Low pressure receiver
Compressor 1
Plate Freezer / evaporator
P=6.8bar

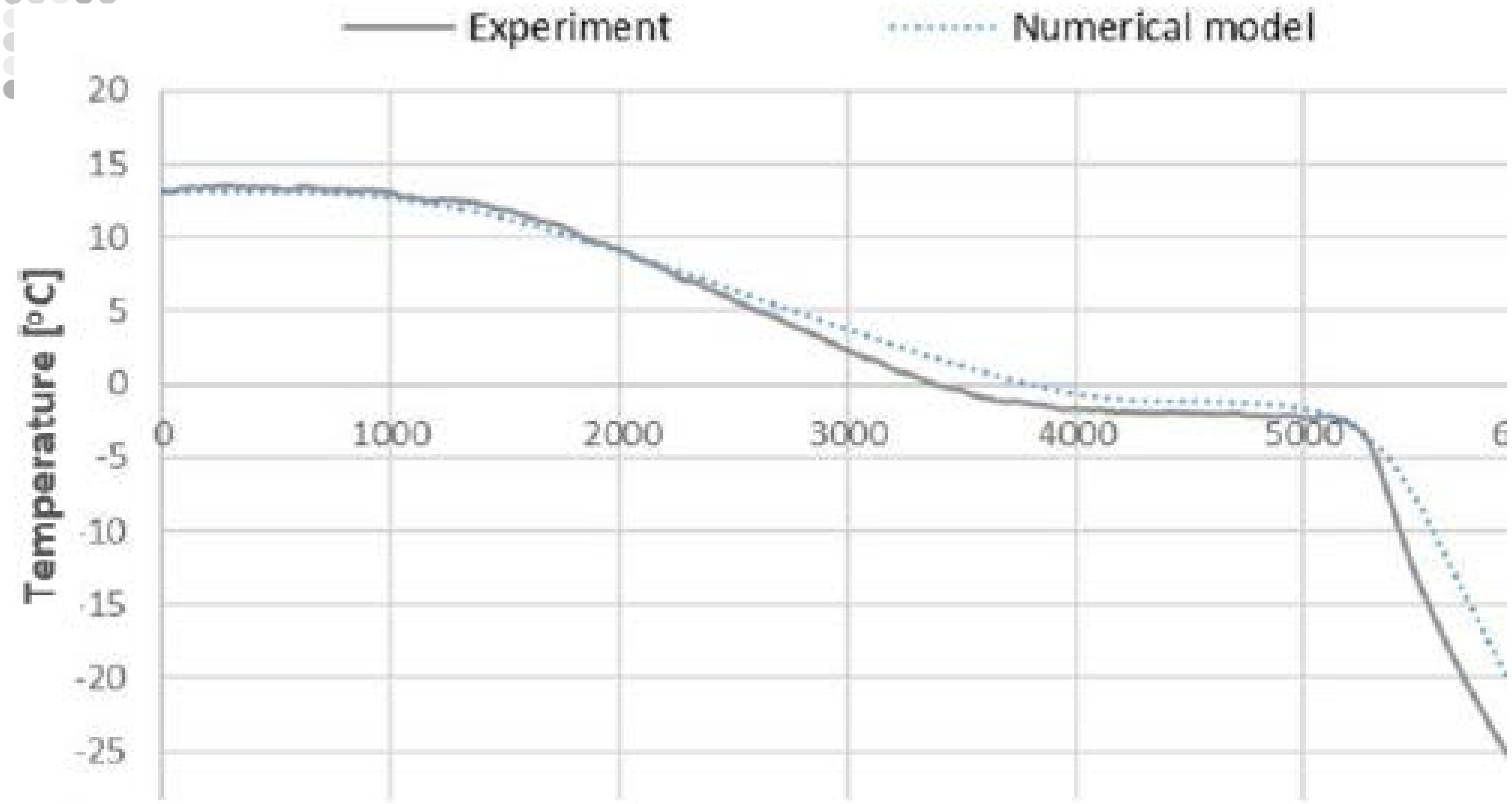


Numerical freezing model

- MATLAB based
- Solves the 2D heat equation
  - Updating thermophysical properties
  - Includes phase change
- Allow us to freeze different dimensions and different evaporating temperatures
- Was validated in an industrial plate freezer





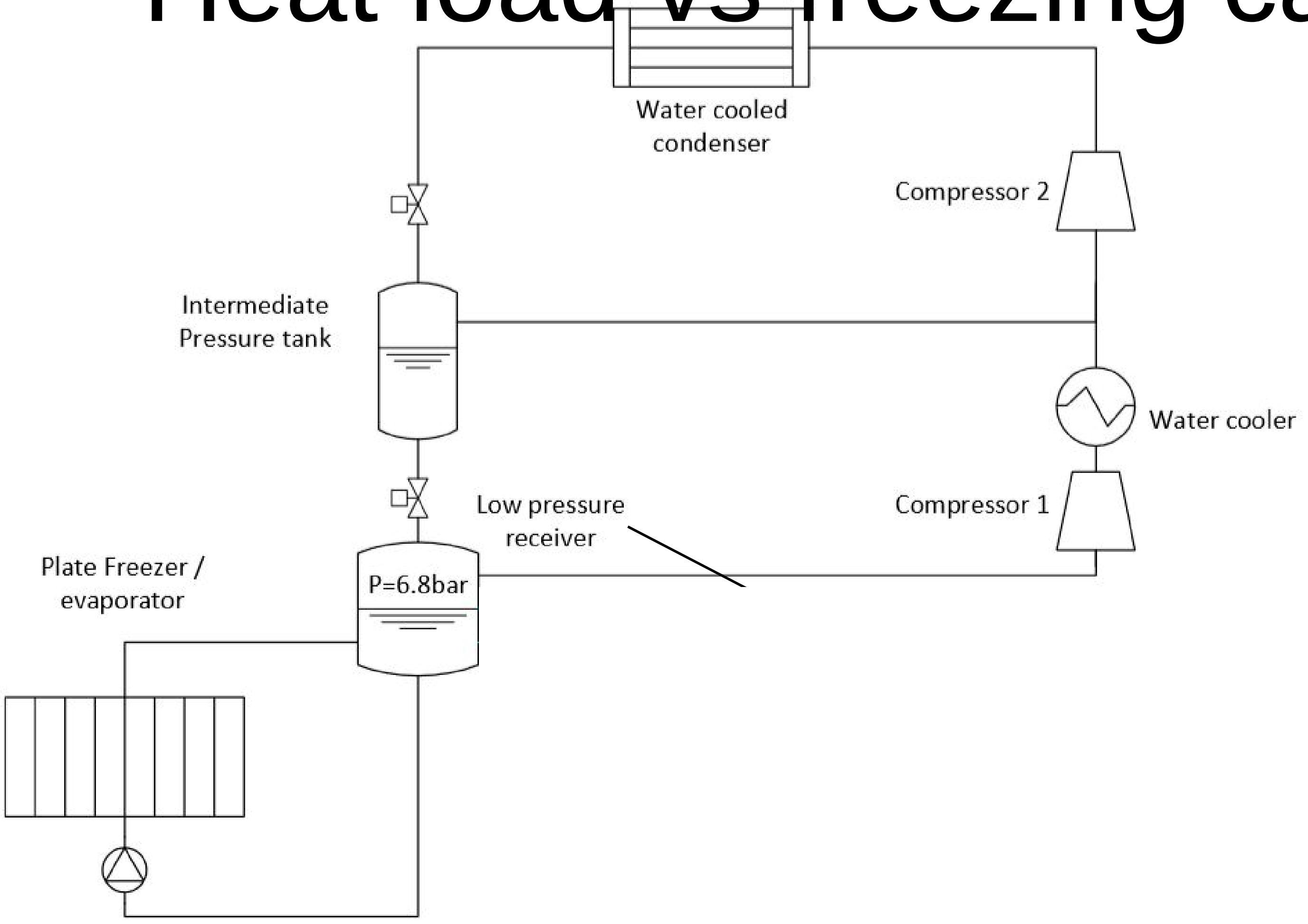

Experiment
Numerical model
Temperature [°C]
20
15
10
5
0
-5
-10
-15
-20
-25
0
1000
2000
3000
4000
5000

Results

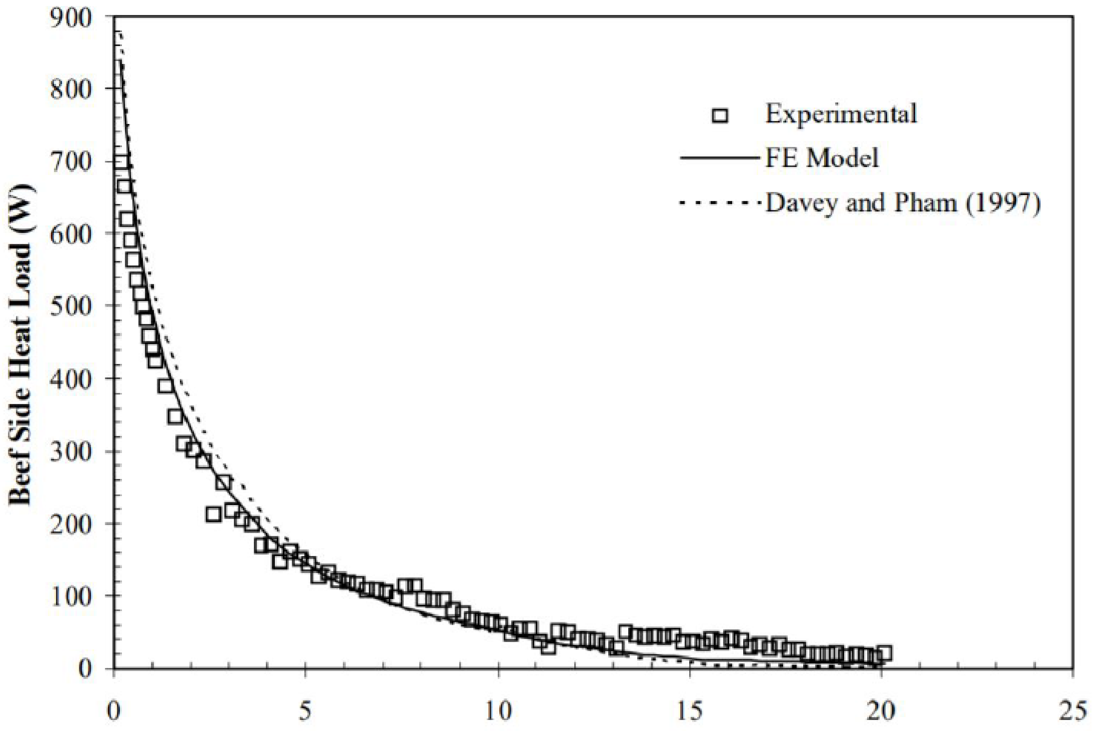
- Freezing times are reduced
- Increase in energy use
- Most important: Increase in production capacity

		Freezing time[min]			Energy use [kWh/ton]			Production capacity [kg/h]		
Evaporating temperature		-50 °C	-40 °C	-30 °C	-50 °C	-40 °C	-30 °C	-50 °C	-40 °C	-30 °C
Block thickness [mm]	50	19 %	23 %	31 %	149 %	108 %	81 %	188 %	161 %	126 %
	75	36 %	45 %	61 %	156 %	122 %	90 %	177 %	146 %	111 %
	100	58 %	73 %	100 %	172 %	133 %	100 %	166 %	134 %	100 %

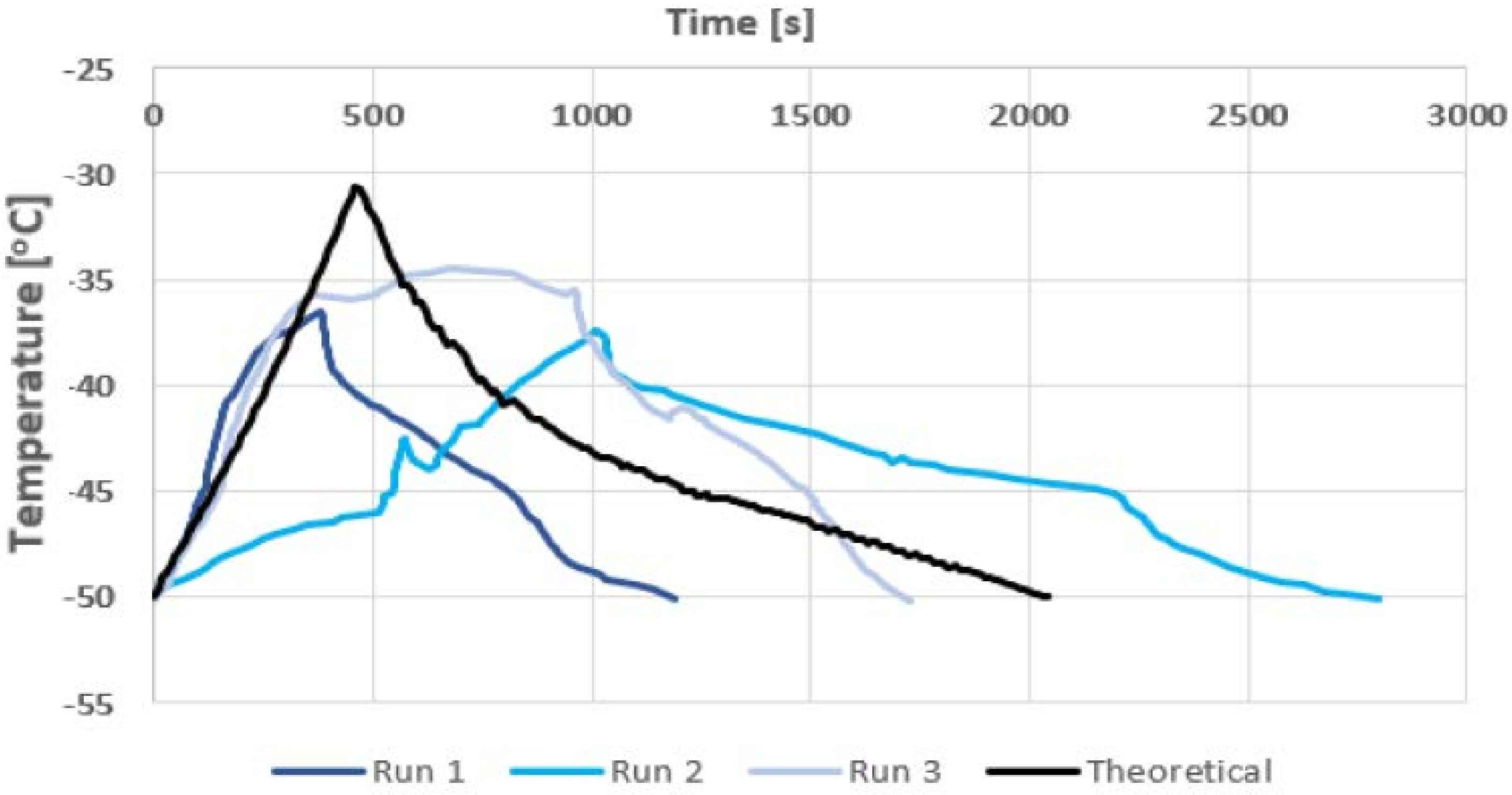
Heat load vs freezing capacity



Q.T. Pham (2002)

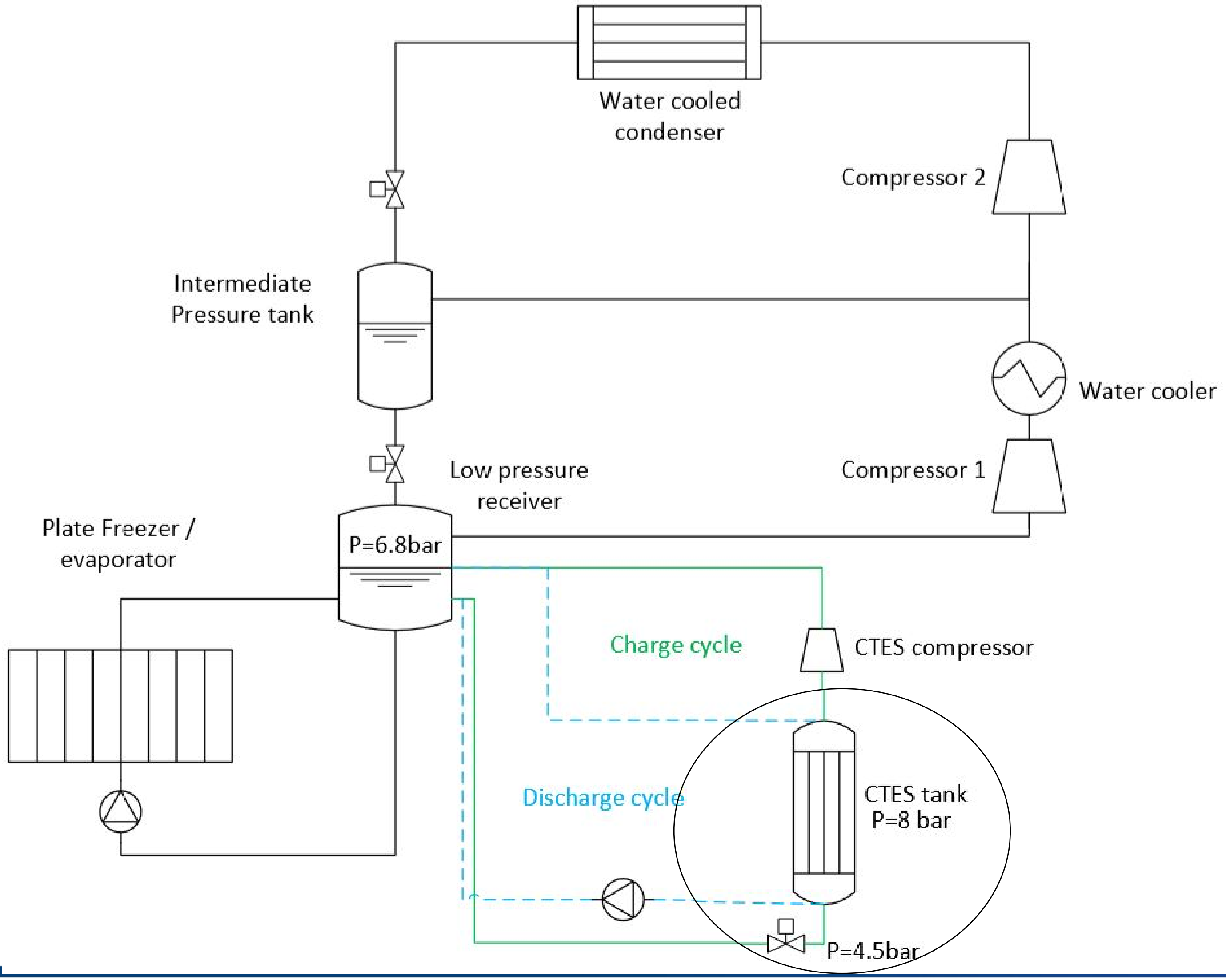


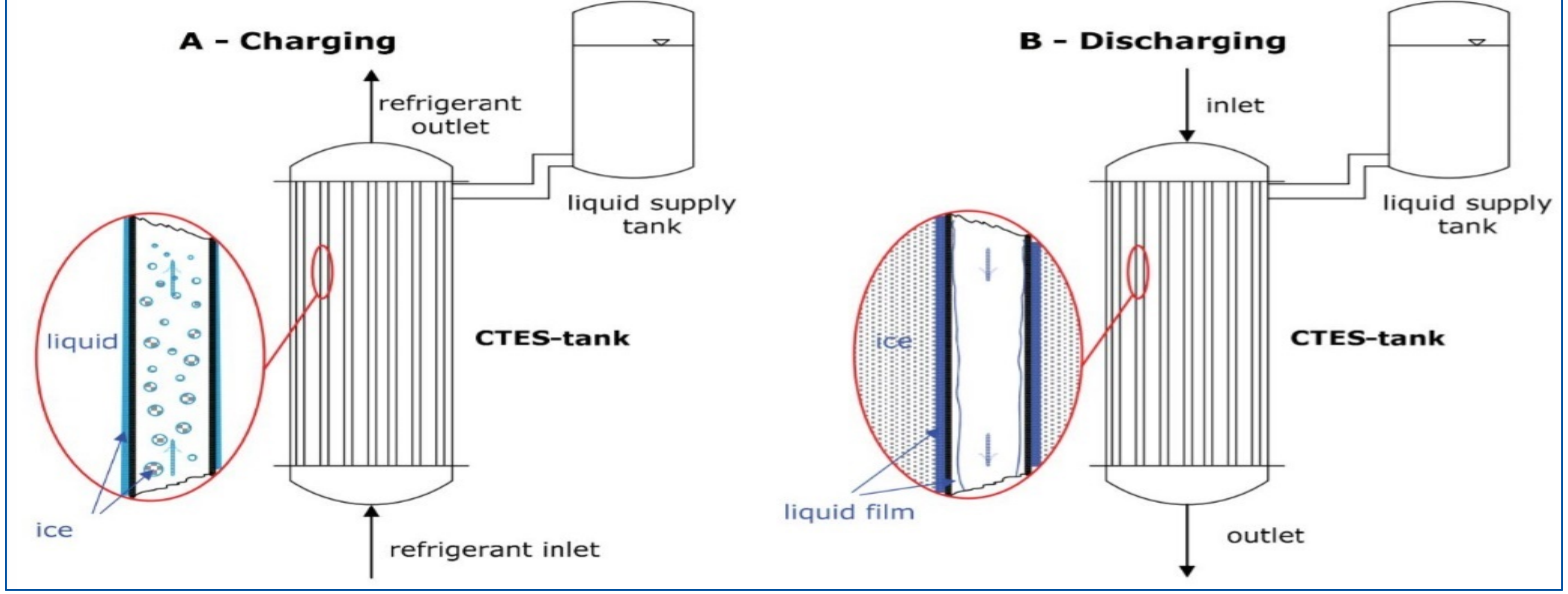
Temperature in flash tank

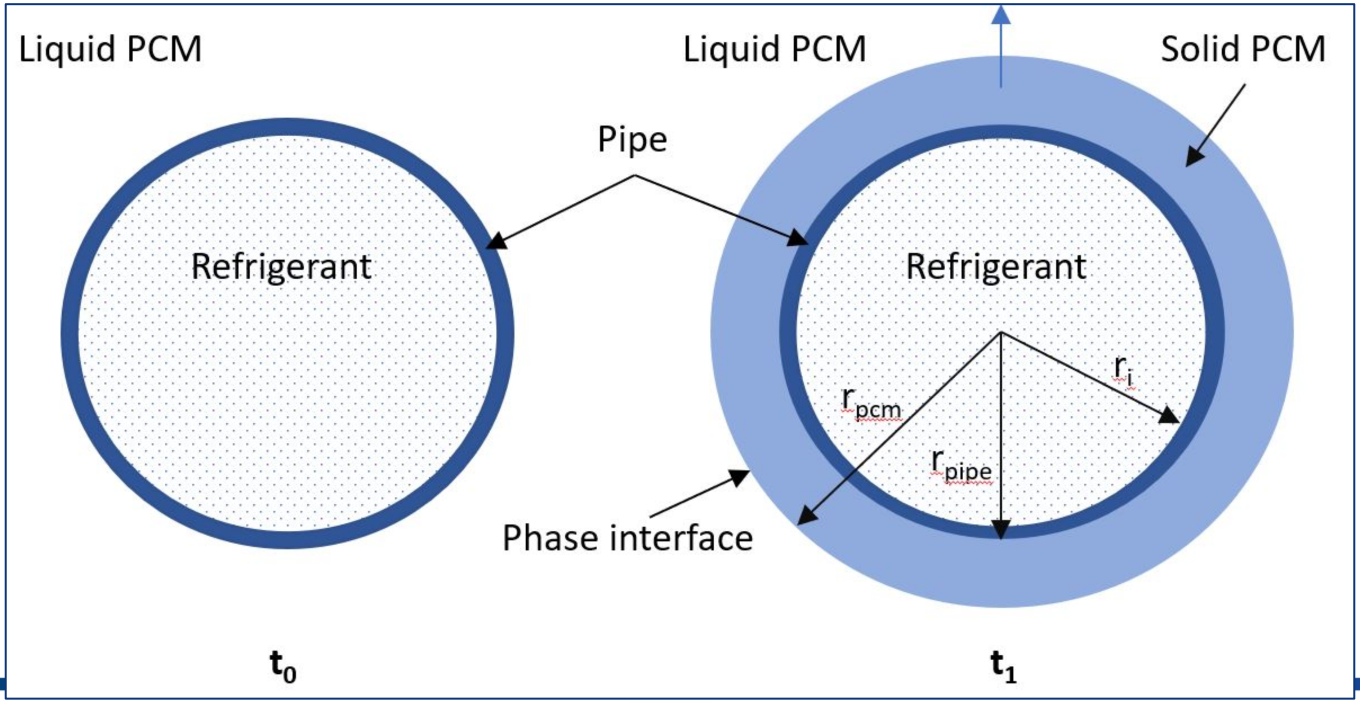


SINTEF NTNU

CTES

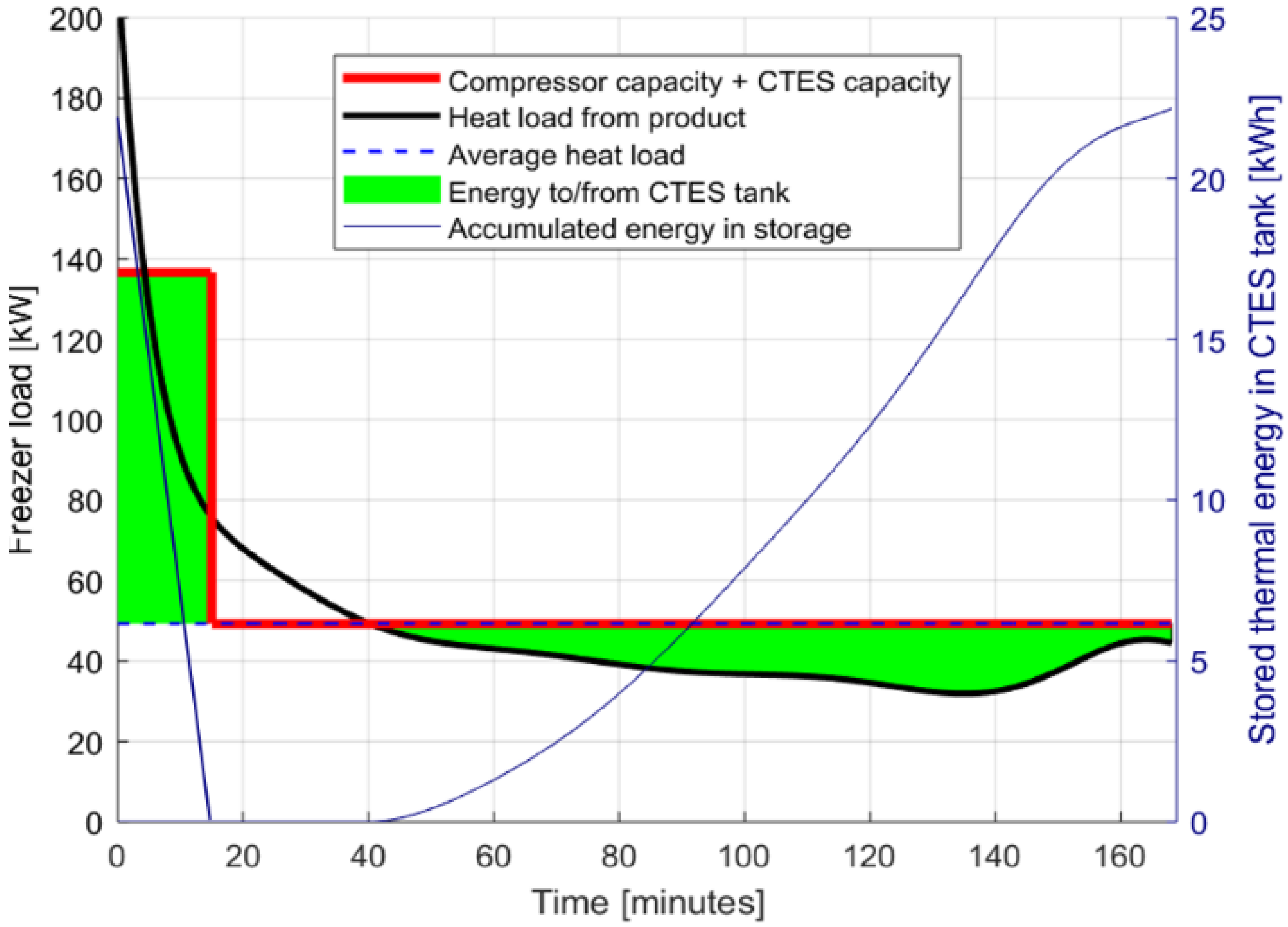

Water cooled
condenser
Compressor 2
Intermediate
Pressure tank
Water cooler
Low pressure
receiver
Compressor 1
Plate Freezer /
evaporator
P=6.8bar
Charge cycle
CTES compressor
Discharge cycle
CTES tank
P=8 bar
P=4.5bar


A – Charging
refrigerant outlet
liquid supply tank
liquid
CTES-tank
ice
refrigerant inlet
B – Discharging
inlet
liquid supply tank
ice
CTES-tank
liquid film
outlet


Liquid PCM
Liquid PCM
Solid PCM
Pipe
Refrigerant
Refrigerant
r_i
r_{pcm}
r_{pipe}
Phase interface
t_0
t_1

Heat load and compressor capacity with CTES

- The CTES system helps the compressor to remove gas from the receiver in the beginning
- CTES tank is charged when compressor capacity is larger than the heat load
- Lower temperature increase in the receiver during freezer
- More stable compressor run



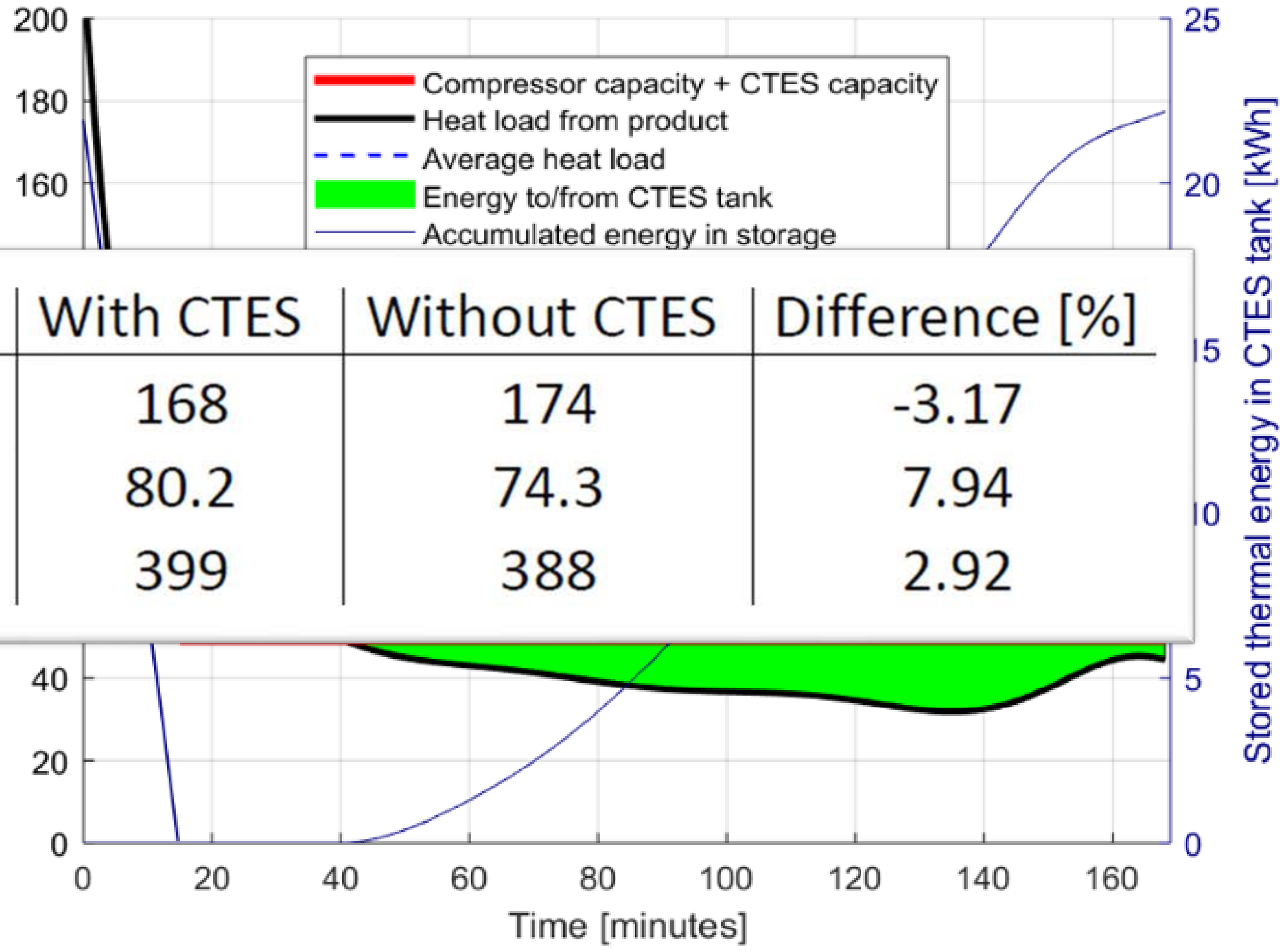
Heat load and compressor capacity with CTES

- The CTES system helps the compressor to remove

	With CTES	Without CTES	Difference [%]
Freezing time [min]	168	174	-3.17
Specific energy use [kWh/ton]	80.2	74.3	7.94
Production capacity [kg/h]	399	388	2.92

increase in the receiver during freezer

- More stable compressor run



Summary and Conclusion

- Freezing in plate freezers is well modelled
- Higher capacity with lower evaporating temperature
- CTES can be used to reduce the receiver temperature spike during initial freezing and therefore additionally reduce freezing time
- Economically important to increase product capacity

Thank you for your attention!