Integrating process simulation and MINLP methods for the optimal design of absorption cooling systems

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CONTRIBUTION

- Novel framework for the design of sustainable thermodynamic cycles.
- Combined use of process simulation tools (Aspen Hysys and Aspen Plus), optimization software (Matlab) and LCA.
- The problem is mathematically formulated as multi-objective mixed-integer non-linear programming (moMINLP) problem.
- Two different thermodynamic cycles are optimized a 10MW Rankine power cycle and a 100kW water-ammonia absorption cooling cycle.

1. INTRODUCTION

• **Energy consumption** is one of the main factors affecting global warming. Over the last 25 years has increased worldwide by 66%.

• The energy is usually produced by power plants, mainly Rankine cycles, which operate by the combustion of fossil fuels. Moreover, conventional air conditioning systems are based on compression cycles which require mechanical energy for its operation

• Clear need to introduce new technologies. **Develop a systematic method for the optimal design of thermodynamic cycles** based on the combined use of process simulation and optimization tools

2. METHODOLOGY

2.1. MATHEMATICAL FORMULATION

Problem Statement

- **Rankine cycle.** Given are: the flowsheet arrangement (Moran and Shpiro, 1993), the net power yield, turbines and pump efficiencies, the overall heat transfer coefficients, thermodynamic properties, cost estimation correlations, economic parameters and environmental indicators.
- **Absorption Cycle.** Given are: the cooling capacity, the inlet and outlet temperatures of the external fluids.
- **Objective:** determine the optimal process design for the minimization of the total annualized cost and the corresponding environmental impact (Eco99).

Formulation

- The design of thermodynamic cycles with environmental concerns can be formulated as a moMINLP problem :

$$\begin{aligned} \min_{x_p} \quad & z = \{f_1(x, u, x_p), \dots, f_p(x, u, x_p)\} \\ \text{s.t.} \quad & h_1(x, u, x_p) = 0 \\ & h_2(x, u, x_p) = 0 \\ & g_E(x, u, x_p) \leq 0 \end{aligned}$$

2.2. SOLUTION PROCEDURE

- The solution of optimization problem is given by a set of Pareto optimal process designs
- The proposed algorithm iterates between master and primal subproblem.
 - 1) We solve the problem via the epsilon constraint method.
 - 2) The primal subproblem is solved with fmincon implemented in Matlab NLP.
 - 3) The master MILP problem is solved with CPLEX using GAMS.
 - 4) The algorithm solves iteratively both subproblems until the two termination criteria are satisfied.

The algorithm presented takes around 1,000 CPU seconds and around 3,000 CPU seconds to generate 10 Pareto solutions for the Rankine cycle and absorption cycle respectively, on a computer AMD Phenom™ 8600B, Triple-Core Processor 2.29 GHz and 3,23GB of RAM.

3. RESULTS AND DISCUSSION

3.1. CASE STUDY I: STEAM RANKINE CYCLE

The cycle provides 10 MW. The main process units are Boilers 1 and 2 (B1, B2), turbines 1-4 (K1, K2, K3, K4), condenser (C), pumps 1,2 (P1, P2) and a shell-tube heat exchanger (HX). The cycle also includes two splitters (T1, T2) an expansion valve (VLV1) and a mixer (MX1).

Parameters	minCost	minEI
TAC [€/yr]	659,876	689,230
ECO99 [Points]	227,114	215,396

3.2. CASE STUDY II: ABSORPTION COOLING CYCLE

The system provides chilled water for cooling applications. The basic components are the absorber (A), condenser (C), the desorber column (D), and evaporator (E). The cycle also includes the refrigerant subcooler (SC), refrigerant expansion valve (RV), solution heat exchanger (SHX), solution pump (P), and solution expansion valve (SV).

Parameters	Cooling minCost/minEI	Refrigeration minCost/minEI
COP[-]	0.699/0.762	0.504/0.573
TAC [€/yr]	21,9160/23,445	28,771/32,293
CostOP [€/yr]	14,534/13,334	17,762/20,133
CostC [€/yr]	7,382/10,105	8,537/13,236
AT [m2]	89.1/129.3	103.5/175.9
Steam [kg]	829,668/904,972	1,256,111/1,101,775
Elec. [MJ]	10,790/10,453	13,548/15,577
ECO99 [Points]	16,926/16,926	23,451/20,807

4. CONCLUSIONS AND FUTURE WORK

- This work presents a novel framework for the design of sustainable thermodynamic cycles.
- Both case studies were validated with existing models and optimized from these base points. Obtaining improvements of the cycle, which reduces the total annualized cost and environmental impact.

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