The role of process integration techniques in the thermo-economic optimization of energy conversion systems

Laurence Tock*, François Maréchal. Industrial Energy Systems Laboratory (LENI), EPFL. *laurence.tock@epfl.ch

Context
Within the global challenge of sustainable energy supply and climate change mitigation
→ Design of complex integrated energy conversion systems
→ Multi-disciplinary problem taking into account:
  - Thermodynamics
  - Economics
  - Environmental considerations
→ Process performance defined by
  - Energy conversion
  - Quality of process integration
  - Waste heat valorization
  - Combined heat and power generation

Objectives
Development of computer-aided process design strategy simultaneously considering thermodynamic, economic and environmental aspects to systematically generate process options and assess trade-offs.
→ Thermo-environmental optimization approach combining flowsheeting and process integration techniques with economic evaluation and life-cycle assessment in a multi-objective optimization framework.

Methodology: Thermo-environmental optimization - Systematic framework for process analysis design and optimization.

1. Physical model
   - Superstructure of technology options
     - Fuel decarbonization
   - Process unit operation models
     - Chemical/physical transformations
     - Heat transfer requirements

2. Energy integration
   - Heat cascade resolution
   - MILP problem
     - Maximum heat recovery
   - Optimal combined heat & power
     - Waste heat valorization
   - Composite curves analysis
   - Process improvements identification

3. Performance computation
   - Economic analysis
     - Equipment sizing
   - Capital and operating costs
   - Life Cycle Impact Assessment (LCIA)
     - Functional unit: 1 GtCH4
     - IPCC impact method
     - Global warming potential (GWP)
     - Ecoinvent database

4. Multi-objective optimization
   - Configurations & operating conditions
   - Competing objectives:
     - \( x^2 \leq x \leq x^2 \)
     - \( h(x,z) = 0 \)
     - \( g(x,z) \leq 0 \)
     - \( f(x,z) \leq 0 \)

5. Energy integration model & LCA model

Process improvement through process and mechanical vapor recompression integration
→ Pre-combustion CO₂ capture in biomass fed power plant

Integrated Carnot composite curve of steam cycle: Process without MVR
Integrated Carnot composite curve of MVR unit
Integrated Carnot composite curve of steam cycle: Process with MVR

CO₂ capture [\%]

CO₂ rich fuel

CO₂,eq

CO₂,eq

Global warming potential (GWP)

Natural gas

Wet biomass

Biogas

Performance evaluation: MVR integration

MVR

\( E_{\text{ex}} \)

\( E_{\text{env}} \)

\( E_{\text{penalty}} \)

\( E_{\text{CO}_2} \)

\( E_{\text{H}_2} \)

\( E_{\text{N}_2} \)

\( E_{\text{B}} \)

\( E_{\text{air}} \)

\( E_{\text{CO}} \)

\( E_{\text{H}_2} \)

\( E_{\text{N}_2} \)

\( E_{\text{air}} \)

\( E_{\text{CO}} \)

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