Exergy Analysis within a Simulation and Optimization Software

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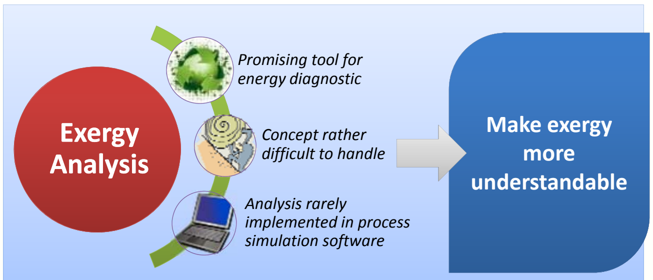
Introduction

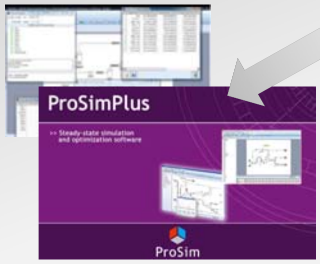
- In the context of reducing CO_2 emissions and high volatility of energy prices, investments in energy efficiency of industrial sites are often the result of a complex decision process.
- Among the different existing approach to improve industrial processes, exergy analysis appears to be one of the most promising.
- Exergy analysis, although used since the 80s, remains unknown and reserved to some experts because of the complex calculations and a concept (exergy) relatively difficult to handle.
- The COOPERE-2 project, focusing on the development of a software platform for simulation and energetic optimization of industrial processes, has been selected by the ANR (French National Research Agency, ANR-11-SEED-0012).

Definition of exergy

Exergy is defined as the maximum theoretical useful work obtained if a system S is brought into thermodynamic equilibrium with the environment by means of (reversible) processes in which the system S interacts only with this environment. (Kotas., 1985).



Our approach



« Classical » exergy analysis:

- **Grassmann Diagrams**: graphical representation of exergetic balance and exergy flows
- **Internal losses**: thermodynamic inefficiencies of a process due to pressure drop, thermal losses or chemical reactions…
  → avoidable irreversibility ≠ unavoidable irreversibility
- **Exergetic efficiencies**: universal exergy based criteria enables the thermodynamic performance of unit operations to be evaluated

Exergetic efficiency η

$$\eta = \sum_{k=1}^{N_{OPU}} \left[\lambda_k^p . \eta_k - \lambda_k^{1-p} . (1-\eta_k)\right]$$

Coefficients λ_k^p et λ_k^{1-p}:

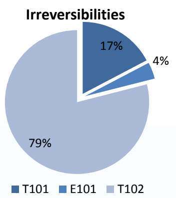
- $\lambda_k^p = \frac{\Delta B_k^{consumed,p}}{\sum_{k=1}^{N_{OPU}} \Delta B_k^{consumed,p}}$
- $\lambda_k^{1-p} = \frac{\Delta B_k^{consumed} - \Delta B_k^{consumed,p}}{\sum_{k=1}^{N_{OPU}} \Delta B_k^{consumed,p}}$

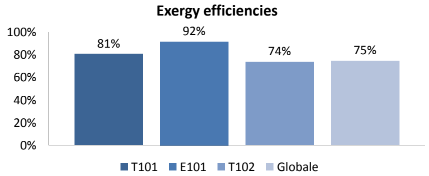
Exergy efficiency of a unit operation:

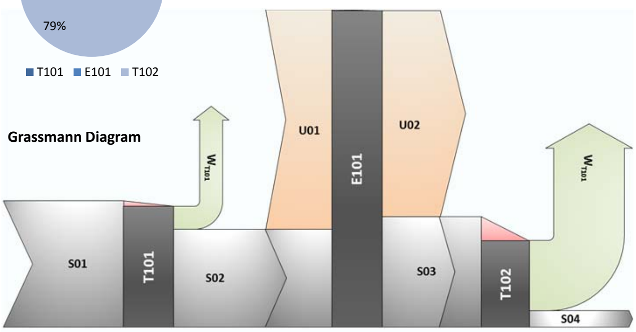
$$\eta_k = \frac{\Delta B_k^{produced}}{\Delta B_k^{consumed}}$$

The « **exergy load distribution** » methodology is an exergy analysis methodology relying on the evaluation of exergy efficiency (Brodyansky, 1994). This formulation is based on both the concept of **transiting exergy** (Cornelissen, 1997) for the evaluation of intrinsic efficiencies η_k, and the concept of primary exergy, denoted by p, to evaluate coefficients λ_k^p and λ_k^{1-p}.

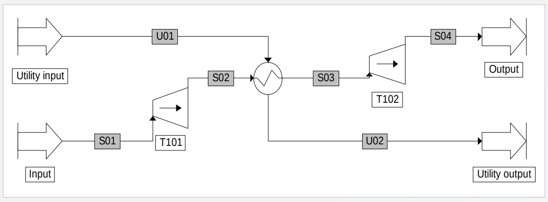
Nominal operating: $P_{T101} = 13 atm$







Case study: Two-stage turbine with intermediate reheater



The intermediate heat exchanger increases the process stream temperature up to 770 K.

Nominal operating conditions:

- Isentropic efficiency = 0.65
- Output Pressure T101 = 13 atm
- Output Pressure T102 = 1 atm

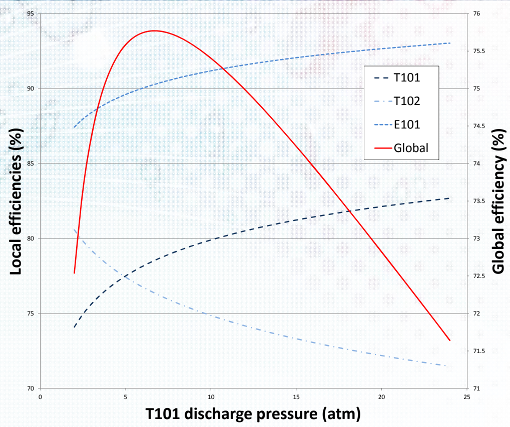
	Flowrate	Temperature	Pressure	Physical Exergy
	kmol/h	K	atm	kW
S01	10	773.15	25	39.05
S02	10	695.68	13	30.34
S03	10	770.00	13	34.32
S04	10	525.62	1	5.06
U01	10	873.15	15	68.14
U02	10	812.63	15	63.80

Sensitivity analysis

Implemented in a process simulator, the "exergy load distribution method" allows the engineer to study the influence of operating conditions on the process efficiency .

Example: influence of the T101 pressure on the overall effectiveness

→ *Influence of T101 pressure discharge on system efficiencies*



Conclusion

- Despite the diversity of exergy efficiencies proposed in the literature, only the intrinsic efficiency presents a generic way to compute an exergy efficiency for implementation in a process simulation software. It is being implemented in ProSimPlus® software.
- The originality of our approach comes from the coupling of the simulation software and exergy analysis for process optimization.
- To go further in the optimization and process integration, a first step would eventually analyze the exergy potential of effluents for an eventual chemical, mechanical or thermal valorization.
- The combination of Pinch methodology and Exergy analysis implemented in a process simulation software would also enable engineers to go further in the analysis of industrial processes.

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