Optimal network synthesis adopting operating unit model with flexible and multicomponent streams

Theses of doctoral (PhD) work

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State of the art and objective

The pace of globalization is quickening and it has significant economic impact on industrial development and production. The engineering design of production processes gets more and more focus whether it is about the cost reduction or increasing the production volume. One of the main reason is that the structure of processes fundamentally changed. Whereas before some chemical industrial processes were designed in such a way that they can proceed invariably due to the inexhaustible commodity stocks, nowadays constant change and adaption can be observed. The spreading of renewable energy sources and alternative technologies is on the rise which causes constantly changing variables in the investigated systems.

Taking into account these considerations requires the optimization of large scale and complex systems. The heuristic methods based on the engineers practical knowledge is no longer enough, there is a need for special methods and software components which are capable to support effectively the large scale system design. Numerous former studies pointed out that system wide approach is more appropriate than modeling smaller parts in a more detailed way. The objective of this approach is the structural modeling. I.e., the determination of the optimal structure of a process is called process network synthesis.

The P-graph framework was elaborated by Friedler et al. in the early 90’s. The framework introduces a unique class of graphs which allows the formal and graphical representation of process networks. P-graph is based on a well-designed axiom system. Due to these axioms it is possible to formulate the combinatorial attributes of structures and the use of rigorous mathematical tools.

In my researches I developed optimization methods mostly based on the extensions of the P-graph framework. Due to these optimization methods, the P-graph framework can be used in the solution of new problem classes. In my thesis I introduce them in detail. The practical application of the elaborated models and algorithms will be demonstrated via industrial size examples.
Methods and approaches adopted

The research resulting in the presented results demanded complex knowledge:

- Developing mathematical models, investigation and solution. These activities require stable knowledge in advanced mathematics and operations research.

- Software developing tools and methods for supporting the research and testing new methods based on practical examples. It demands improved programming skills.

- Advanced engineering knowledge and know-hows for developing proper mathematical models for special devices and technologies in chemical or energy industry.
Major results and summary of accomplishments

The new scientific results can be summarized as follows. After each thesis, the reference in the braces indicates the chapters of the PhD thesis, where the results are presented in detail.

1. A new integrated network synthesis problem was introduced which contains process and separation subnetworks. In contrast to the former sequential approaches the two type of subnetworks are handled at the same time in an integrated model. *(Chapter 3)*

   1.1. A component-based P-graph representation was introduced. It allows the P-graph representation of the multicomponent streams and devices in the separation networks.

   1.2. The properties of the SNS problem class with clean products, sharp separators (linear cost function with fixed part) was investigated. These properties were utilized at the definition of the maximal structure. A novel algorithm was developed for the maximal structure generation.

   1.3. A new method was elaborated for the mathematical model generation of PNS problems containing separation subnetworks. The introduced model was solved with the efficient algorithms of the P-graph.

   1.4. The advantages of the extended network was described. It was compared with the sequential methods using an illustrative example. The benefits of the new approach was demonstrated it gives better results I many cases.

2. For the optimal solution of SNS problems containing separators with concave cost function, a new global optimization method with based on intervals is developed. The algorithm specifies the structure of the optimal network and the corresponding components flowrates in the streams in an arbitrary precision by adjusting the tolerance values. The operation of the method was illustrated via an illustrative example. *(Chapter 2)*

   2.1. The nonlinear parts of the mathematical model was specified. A method was elaborated for handling the nonlinear parts with linear tools. At first, the nonlinearity in the dividers mass balance equations were handled by introducing splitting intervals instead of splitting values. At second, nonlinearity arises in the cost function of separators. This were handled by using linear lower estimating functions.

   2.2. The IGOS algorithm was developed based on Branch & Bound framework and linear programming tools. The algorithm was compared with other solution methods and solvers. IGOS performs better than the nonlinear OpenOpt NLP solver but it is slower than the state-of-the-art optimization solvers.

   2.3. An accelerated subproblem selection strategy was elaborated which results a 60 times faster algorithm.

Publication related to the results: [P1], [P4]
3. An extension of the P-graph framework was introduced for handling flexible input rates. This model is applicable for the optimal design of complex energy production networks including renewable energy sources. The specific components of the problem class are treated with a new mathematical model. The operation of the extended P-graph framework is demonstrated through a case study. *(Chapter 4)*

3.1. The original P-graph framework introduced by Friedler et al. has fixed input and output ratios in the model of operating units. In this work a new mathematical model is elaborated for the operating units which allows flexible input ratios. The size of the output streams depends on the composition of the input streams. This approach gives better model approximation in many fields e.g. in energy supply systems design.

3.2. The new mathematical model can handle not only the renewable energy sources, but the limitations for pollutant discharges.

3.3. Sensitivity analysis was performed related to the renewable energy network. It was investigated how the optimal network structure and the quantity of consumed raw materials changed as a function of the energy demand.

**Publication related to the results: [P3]**

4. A novel method was given for modeling multiperiodic devices based on the P-graph framework. The new type of devices were represented with the conventional operating units and material nodes. *(Chapter 5)*

4.1. The multiperiodic devices were introduced and compared with the behavior of the conventional devices. The differences between the two types of models were demonstrated using an illustrative example.

4.2. The P-graph method was applied for modeling and representing the special devices in the multiperiodic approach. It was achieved with conventional P-graph building blocks instead of introducing new components.

**Publication related to the results: [P2], [P5]**
Publication list

Related papers


Related international conference presentations


**Related Hungarian conference presentations**


Adrian Szlama, Karoly Kalauz, Botond Bertok, Istvan Heckl, *Solving separation-network synthesis problem adopting interval optimization techniques*, 1st Winter School of PhD Students in Informatics and Mathematics, Veszprem, Hungary, November 15-17, 2013.


Applications of the scientific results

During my work I have developed a global optimization method using intervals for solving separation network synthesis problems. Using this method the structure of the separation network and the flow rate of the streams can be determined in the case of concave cost functions for the separators.

In addition, I have implemented various extensions for the P-graph framework. Due to these extensions the framework is properly applicable in new research areas and it can handle accurately the operating units with advanced behavior. One of the major new areas is the field of large scale network design with separation and process subnetworks. Also I gave an efficient algorithm for solving such Process Network Synthesis problems in which the operating units have flexible input and output ratios in contrast to the original fixed ratios. This representation is well applicable in the area of energy production networks due to the renewable energy sources. Finally, I have introduced another extension of the P-graph framework which is adopted to the periodically variable external impacts. In association, I have elaborated the multiperiodic P-graph model.