ATMOsphere AMERICA business case natural refrigerants

June 18-19, 2014 - San Francisco

Design of Heat Exchangers for Heat Recovery in Transcritical CO_2 Systems

Rolf Christensen

Agenda

- I do apologise…No practical case stories
- Alfa Laval shortly..
- Apologise again….Some theory…however basic.
- The transcritical process in PH and TH diagrams
- LMTD and Heat Exchanger Design models
- The consequences of physical properties in transcritical state
  - Internal pinch point
  - Minimum operating pressure and outlet temperature
  - Impact on heat exchanger design
- Which is the basis for successful case stories…

Alfa Laval – a global company

- 3500 M€ order intake 2013
- >16300 employees
- 34 Production units*
- 106 Service centres
- Sales companies in 55 countries
- Other sales representation in 45 countries

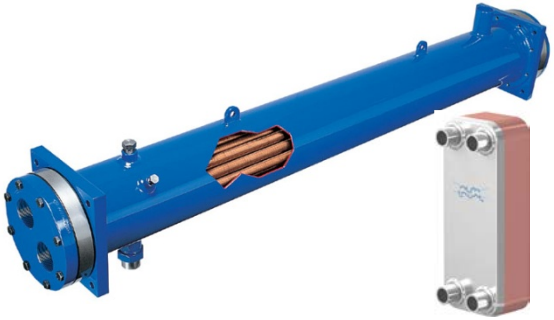
* Plus a number of minor production and assembling units

Alfa Laval – a global company

Alfa Laval aims at creating better everyday conditions for people by providing highly efficient and environmentally responsible solutions for water supply, energy production and food.

Focus in refrigeration

- Energy efficiency
- Heat recovery
- Heat pumps
- Natural refrigerants
  - CO_2, NH_3 and HC
- Complete product range



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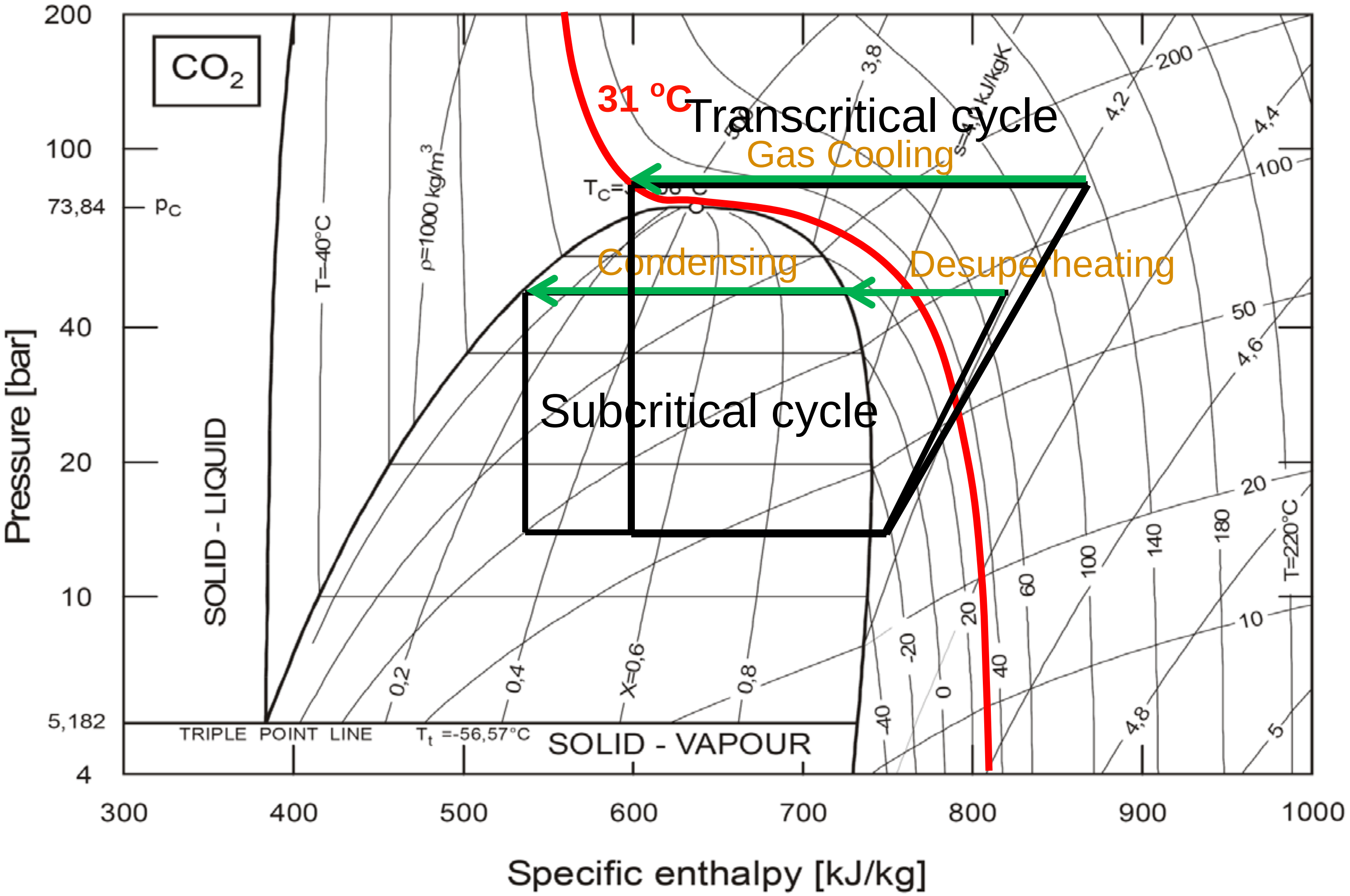
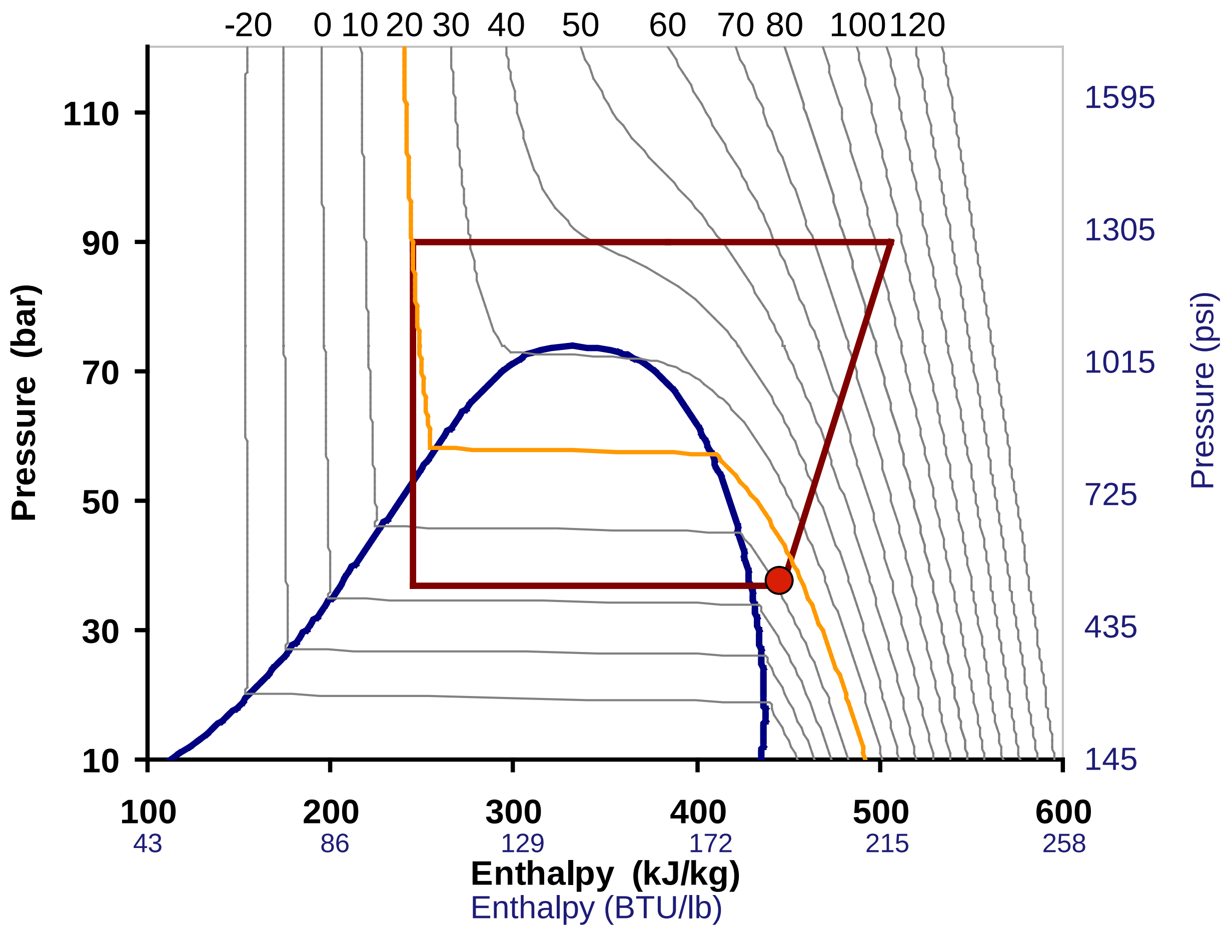
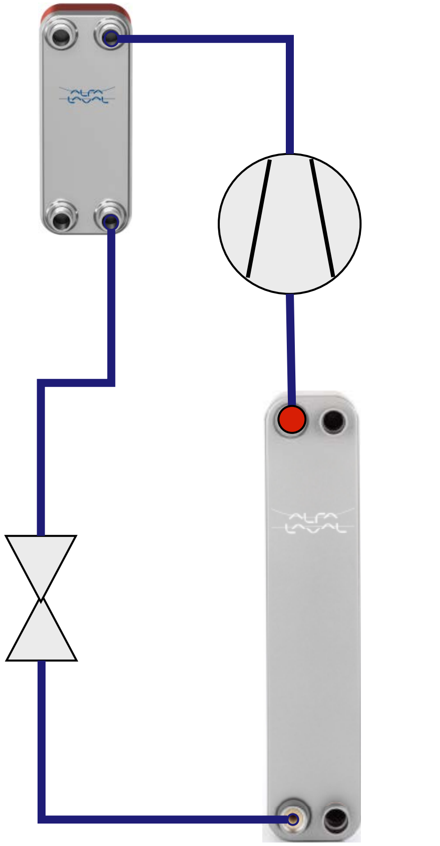
Thermodynamic cycles CO_2



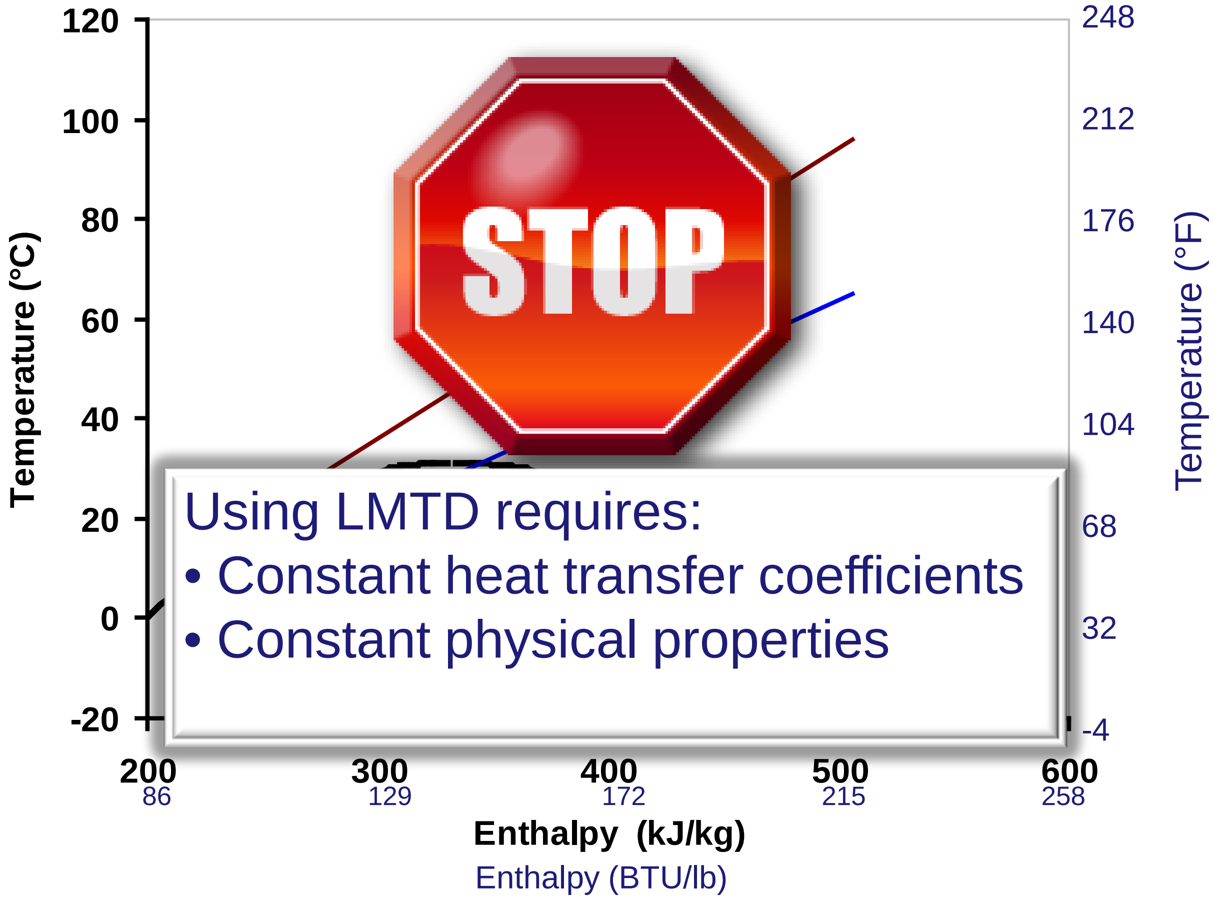
Simple transcritical cycle PH-chart





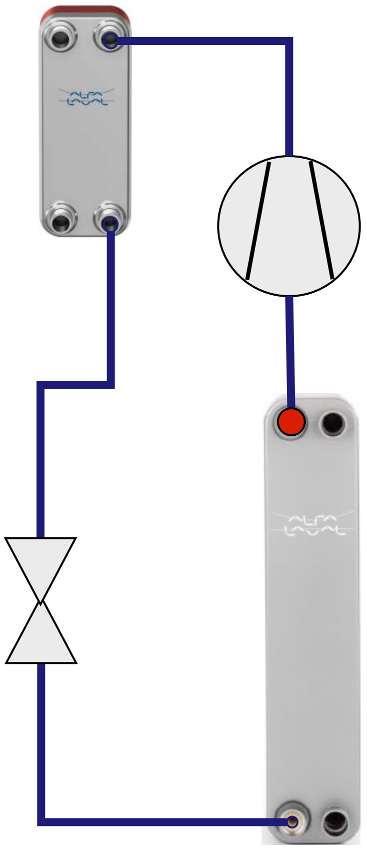
Simple transcritical cycle TH chart

$$LMTD = \frac{(Tgin - Twout) - (Tgout - Twin)}{\ln\left(\frac{Tgin - Twout}{Tgout - Twin}\right)} = \frac{(96-65)-(20-10)}{\ln\left(\frac{96-65}{20-10}\right)} = 18.6°C$$

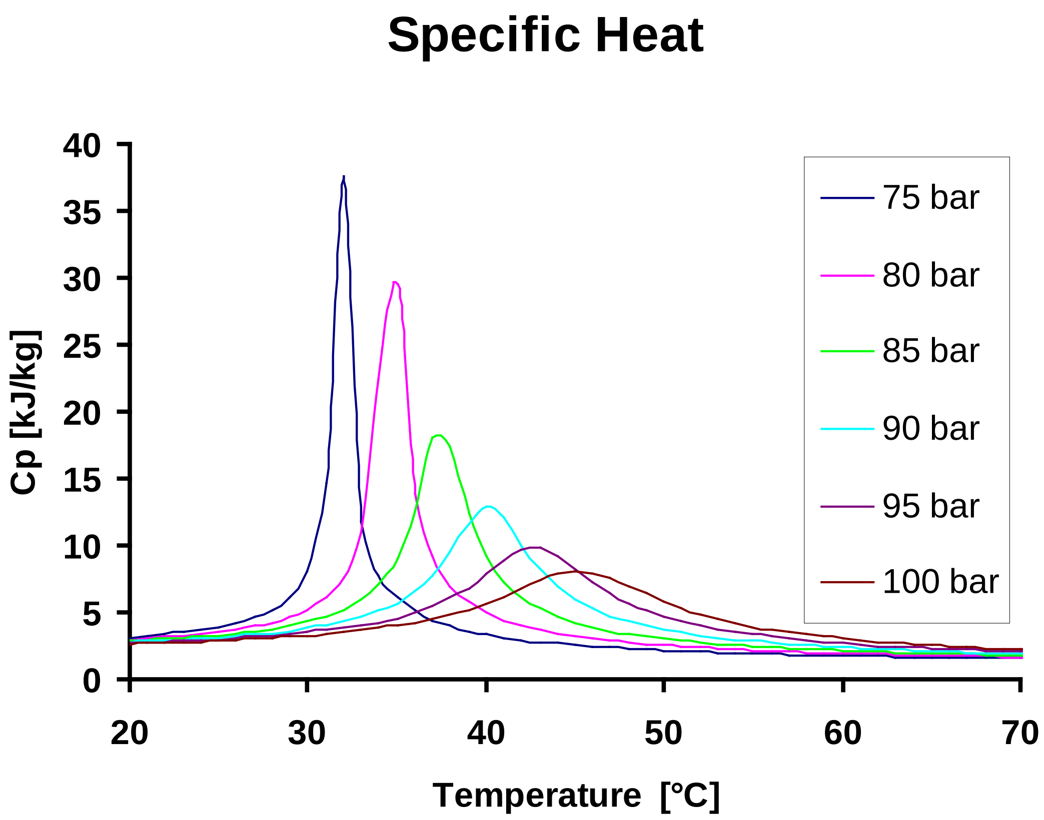


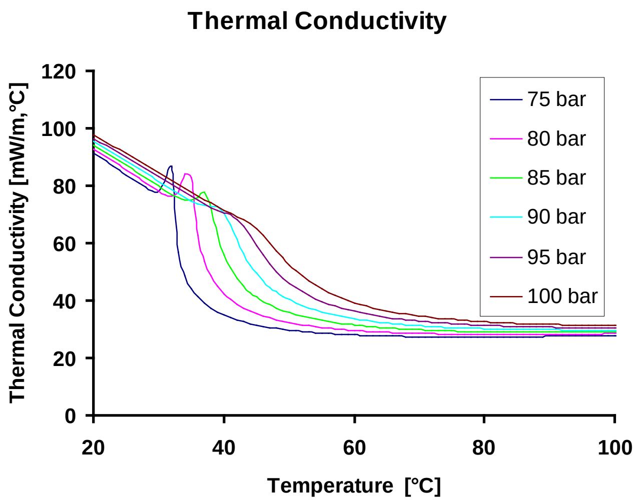
Using LMTD requires:

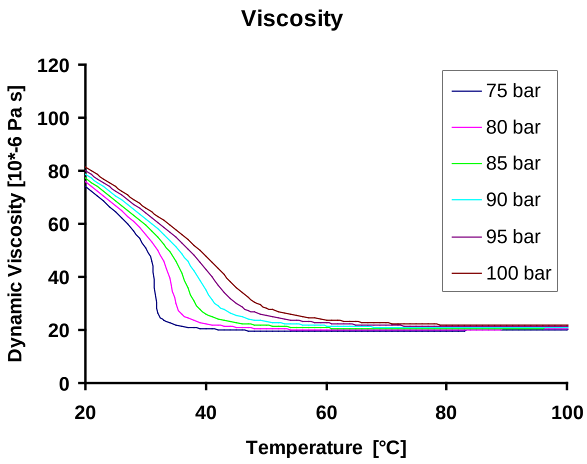
- Constant heat transfer coefficients
- Constant physical properties



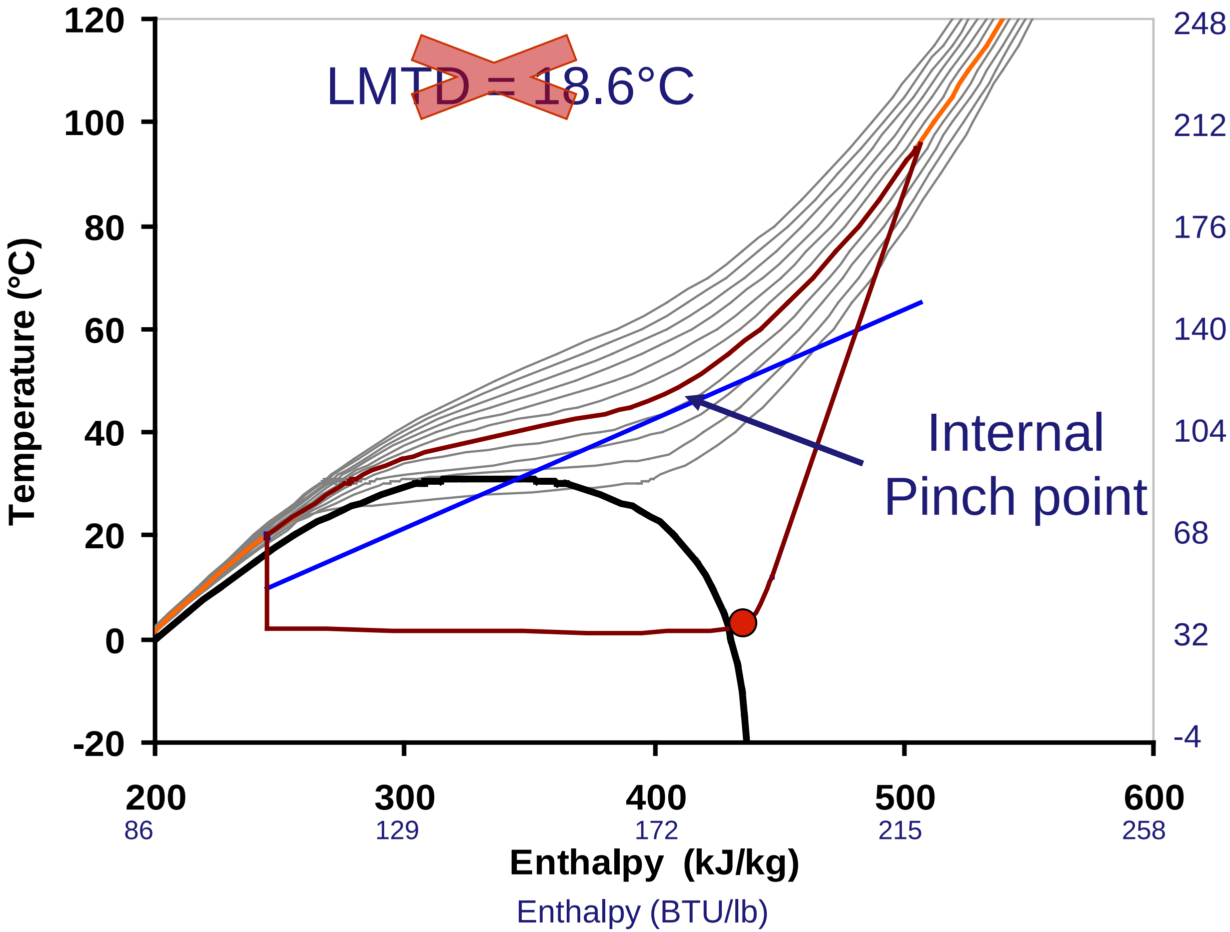
Properties for transcritical CO_2

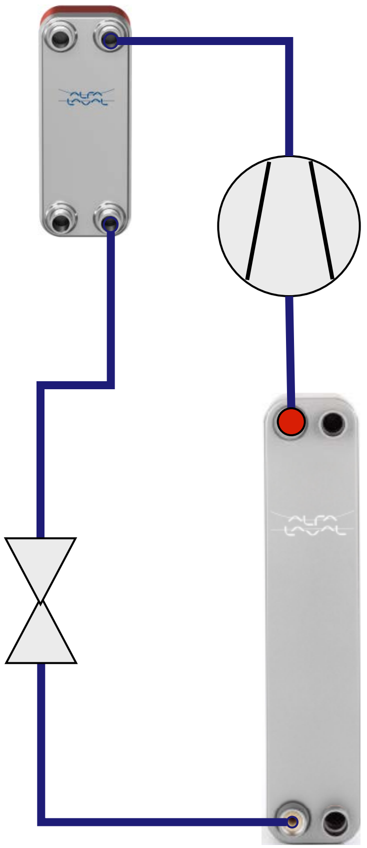






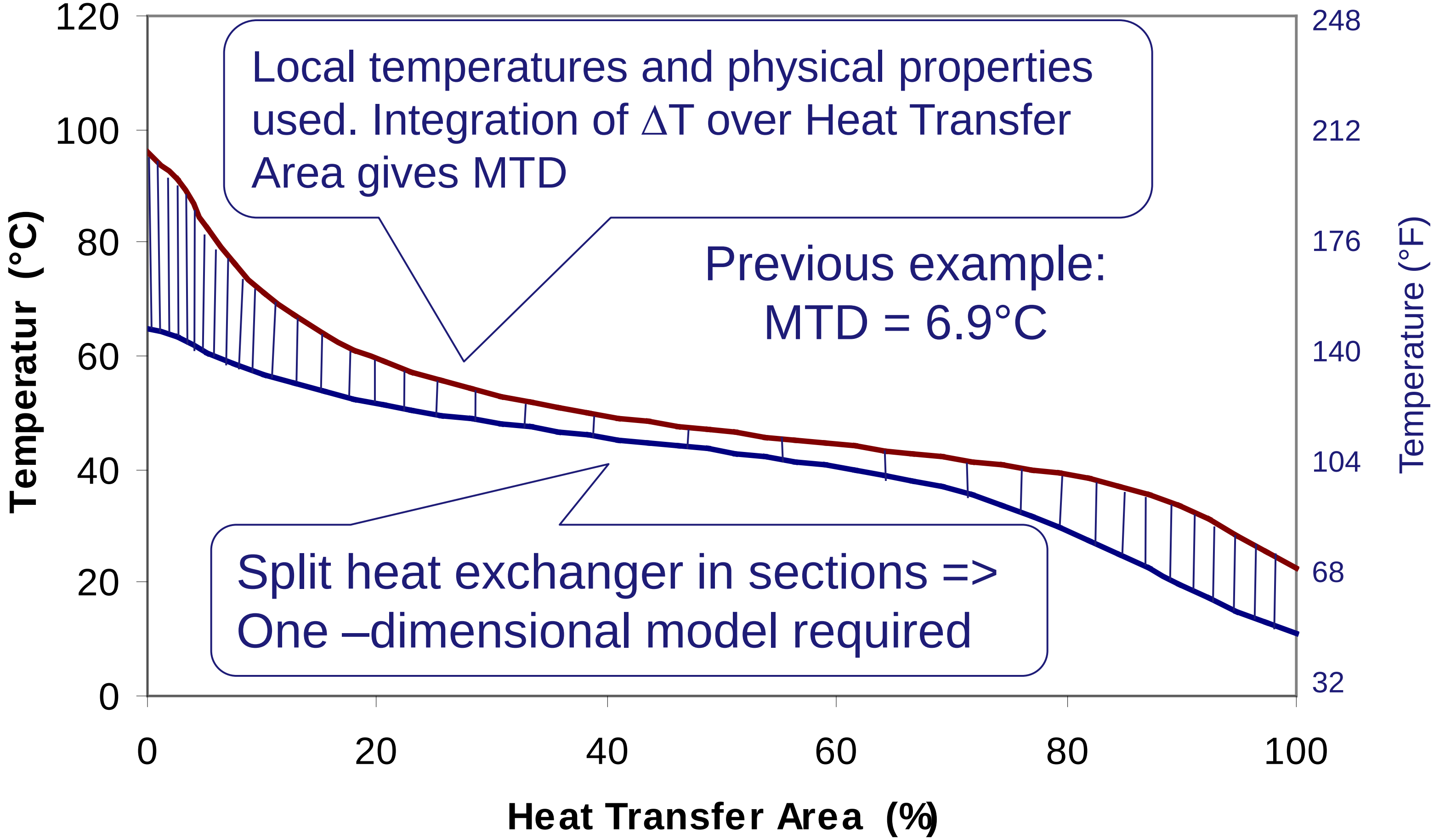
Simple transcritical cycle TH chart
Internal pinch point



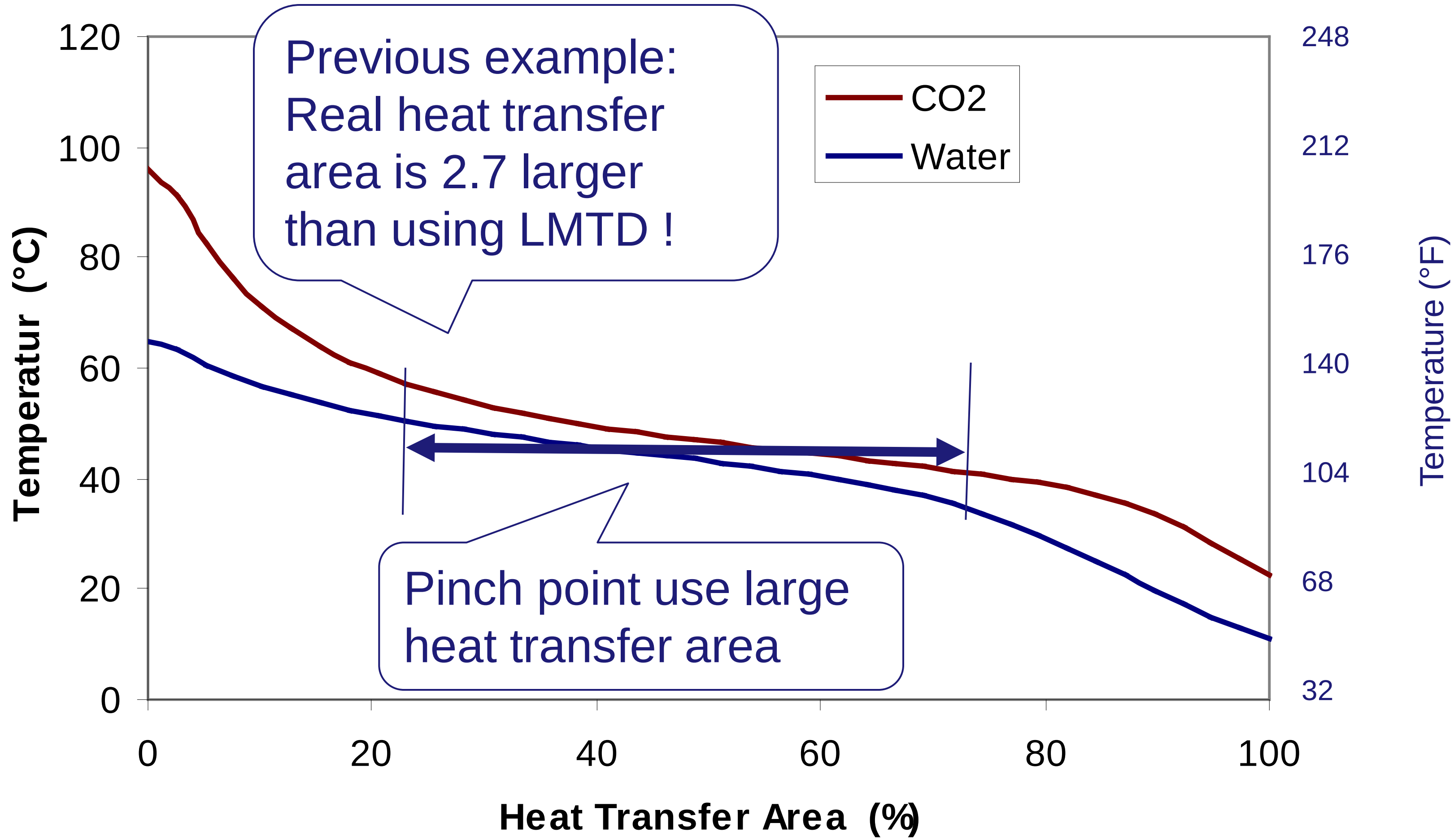


Consequences of pinch point

Heat exchanger design



Consequences of pinch point
Heat exchanger design



Heat Exchanger Design

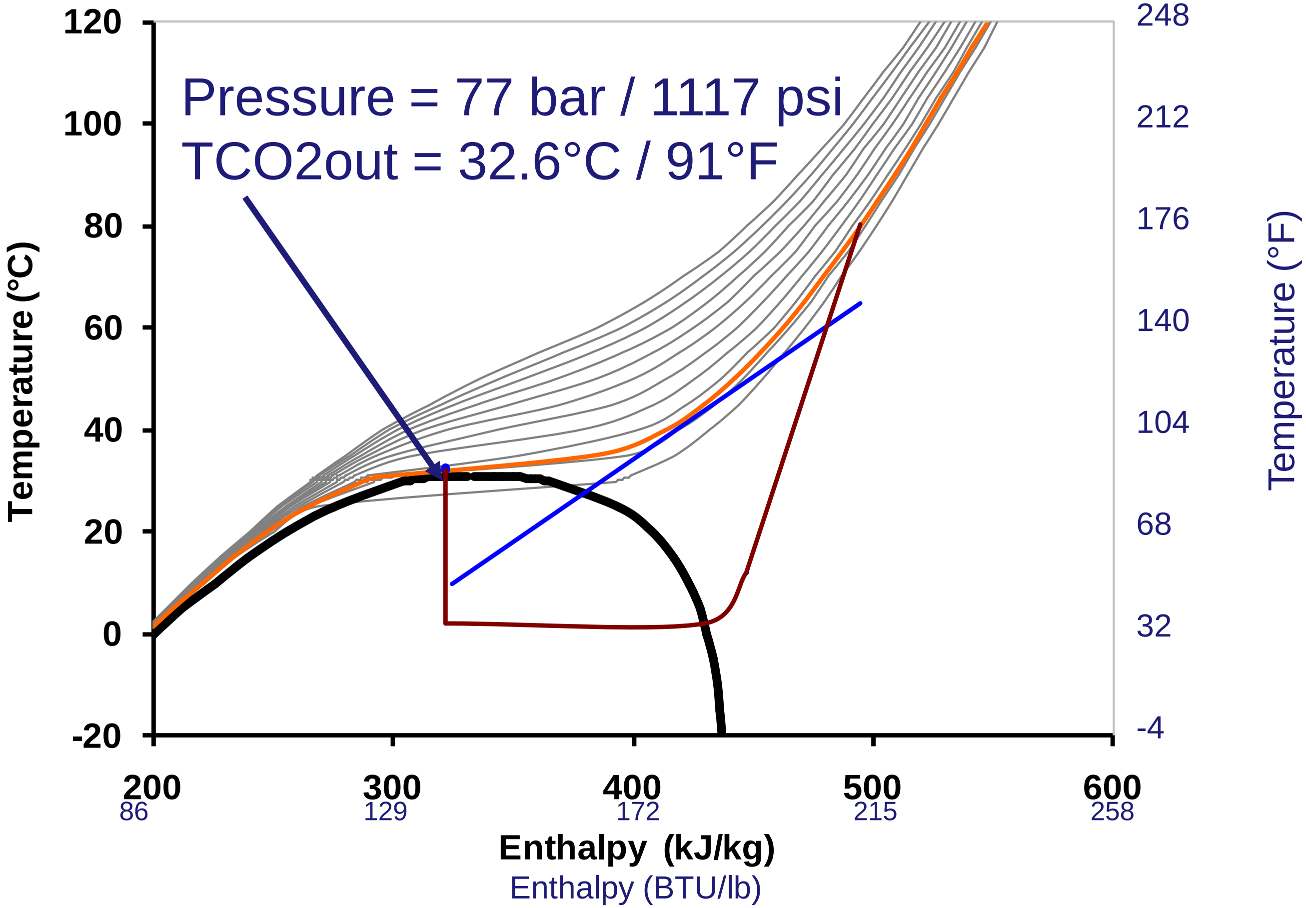
Water heating

- Heating water from 10 to 65°C (50 to 149°F)
- What is the optimum operating pressure?
- What is the minimum approach temperature for different operating pressures?
- What is optimum COP?

Consequences of pinch point

Minimum CO_2 outlet temperature

Twin= 10°C, Twout = 65°C, Pinch point = 1°C
Twin= 50°F, Twout = 149°F, Pinch point = 1.8°F



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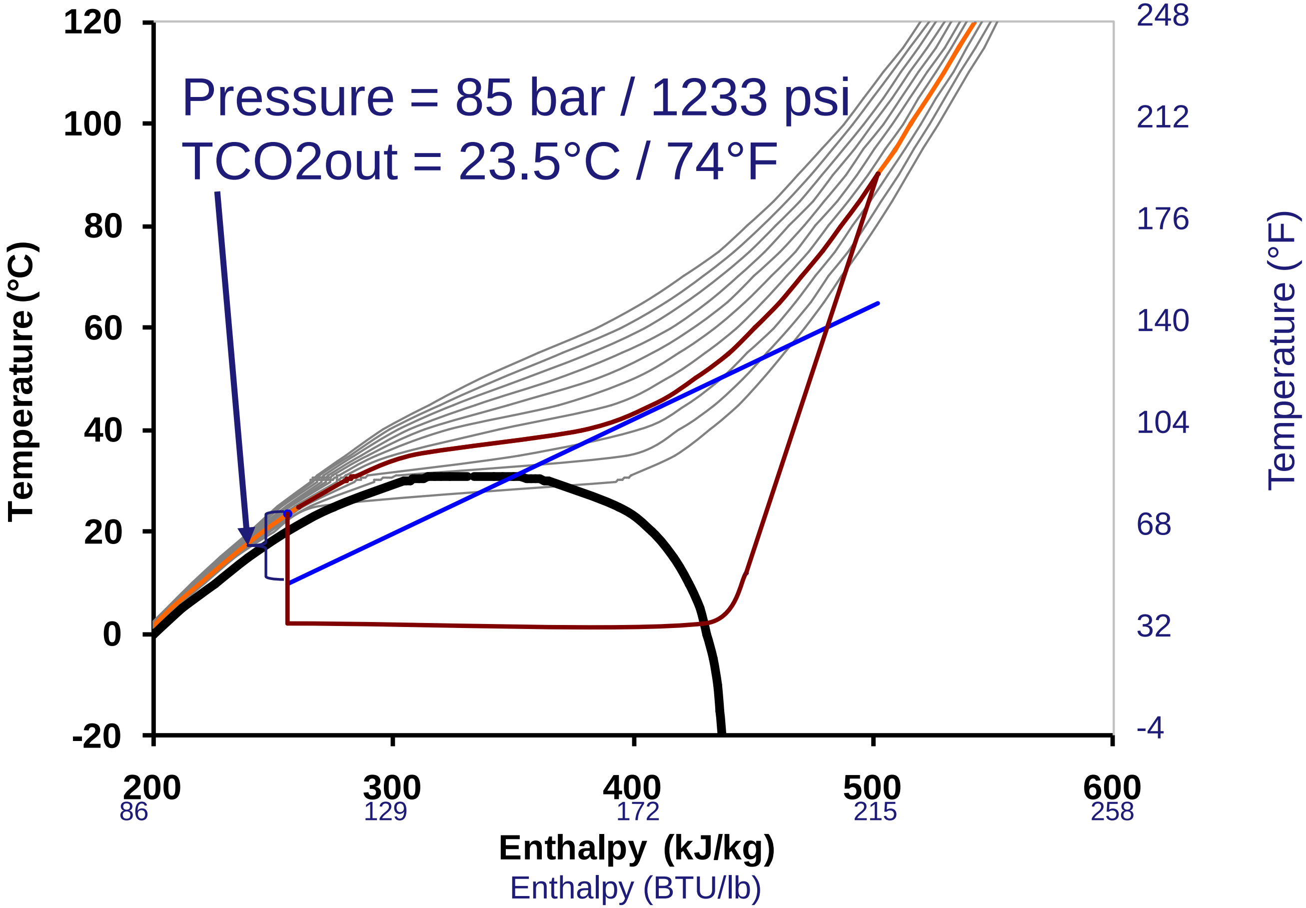

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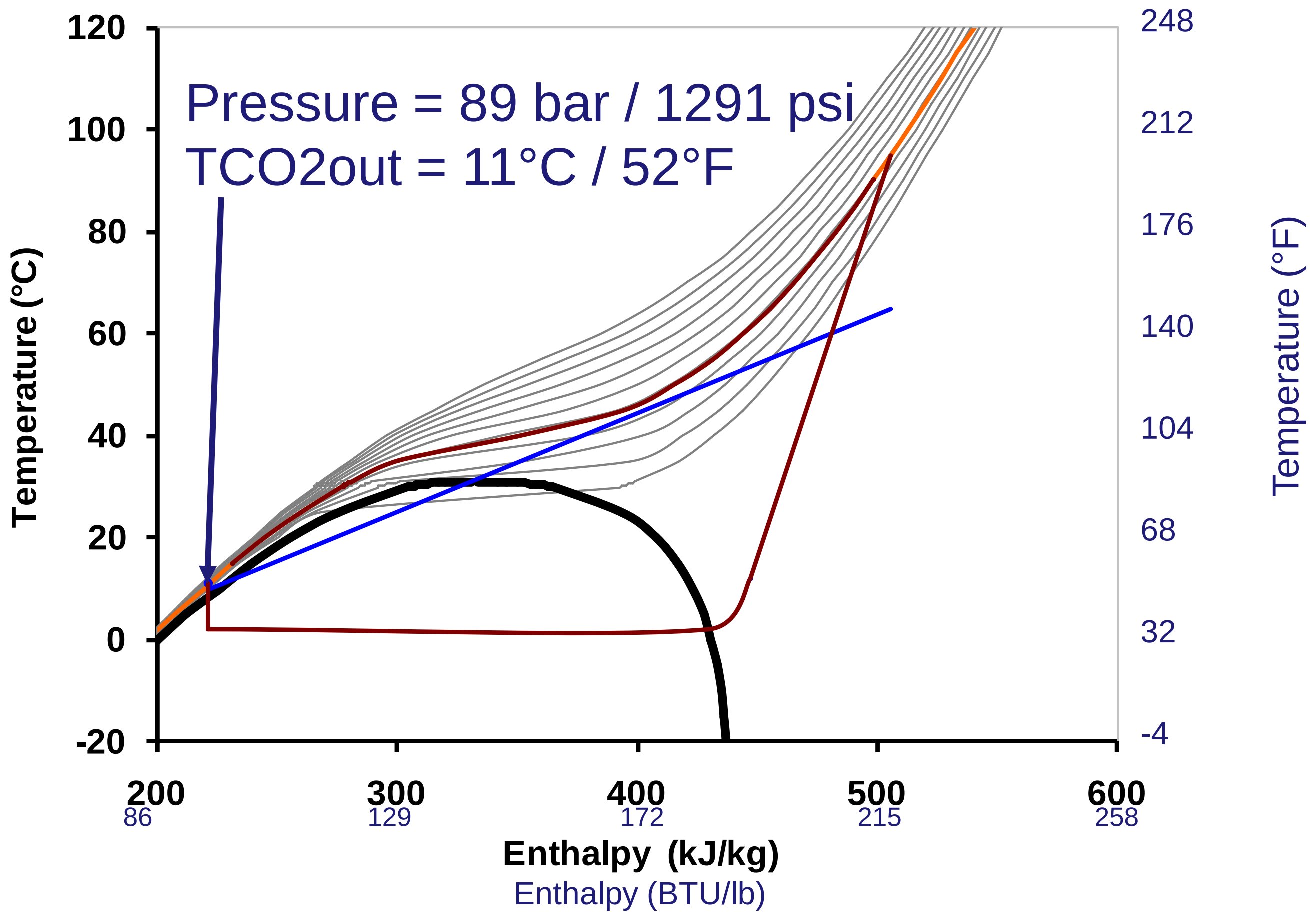
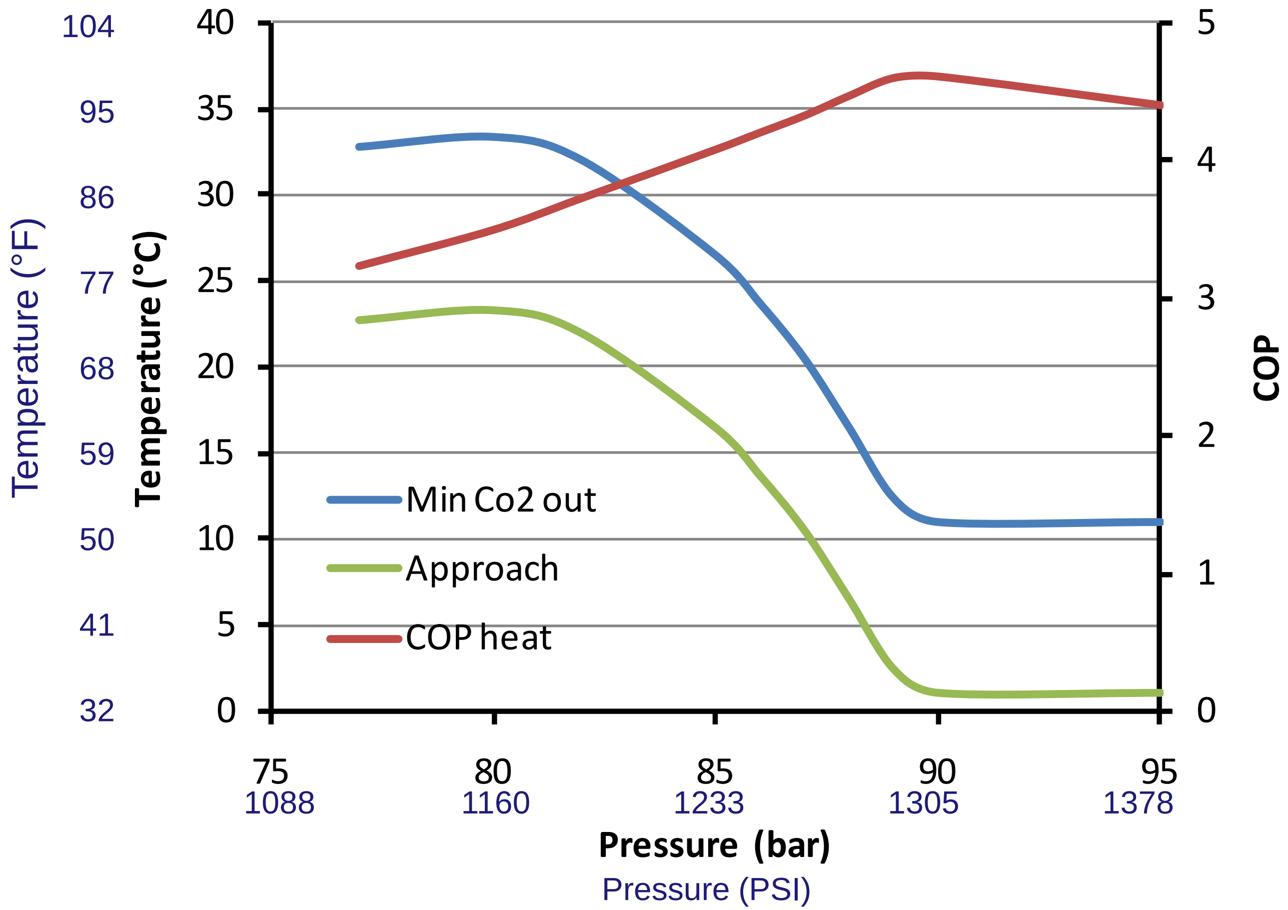


Consequences of pinch point

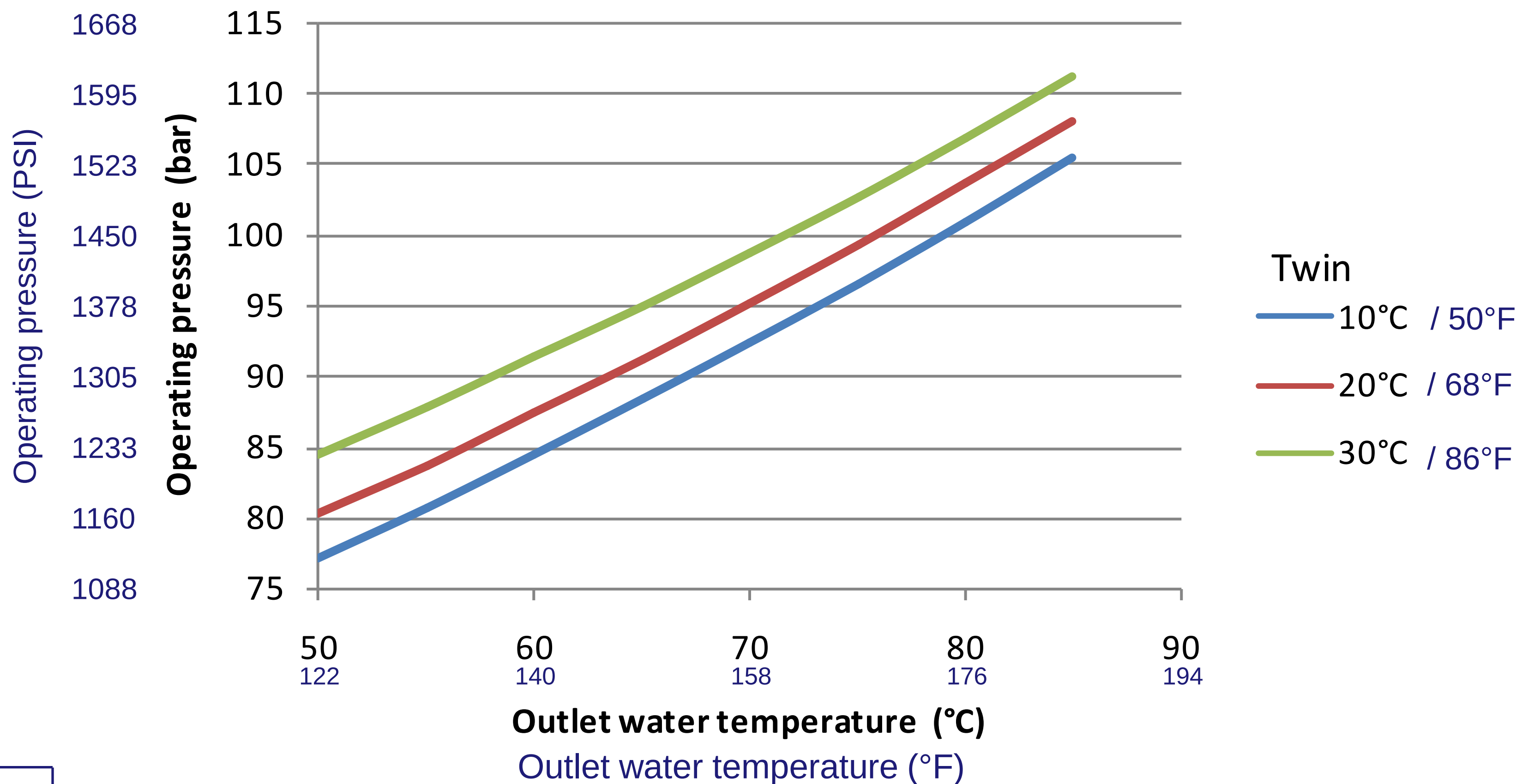
CO2 outlet temp and COP

Twin= 10°C, Twout = 65°C, Pinch point = 1°C
Twin= 50°F, Twout = 149°F, Pinch point = 1.8°F



Consequences of pinch point
Minimum operating pressure

Required operating pressure to obtain 1°C (1.8°F) approach @ a pinch point of 1°C (1.8°F) for various inlet and outlet water temperatures

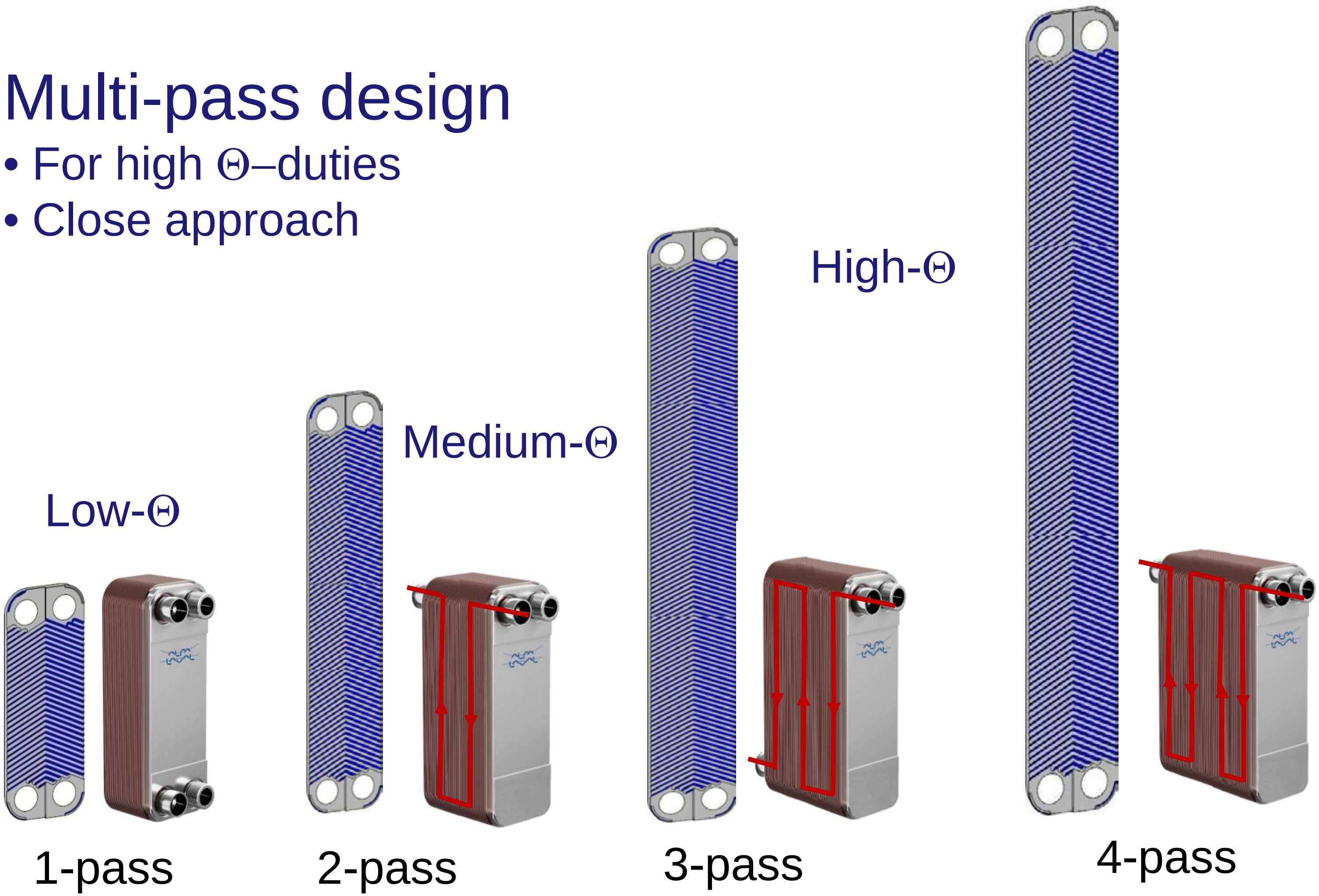


Consequences of pinch point

Multipass design- effective length

Multi-pass design

- For high Θ–duties
- Close approach

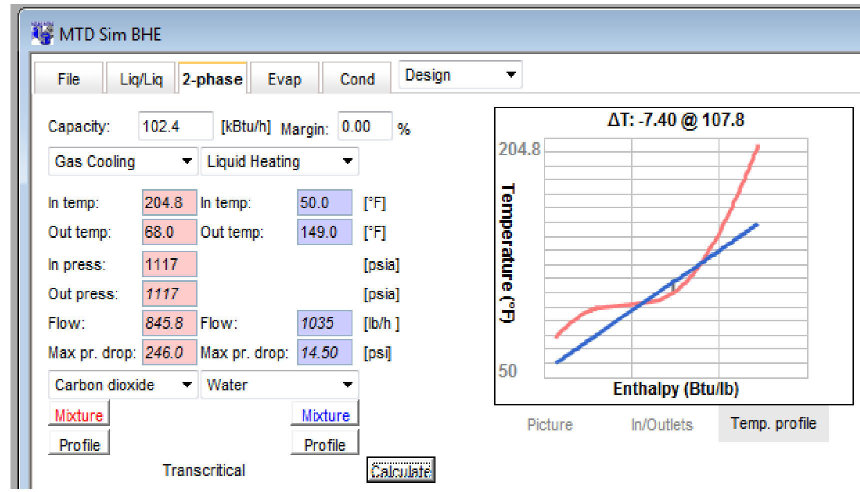


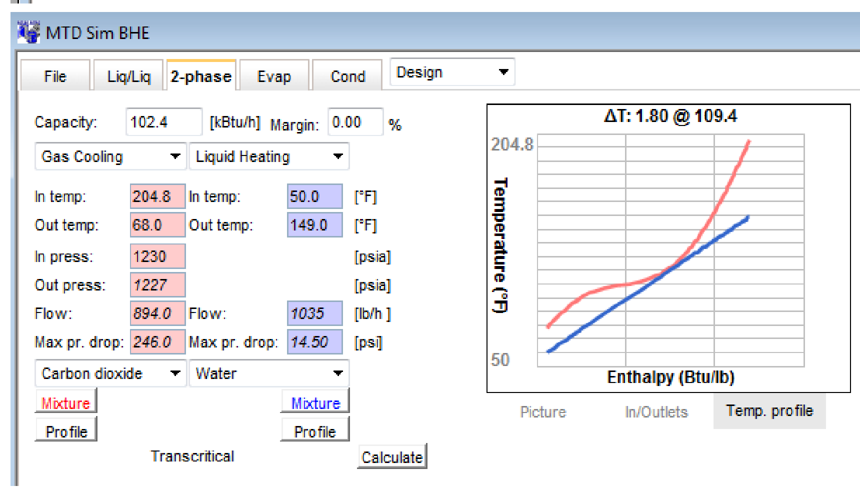
Transcritical CO_2 portfolio

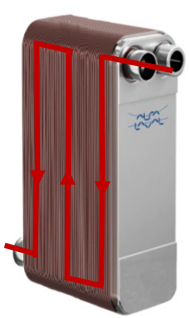
	AXP10	AXP14	CBXP27	CBXP52	AXP27	AXP52	CBXP112
Capacity kW	**2-15**	**10-35**	**40-70**	**40-100**	**10-100**	**30-150**	**100-300**
PS bar @ 150°C	**154**	**140**	**90**	**90**	**130**	**130**	**85**
Release	**Sept 2009**		**April 2010**		**June 2010**		**Soon 2014**

Consequences of pinch point
Heat exchanger design

- **Design calculation requirements**
  - Use TH chart to check that internal pinch point is positive and determine minimum operating pressure
    - Liquid flow rate (temperature program)
  - Segmented model required
    - High accuracy => 100 sections
    - Local physical properties
    - Using NIST / Refprop
    - Multipass calculations with coupling factor







Summary

- Use the TH chart in Refrigeration !
- To have successful transcritical CO_2 heat pump performance :
  - The operating pressure must be chosen with consideration to the thermal duty
  - The heat exchanger design can NOT be based on LMTD method
  - Segmented model with local physical properties must be used
  - Gas coolers should be long and slim, high-Θ.
- Close approach at the pinch point and outlet => large heat transfer area
  - Balance between first cost and perfomance can be made by selecting appropriate operating pressure.

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Thank you very much!