# Optimisation of Compact Heat Exchangers for Thermal Energy Storage

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Heatric

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# CURRENT EXPERIENCE

## **HEATRIC'S** INVOLVEMENT INTO ENERGY STORAGE CONCEPTS TO DATE

Heatric

# Thermal Energy Storage Enquiries Timeline

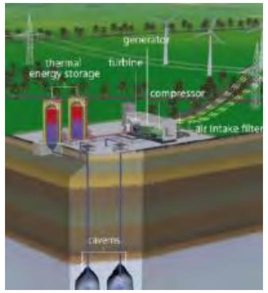
## 2009 - Present

**2009**

Test units for the first Cryobattery Project in the UK (Highview Power)

**2011**

FEED study for large scale CAES project in Germany




**2012**

FID study for TEES system in Switzerland

**2013**

Pre-FEED study for large scale Molten-Salt - sCO2 projects in the US

**2014**

Demonstration units for the first Cryobattery Project in the UK (Highview Power)

**2019**

Energy Storage is back thanks to the Duck-Curve

**2021**

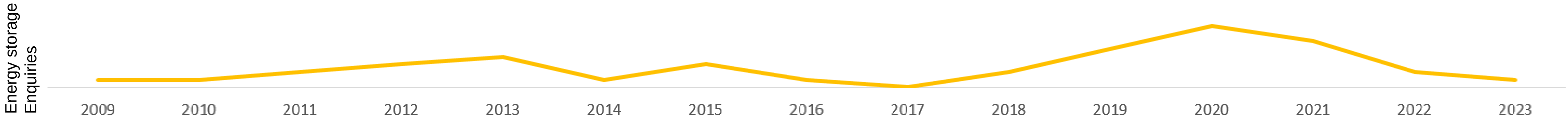
First large scale commercial plant – Heat pump based on Everllence ETES Energy storage

**2023**

Several major projects in FEED – FID phase for 2023-24 build

**2025**

300MWh Highview LAES Plant Under construction in Manchester UK

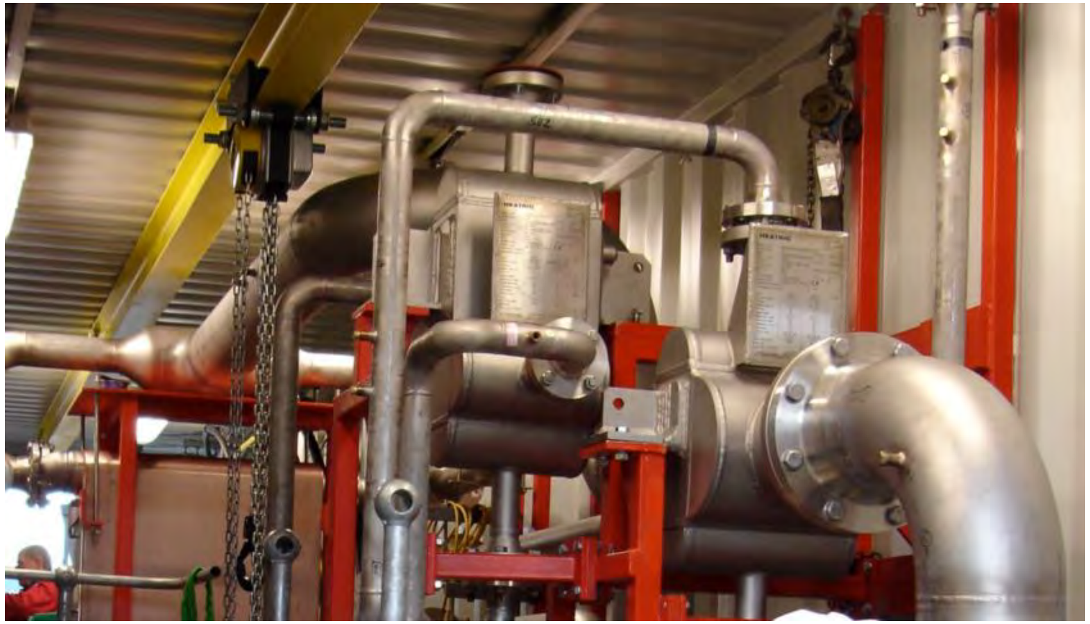


# CRYOGENIC STORAGE – HIGHVIEW POWER

## 2009 – 2019: Proving and validating the Technology

### 2009 – 2013: Slough test site

- Proof of concept successful with operation until site closure 2013
- 3 exchangers supplied



Slough test site PCHEs

### 2014 – 2019: Bury Viridor Demonstration site

- Demonstration plant successfully operated until site closure 2019
- 2 exchangers supplied

Bury Demo site Evaporator and HX1 (front)

# CRYOGENIC STORAGE – HIGHVIEW POWER

## 2025: Carrington 300MWh LAES

**50 Mwe – 6 hours duration - £325m Total financing**

- Ability to charge and discharge at the same time
- Plans to develop four new 2.5GWh power plants in the UK by 2030



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# HEAT EXCHANGERS FOR ENERGY STORAGE

## REQUIREMENTS

## DESIGN OF HEAT EXCHANGER

# REQUIREMENTS

## The ideal heat exchanger … can it be done?

- There has been an increase in customers asking us for Long Duration (10/100's MWhrs) energy storage heat exchangers.
- Such exchangers, which easily require 1,000s $m^2$ of heat transfer, are required to deliver many if not all of the following:

1. High Performance to maximise OPEX by increasing RTE (Round Trip Efficiency) / minimise losses*
2. Compact and light to facilitate integration into tight space / remote area / reduce installation cost
3. Fast Thermal Response to minimise start-up time to optimal operating conditions
4. Robust, but depending on cycles and / or storage medium:
    - high pressures
    - high temperatures
    - Corrosion
    - Aperture size / pressure drop
5. Made in large size / quantities / modularised
6. Cheap to reduce overall CAPEX

# REQUIREMENTS

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# WHAT IS A HEAT EXCHANGER (INDIRECT CONTACT)

**Wikipedia:**

- A **heat exchanger** is a system used to transfer heat between a source and a working fluid. Heat exchangers are used in both cooling and heating processes.[1] The fluids may be separated by a solid wall to prevent mixing or they may be in direct contact.[2] They are widely used in space heating, refrigeration, air conditioning, power stations, chemical plants, petrochemical plants, petroleum refineries, natural-gas processing, and sewage treatment.

**AI Overview (Google):**

- A heat exchanger is a device that facilitates heat transfer between two or more fluids (liquids or gases) without direct mixing of the fluids. It is designed to efficiently transfer thermal energy from a hotter fluid to a cooler one, or vice versa, and is used in a wide range of applications, including heating, ventilation, air conditioning, refrigeration, and various industrial processes.

**Primary function of an indirect heat exchanger is:**

- to transfer heat between fluids flowing through the heat exchanger while kept separated from mixing

# SOME BASICS OF HEAT EXCHANGE SIZING

## Duty, Overall Heat Transfer Coefficient

The amount of heat that can be exchanged in a heat exchanger is expressed as follow:

**Q = m x cP x dT**

Q – Heat Duty (kW/s)

M – Mass flow (kg/s)

cP – Heat capacity (J/kg-1 C-1)

dT – Temperature change between inlet and outlet of one side (K)

For the same heat duty, increasing **dT** will help reduce **M** thus the size of the exchanger and in principle its cost

And can be expressed as follow:

**Q = U x A x LMTD**

Q – Heat Duty (kw/s)

U – Overall Heat Transfer coefficient (W/m2.K)

A – Heat Transfer Area (m2)

LMTD – Logarithmic average Mean Temperature Difference (K)

For the same heat duty, increasing **A** will help reduce **LMTD** and increase amount of heat transferred

# SOME BASICS OF HEAT EXCHANGE SIZING

## Duty, Overall Heat Transfer Coefficient

The overall heat transfer coefficient is expressed as follow:

**U = 1 / (1/h1 + t/k + 1/h2)**

U – Overall Heat Transfer coefficient (W/m2.K)

h1 – local convective heat transfer coefficient of fluid 1 (W/m2.K)

t – wall thickness between fluids (m)

k – thermal conductivity of the wall material (W/m.K)

h2 - local convective heat transfer coefficient of fluid 1 (W/m2.K)

The heat transfer rate is expressed as follow:

**Q(t) = (k x A x (T1 – T2) / t**

Q(t) – Rate of heat transfer (w/s)

k – thermal conductivity of the wall material (W/m.K)

A – Heat Transfer Area (m2)

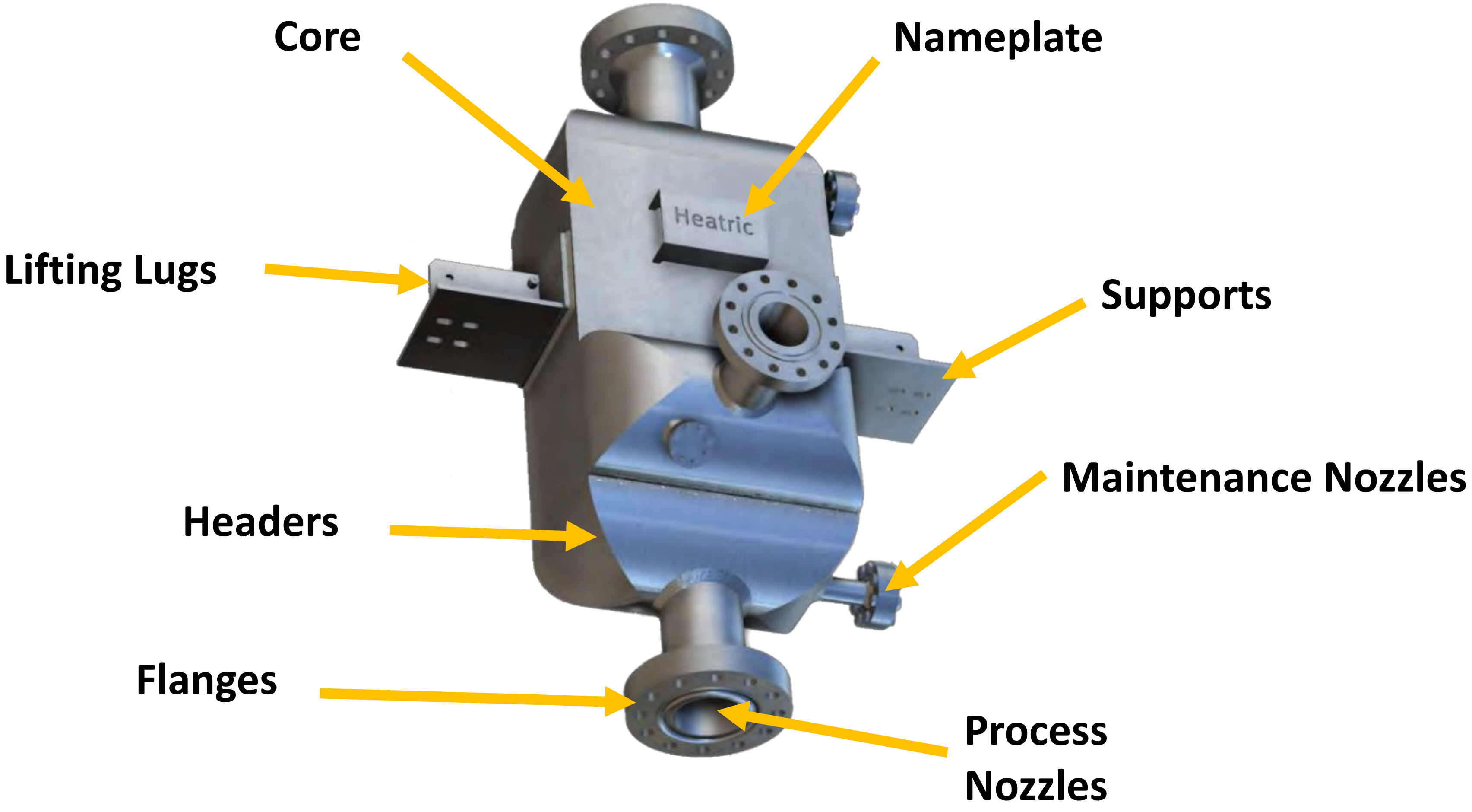
T1-T2 – temperature difference between fluids (K)

t – wall thickness between fluids (m)

To increase Q(t), one can increase **A**, **T1-T2** or reduce **t**

| Fluid | Material in Transmission Surface | Fluid | Overall Heat Transmission Coefficient - U - | |
|---|---|---|---|---|
| | | | *(Btu/(ft$^2$ hr $^o$F))* | *(W/(m$^2$ K))* |
| Water | Cast Iron | Air or Gas | 1.4 | 7.9 |
| Water | Mild Steel | Air or Gas | 2.0 | 11.3 |
| Water | Copper | Air or Gas | 2.3 | 13.1 |
| Water | Cast Iron | Water | 40 - 50 | 230 - 280 |
| Water | Mild Steel | Water | 60 - 70 | 340 - 400 |
| Water | Copper | Water | 60 - 80 | 340 - 455 |
| Air | Cast Iron | Air | 1.0 | 5.7 |
| Air | Mild Steel | Air | 1.4 | 7.9 |
| Steam | Cast Iron | Air | 2.0 | 11.3 |
| Steam | Mild Steel | Air | 2.5 | 14.2 |
| Steam | Copper | Air | 3.0 | 17 |
| Steam | Cast Iron | Water | 160 | 910 |
| Steam | Mild Steel | Water | 185 | 1050 |
| Steam | Copper | Water | 205 | 1160 |
| Steam | Stainless Steel | Water | 120 | 680 |

# Key Components of a Heatric PCHE







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# HEAT EXCHANGE DESIGN PHASES

## Material selection

- Client requirement
- Availability of product form and grade
- Cost
- Mechanical and thermal strength
- Corrosion resistant
- Manufacturability (weldability and formability)

## Thermal design

- All required thermal calculations and fouling
- Plate and core sizing
- Flow pass configuration
- Design with multi-streams, if required
- Ensure maldistribution is avoided
- Optimizing to minimize cost vs. performance

## Hydraulic design

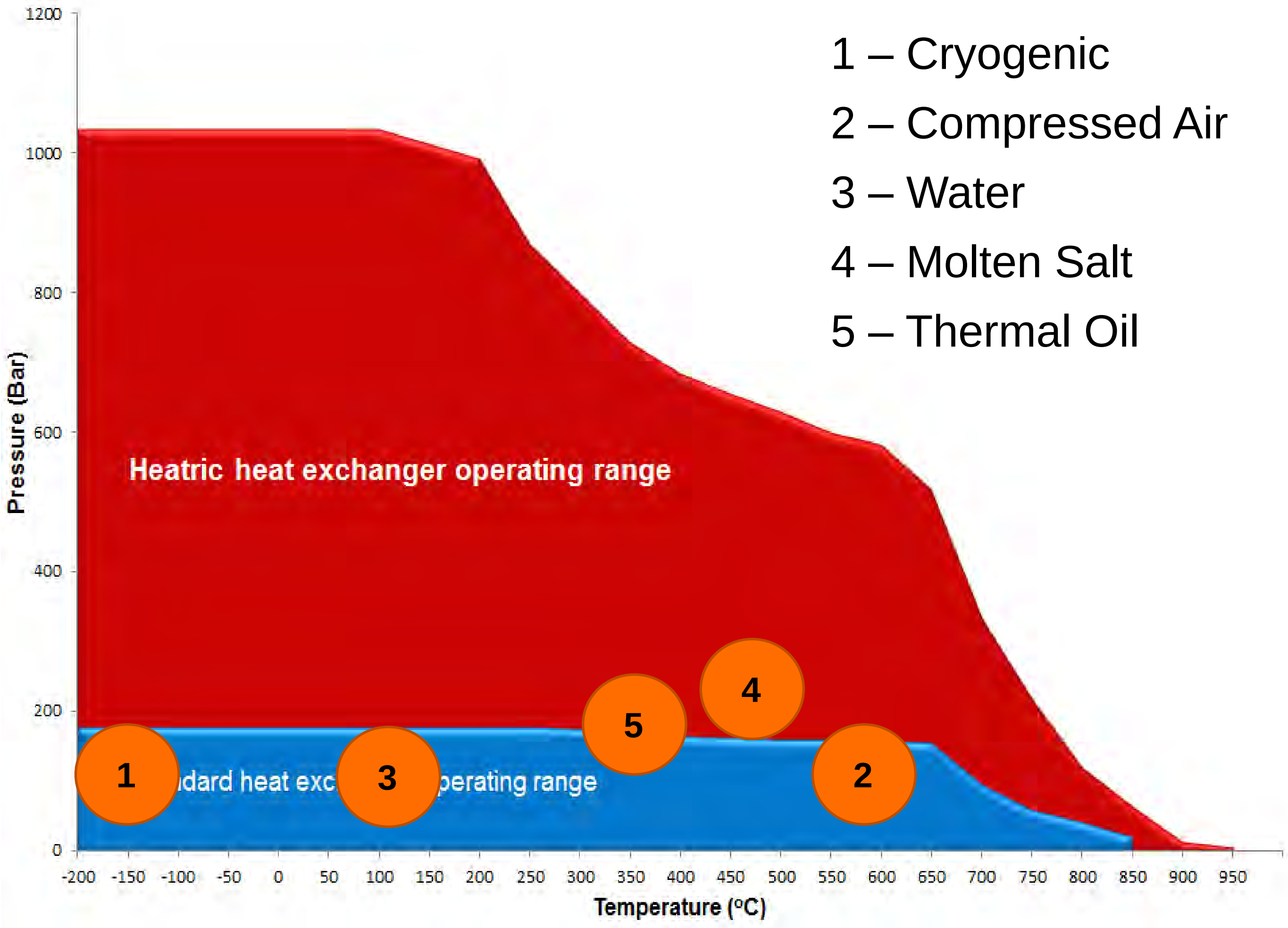
- Mass flow rate
- Overall pressure drop calculation
- Component losses (core, nozzles, headers)
- Other losses on components (manifolds, elbows), due to glycol or liquid injection and two-phase distributors if any)

## Mechanical design

- Thermal and hydraulic design input
- Client design requirements
  - Basic design condition (pressure, temperature)
  - External loads (nozzle loads, wind, snow, motion)
- Design to Code rules (e.g. ASME BPVC VIII-1)
- FEA - if required or design not covered by Core rules
- Creep and Fatigue analysis, if required
- Other specific loading condition

# 1) MATERIAL SELECTION

## Storage mediums and process conditions dictates choice of materials

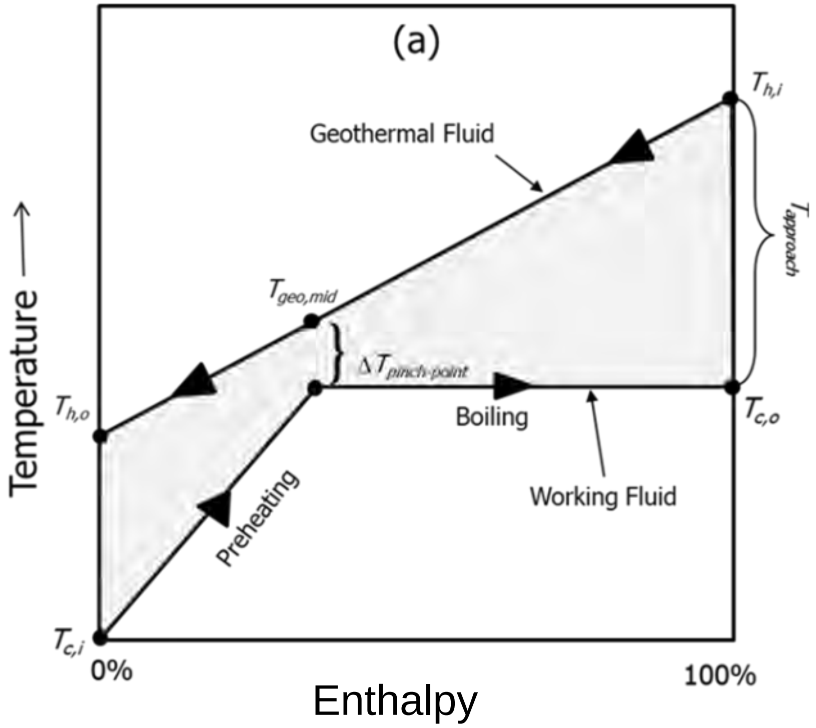


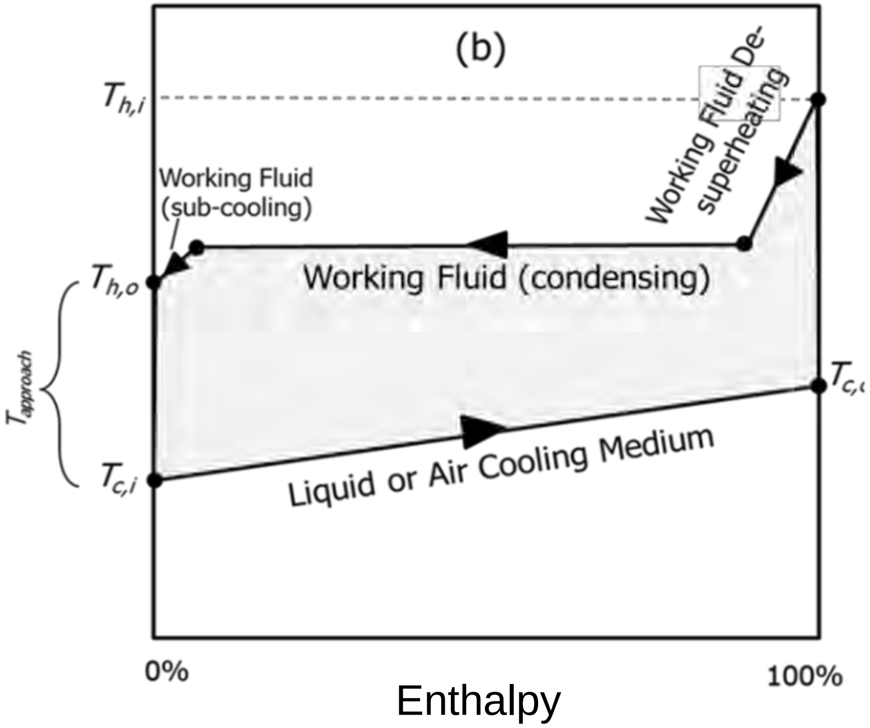

1 – Cryogenic
2 – Compressed Air
3 – Water
4 – Molten Salt
5 – Thermal Oil

1 – SS316
2 – SS316
3 – SS316
4 – SS347
5 – SS316

# 2) THERMAL DESIGN

## A - Process conditions and associated fluid properties (Heat Release Curves)




We need:

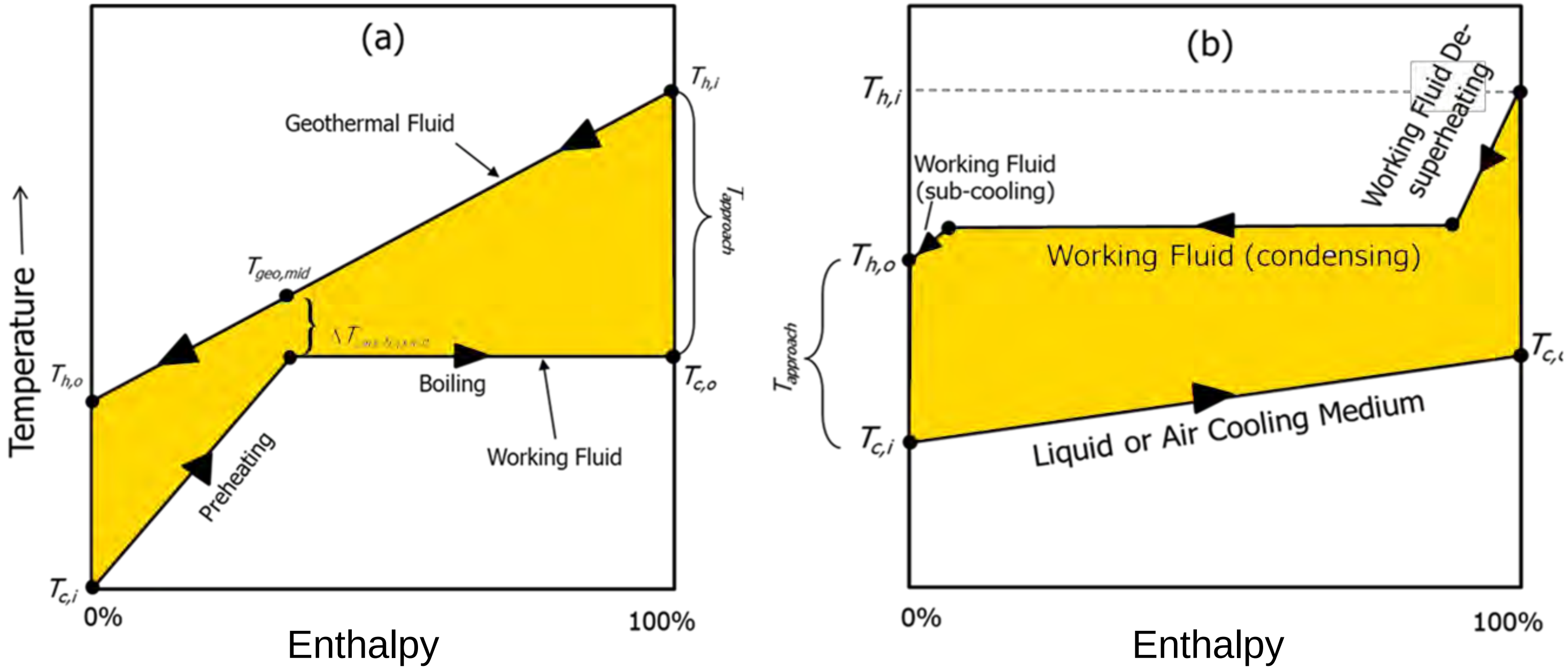
- Fluids
- Inlet and outlet temperatures
- Mass Flow rates
- Inlet Pressures
- Allowable Pressure Drops

We get:

- Heat Capacity (cP)
- Thermal Conductivity (k)
- Density (ρ)
- Viscosity (μ)

# 2) THERMAL DESIGN

## A - Process conditions and associated fluid properties (Heat Release Curves)



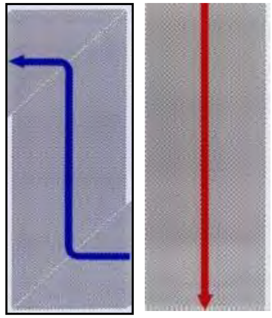

**Q = U x A x LMTD**

**Q = m x cP x dT**

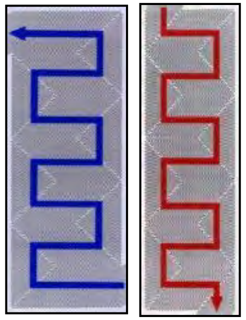
# 2) THERMAL DESIGN

## B – Flow configuration / plate arrangement

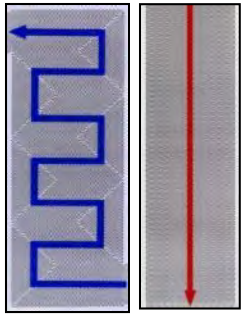
Counter flow



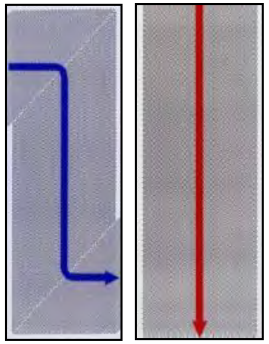
Multipass counter flow



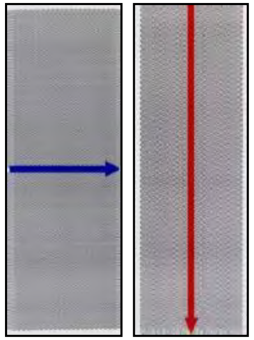
Multipass counter-cross flow



Parallel flow

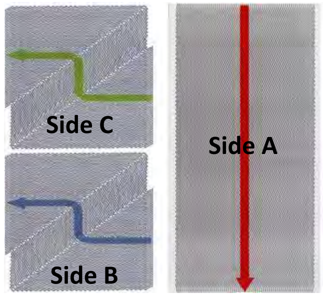


Cross flow

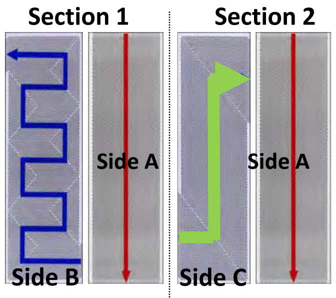


$$Q(t) = (k \times \underline{A} \times (T1 - T2) / t$$

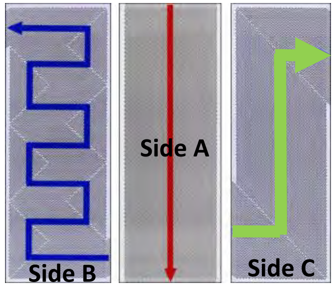
Series




Parallel




Interleaved




# 3) HYDRAULIC DESIGN

## Pressure drop (ΔP)

- Distribution through PCHEs:
  - **Active Core** → min. 50% of the total calculated $\Delta P_{TOTAL}$.
  - **Header** - **Nozzles** → dynamic head losses enforced, check for maldistribution
- Due to friction:
  - Pressure drop through the core
  - Treated similarly to loses in pipes
  - PCHE experimental studies on fanning friction factor ($f$)and Re.

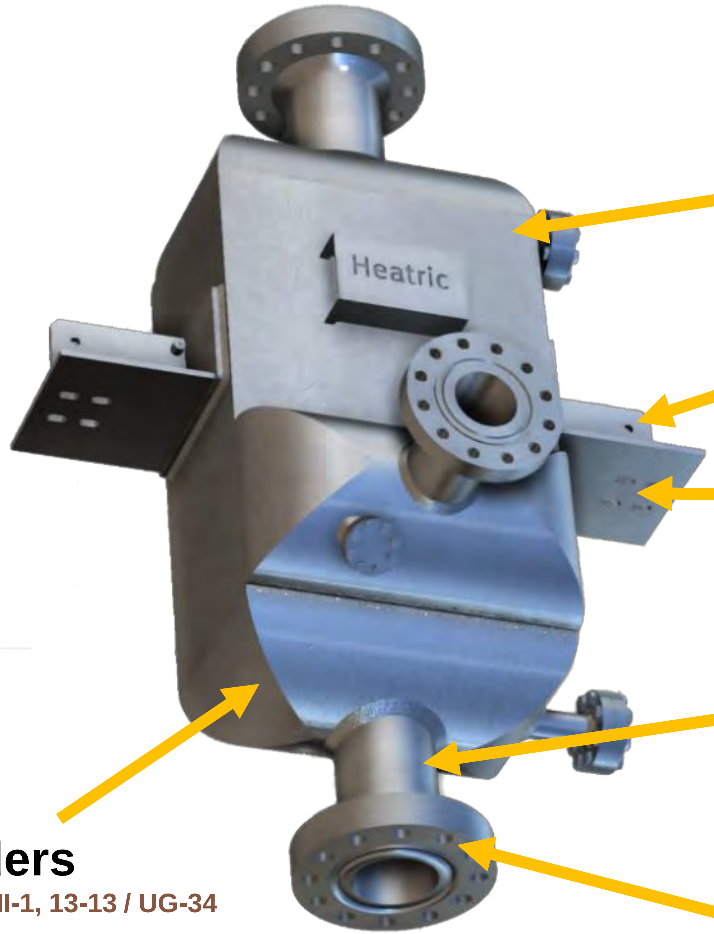
$$\Delta P = \frac{\rho V^2 fL}{2D}$$

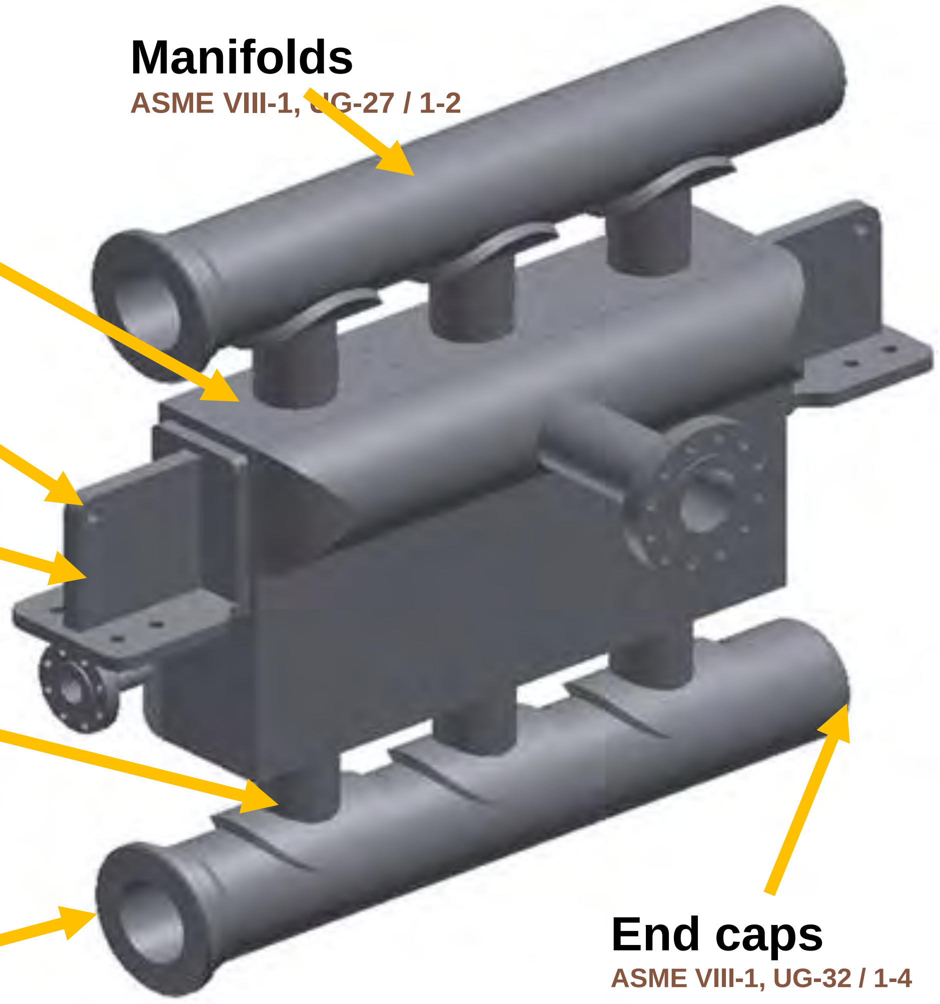
- Due to components geometries:
  - Pressure drop through standard core attachments and additional fittings (elbows, manifolds, etc)
  - Apply the resistance coefficient (K) method
  - Expansion and contraction → most commonly used

$$\Delta P = KV_{head}$$

# 4) MECHANICAL DESIGN

## Key Components



**Manifolds**
ASME VIII-1, UG-27 / 1-2

**Core**
ASME VIII-1, MA-13, 13-9

**Lifting Lugs**
Structural Design Rules
DNV 2-7.3

**Supports**
Structural Design Rules

**Nozzles**
ASME VIII-1
- Reinforcement:
  ASME VIII-1 and ASME VIII-2, Part 5 - FEA
- External loads:
  ASME B31.3, ASME VIII-2, Part 5 - FEA

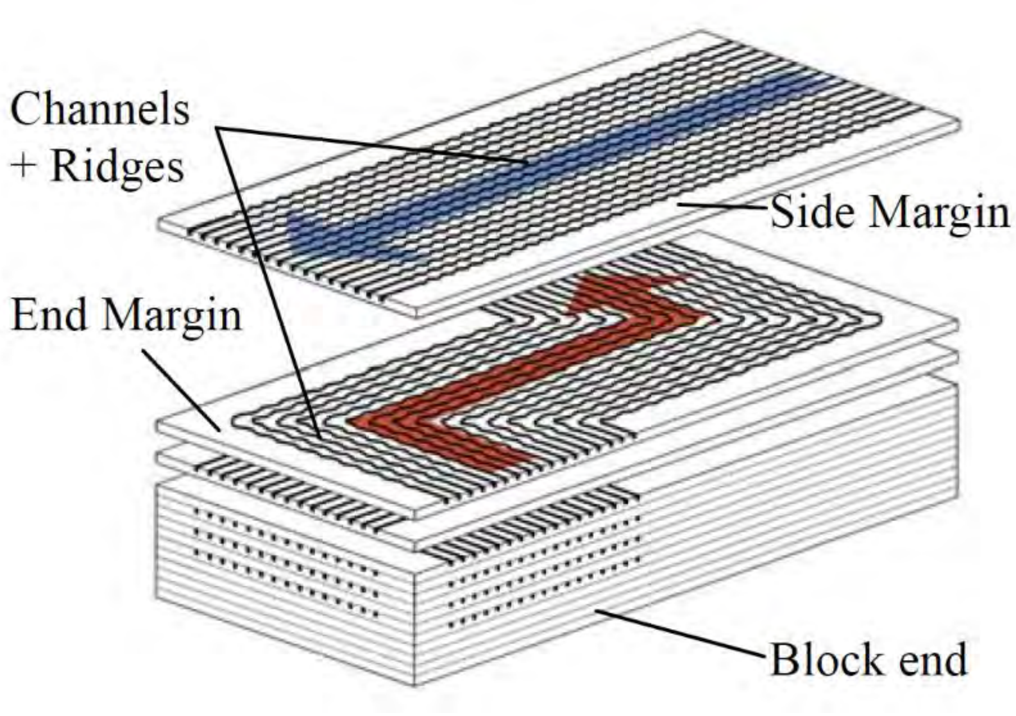
**Headers**
ASME VIII-1, 13-13 / UG-34

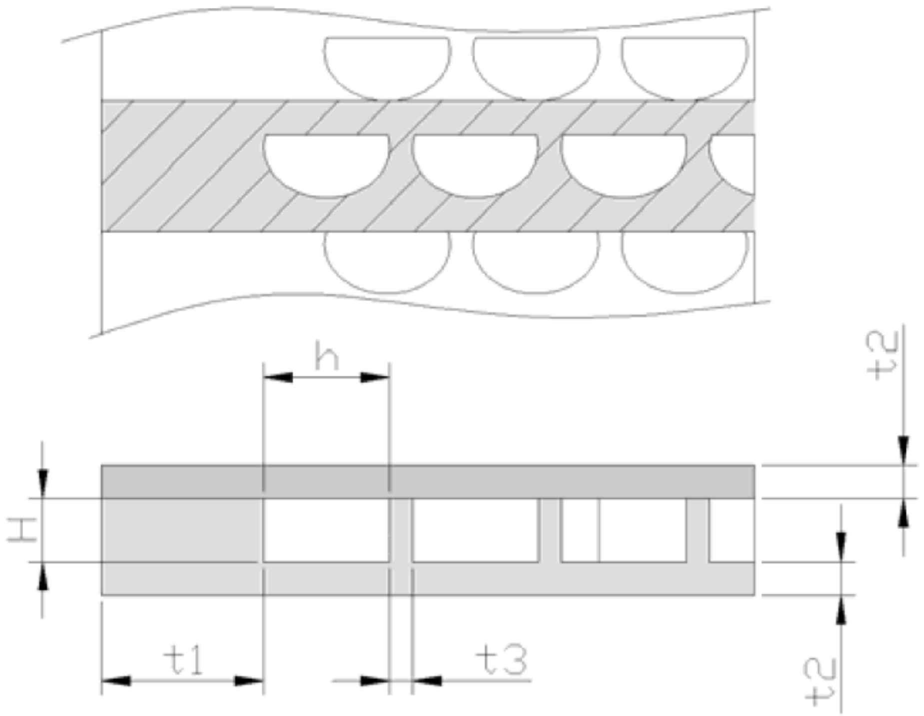
**Flanges**
ASME B16.5
ASME VIII-1, MA-2
SPO
Teklok

**End caps**
ASME VIII-1, UG-32 / 1-4

# Mechanical Design

## Heat exchange



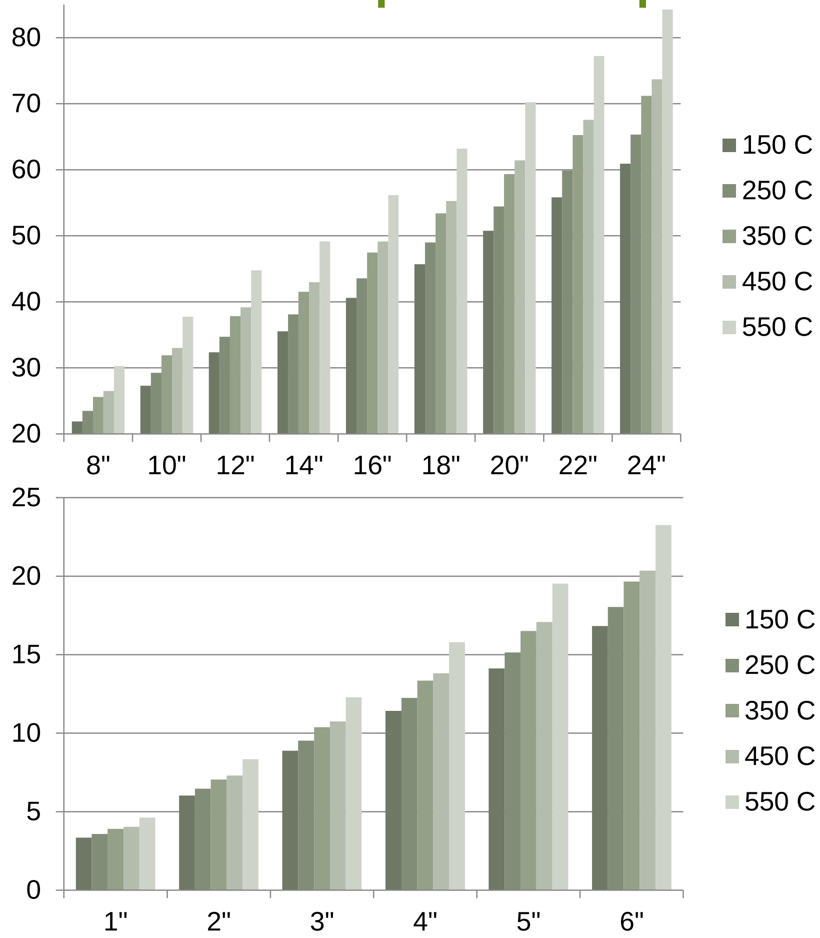

**Q(t) = (k x A x (T1 – T2) / t**

**Q = U x A x LMTD**

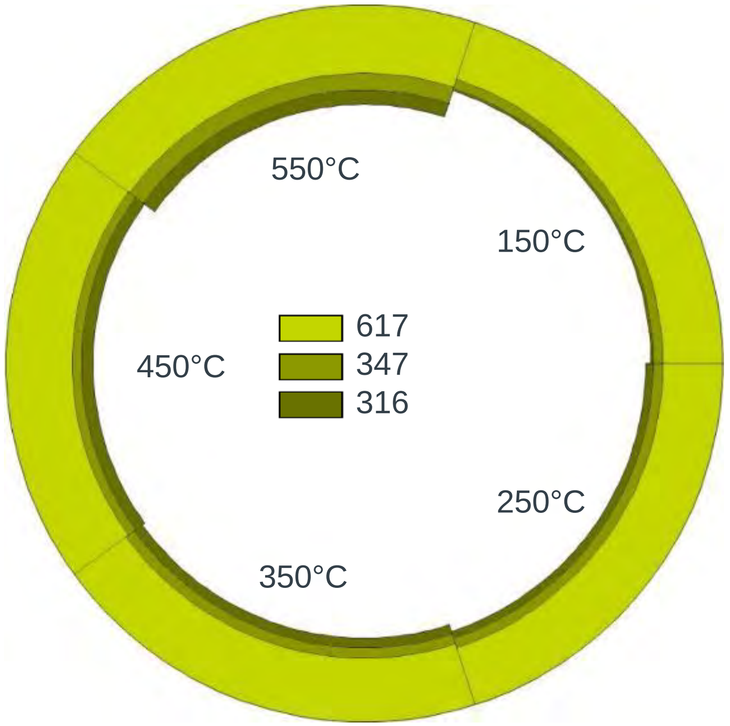
h = channel width
H = channel depth
t1 = edge width
t2 = wall thickness
t3 = ridge width

# Mechanical Design

## Pressure vs Temperature impact

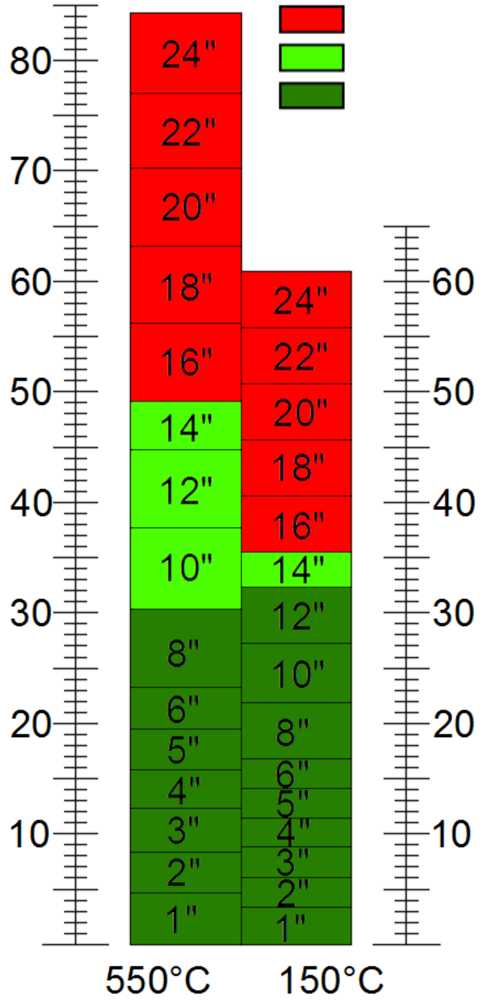



316 Pipe thicknesses vs. design temperature (250 Bar design pressure)




| | 150°C | 250°C | 350°C | 450°C | 550°C |
|---|---|---|---|---|---|
| 316 vs 347 | 3% | 9% | 12% | 13% | 14% |
| 316 vs 617 | 17% | 22% | 24% | 23% | 31% |

316, 347, 617 Pipe thickness reduction vs. temperature (250 Bar pressure)




316 Pipe thickness vs. Std Pipe schedule (250 Bar pressure)

# HIGH EFFECTIVENES IMPACT

## High Performance to maximise OPEX by increasing RTE (Round Trip Efficiency) / minimise losses

How to facilitate highest level of RTE from an exchanger point of view:

- Ensure highest effectiveness / closer temperature approach feasible (cost vs. performance)

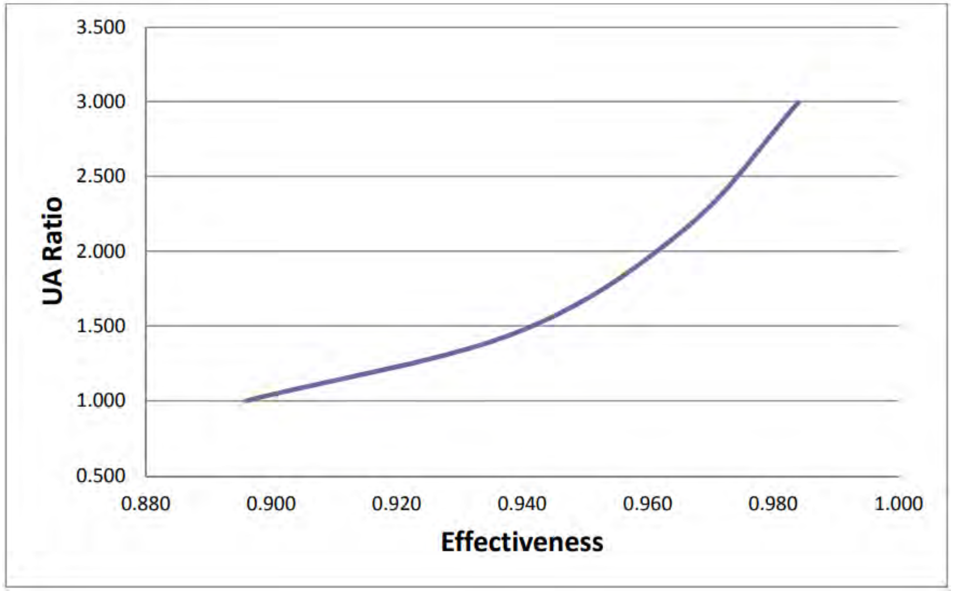
$$Effectiveness = 1 - \frac{\Delta T_{approach}^{*}}{T_{hot\ in} - T_{cold\ in}}$$

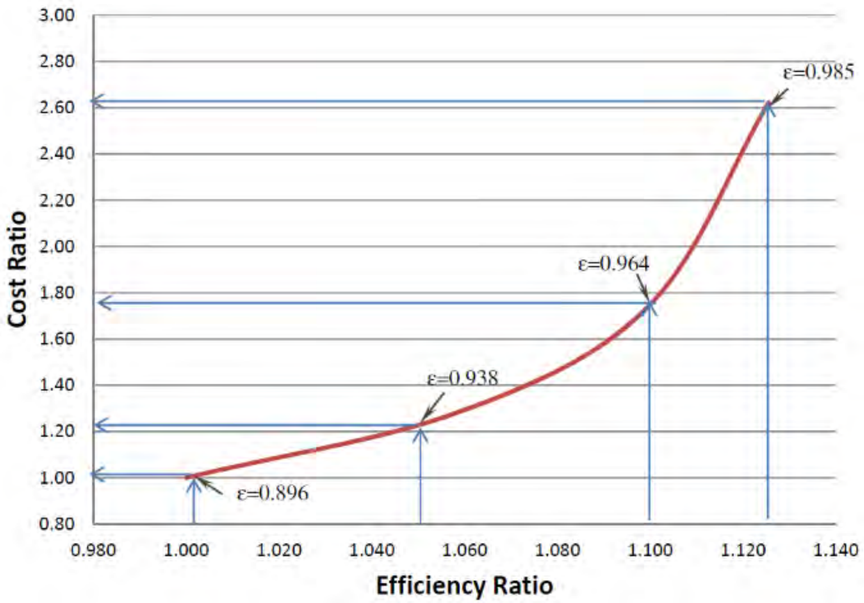
$$^{*}\Delta T_{approach} = Min[(T_{hot\ in} - T_{cold\ out}), (T_{hot\ out} - T_{cold\ in})]$$

**UA** where:

U = Overall heat transfer coefficient

A is heat transfer area



# CHARGE / DISCHARGE IMPACT

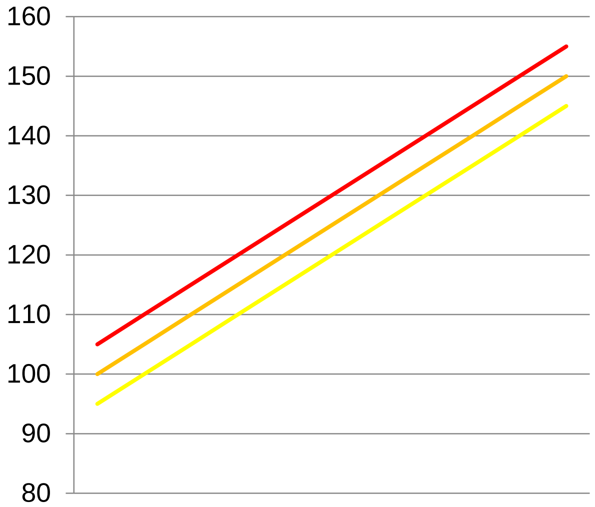
## High Performance to maximise OPEX by increasing RTE (Round Trip Efficiency) / minimise losses

How to facilitate highest level of RTE from an exchanger point of view:

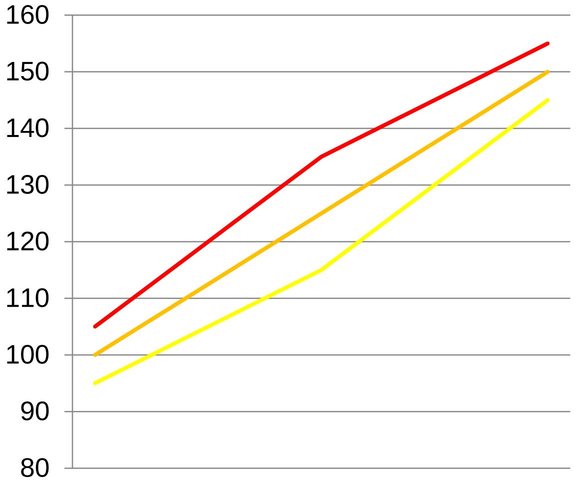
- Check reciprocity of the cycle (excessive losses between charge and discharge for given approach / underperformance due to process conditions)

Surface area requirement may drastically vary between charging and discharging if using the same heat exchanger for both cycles to reduce CAPEX

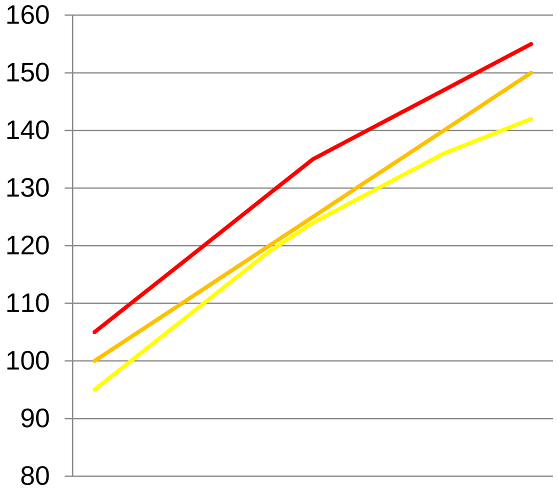
- / - charge
- / - discharge




10° RTE Loss in straight heat release with 5° approach




15° RTE Loss in non-straight heat release with 5° approach




10° RTE Loss in non-straight heat release with 5° approach *

*note the large differences in temperature approaches in the 3rd case between charging and discharging and the implication on heat transfer area


# Heatric