

Global multi-objective optimization of a nonconvex MINLP problem and its application on polygeneration energy systems design

Pei Liu^a, Efstratios N. Pistikopoulos^{*a}, Zheng Li^b

^a*Centre for Process Systems Engineering (CPSE), Department of Chemical Engineering, Imperial College London, London, SW7 2AZ, UK*

^b*Department of Thermal Engineering, Tsinghua University, Beijing, China, 100084*

Session Results

A case study has been conducted using the proposed approach for a coal-based polygeneration plant that produces methanol and electricity.

Illinois #6 coal is used as the main fuel feedstock. Market demand for electricity is 400 MW, and market demand for methanol is considered 500 tonne per day. Element sulphur is sold to the market as a by-product. Prices of feedstocks and products in the first time interval are set to fixed values. Prices in the following time intervals are adjusted according to inflation rate. An operating horizon of 10 years is assumed, and it is divided into three time intervals of equivalent length. Plant availability is set to be 0.85. Technology alternatives of four primary functional blocks are considered.

The overall mathematical model corresponds to a non-convex MINLP model involving 9 binary variables, 1252 continuous variables, 1162 equality constraints, and 194 inequality constraints. The optimization is performed in GAMS [1] using BARON [2] as the MINLP solver. Before solving the problem, the variables and constraints are properly scaled so that values of all variables and coefficients fall in the range of -100 to 100. Priorities are assigned to binary variables and some key continuous variables with great impact on the computational performance in conducting the Branch-and-Reducing algorithm within BARON. The computational results indicate that it takes 201 seconds and 519 seconds, respectively, on a 3.31 GHz CPU to solve the two single-objective optimization problems. After obtaining these two bounds, the whole interval is divided into 100 sub-intervals. These problems are solved in parallel on a 274-CPU cluster with an average CPU speed of 2.03 GHz and total memory of 329.6 GB. The computation times for solving each one of the 100 problems to global optimality is shown in Fig. 1. As can be seen, 98 problems are solved to global optimality within 40 minutes.

The optimal results obtained are used to generate the optimal Pareto curve, the frontier that separates the feasible and infeasible design space, shown in Fig. 2. As can be seen, out of the 18 possible combinations of technologies, only four appear in the Pareto curve. The different types of equipment and technologies that are needed to meet specific design targets are listed below:

- Hot gas cleanup technology should only be used when the emission constraint is extremely strict.
- A combination of quench gasification, cold gas cleanup, and liquid phase methanol synthesis technologies is suitable for conditions where the environmental constraints are either significantly loose or very tight. With a relaxed environmental constraint, this technological combination is chosen due to low requirements on initial capital investment. With a tight environmental constraint, however, it becomes again preferable due to its corresponding minimum requirements on the composition of inlet syngas entering the methanol synthesis reactor.

*To whom all correspondence should be addressed.

Email address: e.pistikopoulos@imperial.ac.uk (Efstratios N. Pistikopoulos)

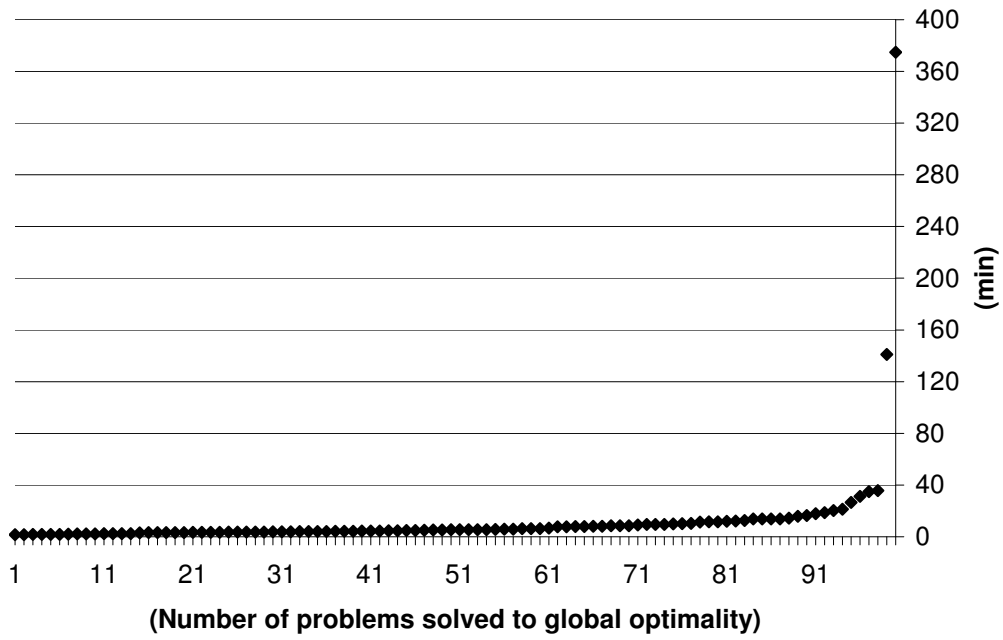


Figure 1: Computation solution time for the 100 problems to global optimality.

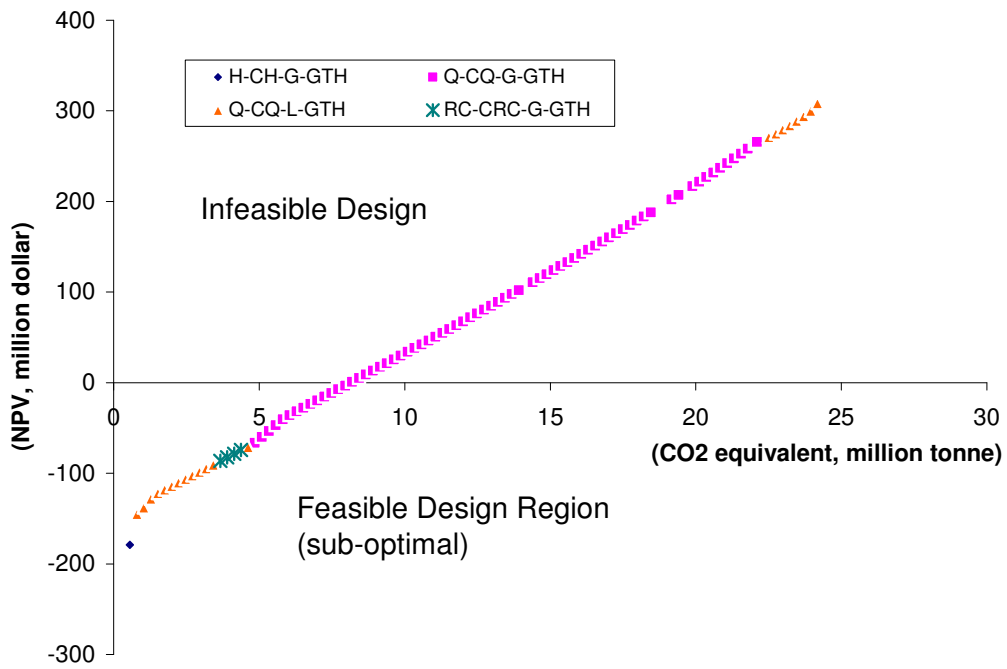


Figure 2: Pareto curve for polygeneration energy systems design.

- Gas phase methanol synthesis, with either a radiative and convective gasifier or a quench gasifier, appears to be the most viable design. It is superior to other types of designs in most circumstances where the emission constraint is neither too strict nor too loose.

References

- [1] R. E. Rosenthal, GAMS - A user's guide, GAMS Development Corporation, Washington, DC, U.S. .
- [2] N. V. Sahinidis, M. Tawarmalani, BARON 7.2.5: Global Optimization of Mixed-Integer Nonlinear Programs, User's manual, URL <http://www.andrew.cmu.edu/user/ns1b/baron/bibliography.html>, 2008.