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Is automatic intelligent synthesis of complex systems possible? An application to Heat Exchanger Networks

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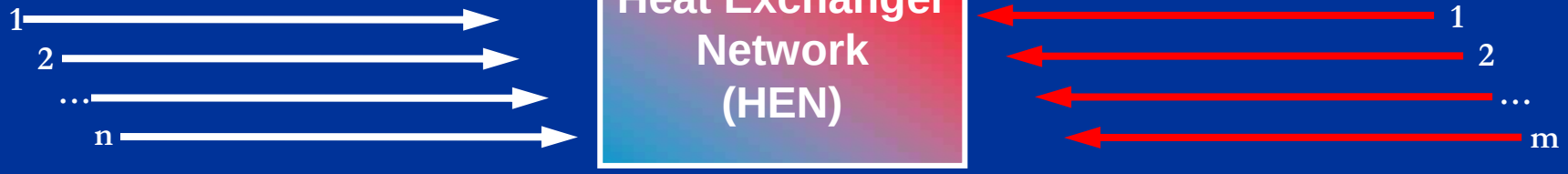
Summary

1. Problem description
2. Introduction and brief description of HENEA
3. A demonstration
4. Conclusions

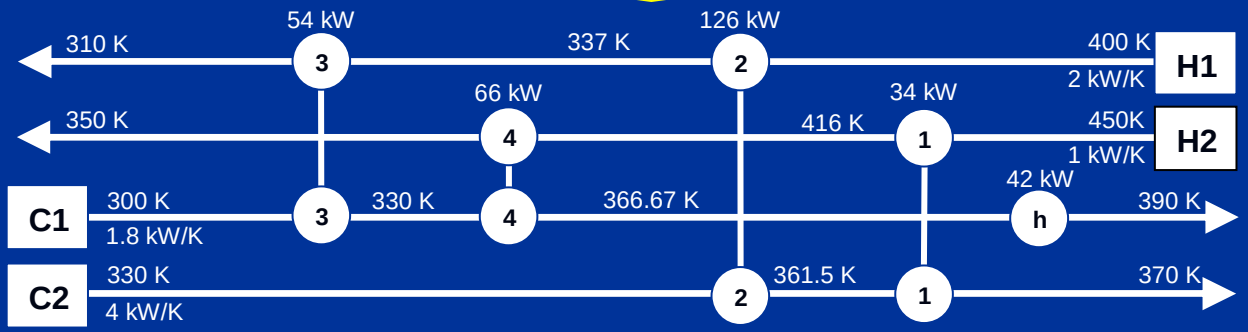
Problem Definition

Cold Streams ("CS")
TC_{in} ,TC_{out} ,m , c_p, Q_c

Hot Streams ("HS")
TH_{in} ,TH_{out} ,m , c_p, Q_h



Synthesis and Optimization



Process heat exchangers

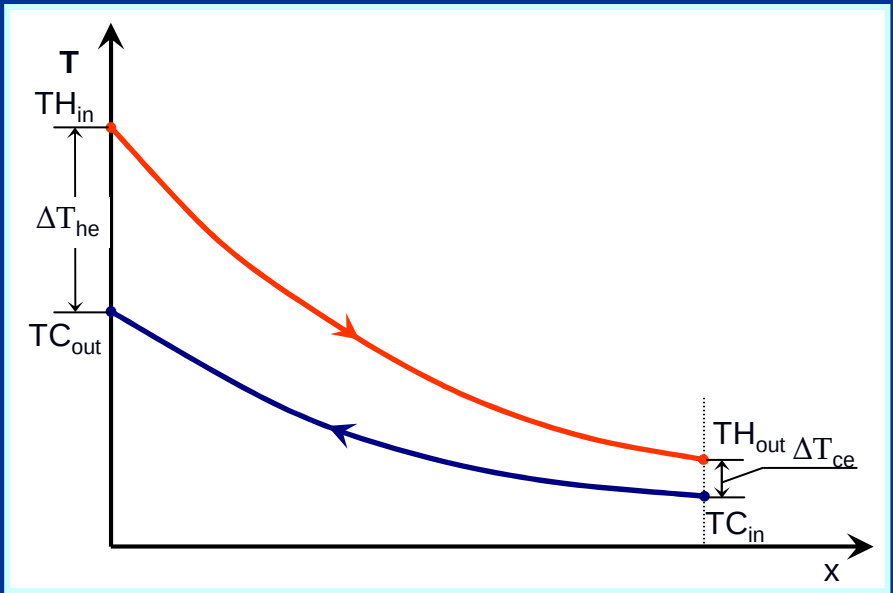
Utility heat exchangers

Optimization criteria

HEN evaluation parameters

Heat Exchangers Area A	Number of Heat Exchangers, N	Utilities Energy Requirement $Q_{external}$
Material Cost	Equipment Cost	Energy Cost

All design parameters depend on the ΔT_{min}



ΔT_{min} is the main parameter for HEN design

Brief description of HENEA

HENEA
(**H**eat **E**xchangers **N**etwork **E**xpert **A**ssistant)

Programming Language: C++

Uses Object Oriented Programming Techniques

Object Oriented

Addition of new "objects" Interaction with existing "objects"

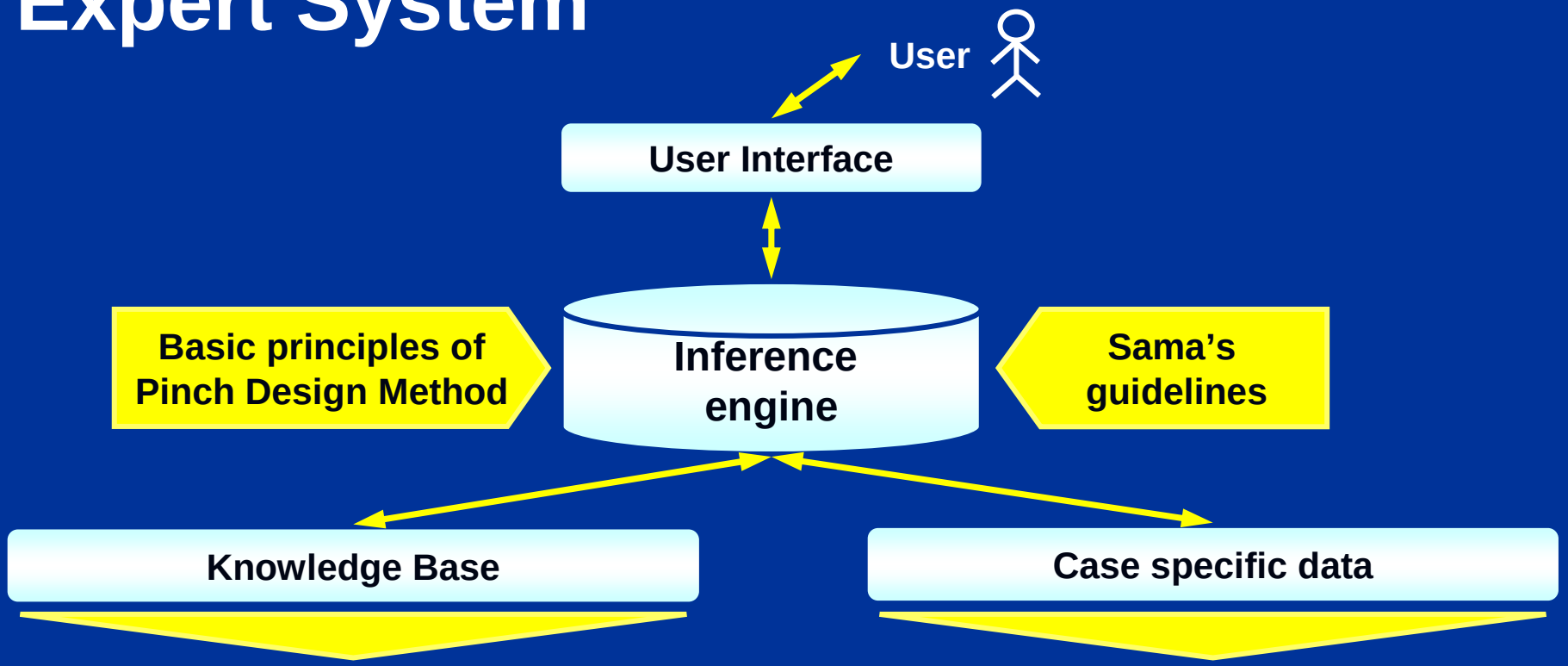
Artificial Intelligence application

Mimicks the "thinking patterns" of an expert

Expert System

Knowledge Based System

Expert System



Heuristic rules for HEN optimization:

- Reduction of mixing losses
- Avoidance of casual coupling
- Heat exchange efficiency
- Minimization of external energy requirement
- Minimization of exergy destruction

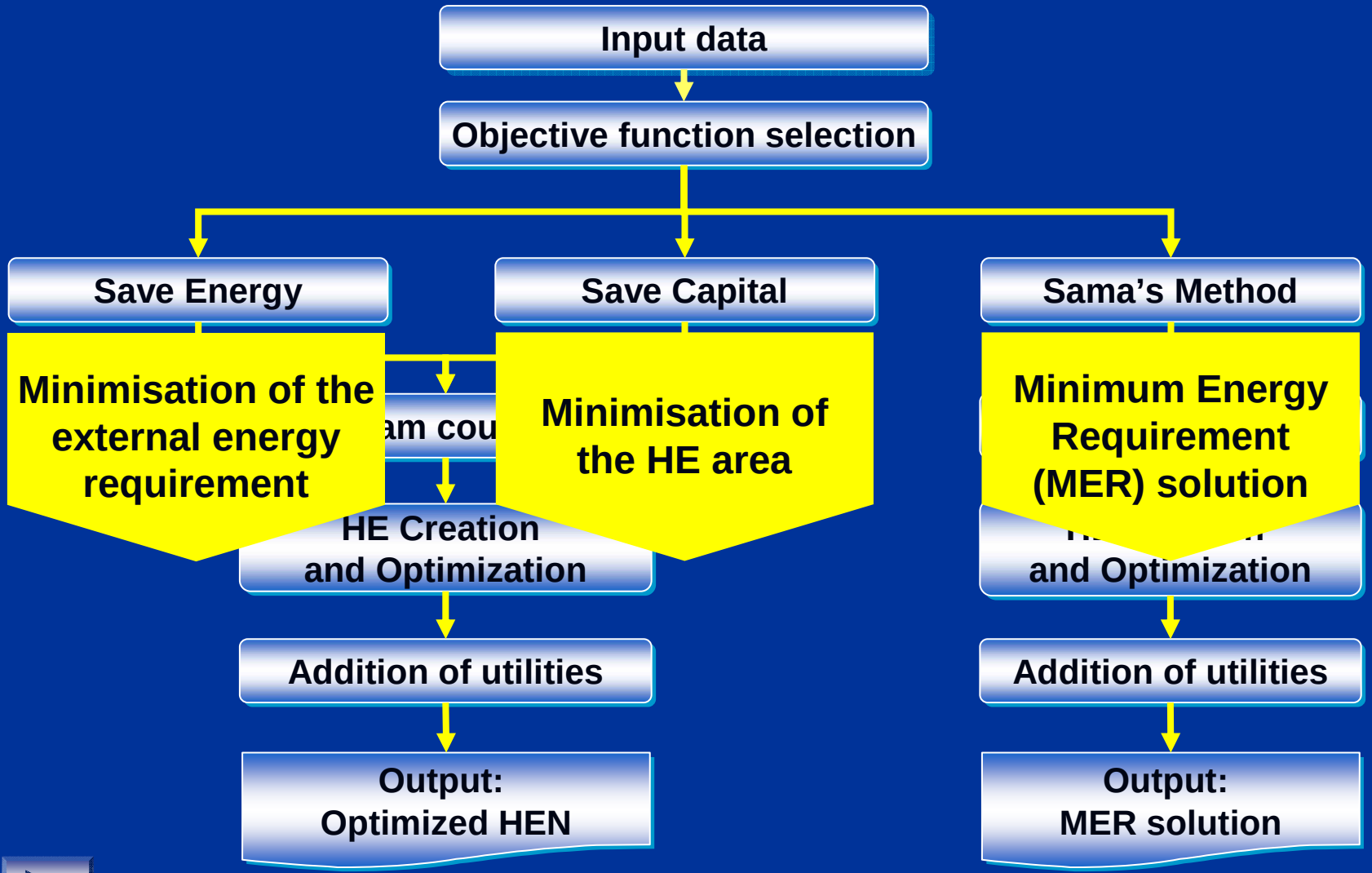
Process and auxiliary streams data:

- Inlet Temperature (T_{in})
- Outlet temperature (T_{out})
- Flow Heat capacity (C)

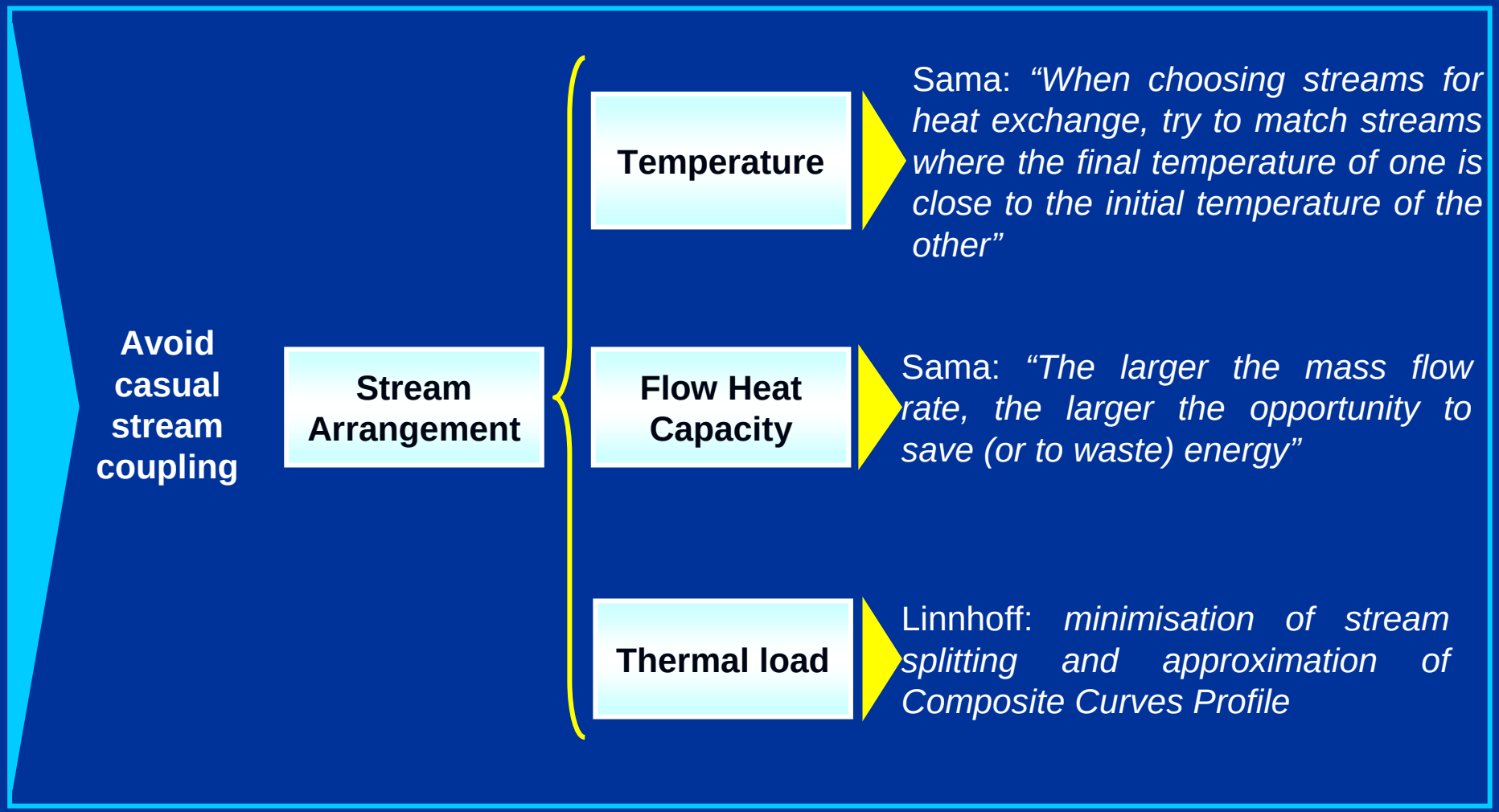
Heat Exchangers:

- Overall heat transfer coefficient (U)
- ΔT_{min}

Description of HENEA



HENEA: Flow Coupling (1)



HENEA: Flow Coupling (2)

Selection of stream pairing

if ($TH_{j,in}$ - $TC_{k,in}$ ≥ ΔT_{min}) then pair streams j & k

Sama: "*Do not use excessively large or excessively small thermodynamic forces in process operations*"

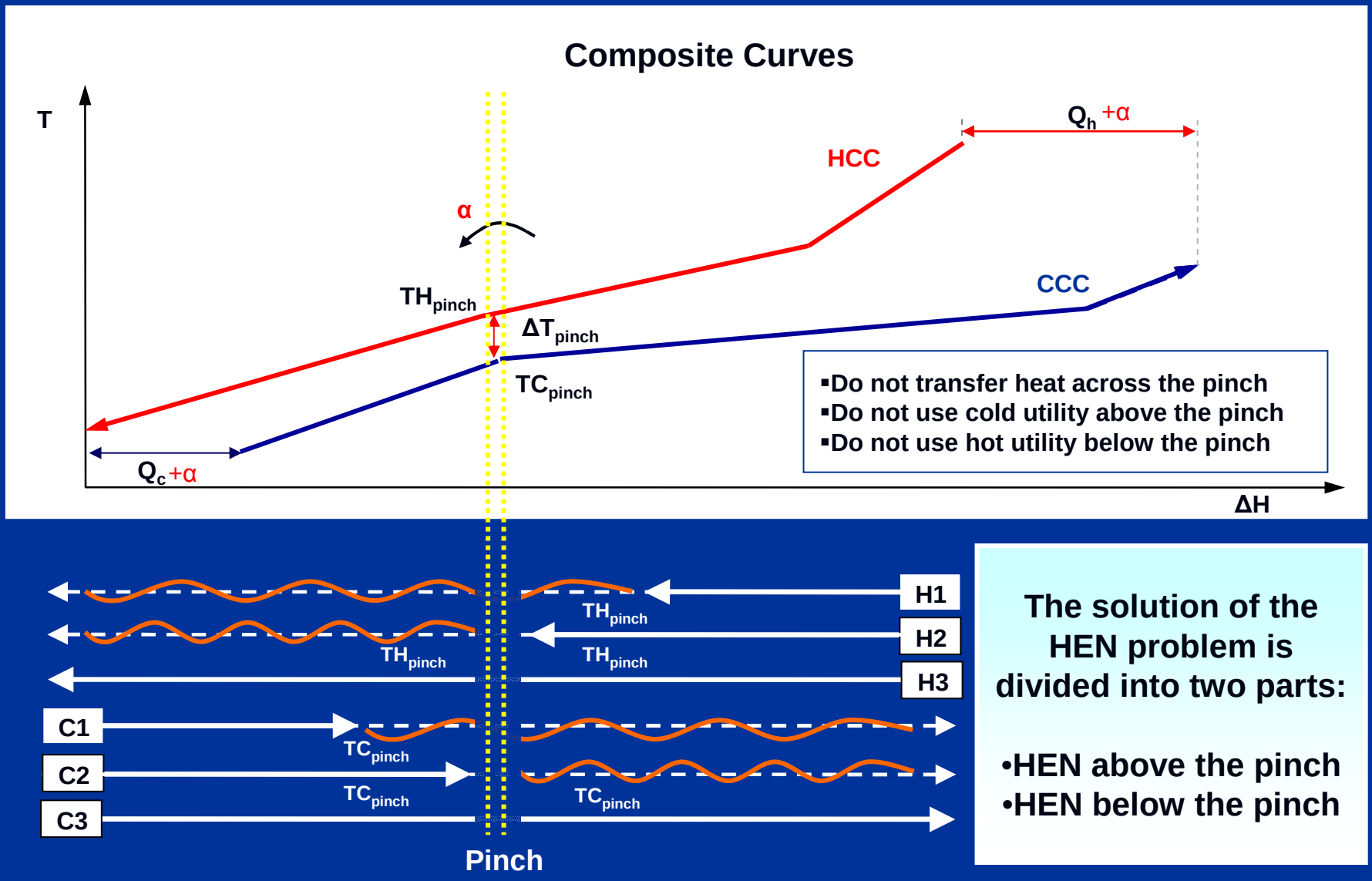
Heat exchange efficiency

$$R = \frac{C_c}{C_h}$$

if not $(R_{min} \leq R \leq R_{max})$ **then splitting**

Sama: "*…the exchange is more efficient if the flow heat capacity of the streams are similar. If there is a large difference between two streams, consider splitting the stream with the higher heat capacity*"

HENEA: Sama-Linnhoff Method



The solution of the HEN problem is divided into two parts:

- **HEN above the pinch**
- **HEN below the pinch**

HE optimisation for stream splitting

Reduction of mixing losses

Sama: "Minimize the mixing of streams with differences in temperature, pressure or chemical composition"

Save Energy and Save Capital

Reduction of the HE load

The ΔT_{min} constraint is abided by and all the T_{out} are equal (No mixing losses)

Sama's Method

Mass flow rate adjustment in the splits

ΔT_{min} constraint respected?

N

accept different T_{out} (mixing losses)

Y

T_{out} are equal (no mixing losses)

Maximization of heat exchange

run henea-3

Conclusions

- The goal of creating an Expert Design Assistant has been achieved
- The results compare very well with available literature data, and confirm the correctness of the implemented inference criteria
- Sama's Method always reaches the MER solution
- The Expert Assistant is able to suggest different "optimal" solutions
- The use of HENEA-3 leads to a substantial reduction of human resources allocated to a HEN design

Future developments

- Introduce post-optimization specifically aimed at the reduction of the number of heat exchangers

- Design improvements:
    1) Introduce T-dependent stream properties
    2) Allow for phase changes
    3) Account for Heat Exchanger fouling effects on U
    4) Account for pressure losses

HENEA: Assumptions

- No phase changes occur during the process (only sensible heat is accounted for)
- The thermodynamic properties of a stream do not depend on the temperature
- Only counterflow heat exchangers are considered
- Both thermal and pressure parasitic losses have been neglected
- Heat exchanger maintenance costs are not accounted for
- The effects of heat exchanger fouling have been neglected