CONFLICT-BASED METHOD FOR CONCEPTUAL PROCESS SYNTHESIS

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Abstract

The paper presents a new methodology for conflict-based process synthesis. The objective is to handle the multi objective requirements and combinatorial nature of process synthesis from the point of view of the creativity-based approach to the problem solving. The development of the methodology deals with two main questions: how to define and identify the conflicts encountered in the design process; and how to build strategies and procedures to resolve the contradictions and improve the process performance with regard to multiple design objectives. The conflict model is proposed for the representation of the design targets and problems. It is made up of three functional levels to allow the decomposition of design targets and the organization of design knowledge. In the context of conflicts, the design paradigm is formulated for conceptual process synthesis. The method is illustrated through the synthesis of the reactor-separator system.

Keywords

Conceptual process synthesis, Conflict-based method, Reactor-separator system

Introduction

The industrial processes have to be designed and operated in a manner enabling the simultaneous fulfillment of the economic criteria, safety, environmental requirements as well as other objectives. The major challenge of design and operation lies in resolving the conflicts between those objectives (Miettinen, 1999). The conflict occurs when improving one objective results in the deterioration of the other ones. Therefore the essential task for process designers is to develop tools for assisting in the trade-off among those objectives.

The chemical process design is aimed at realizing or improving the required performance of the process flowsheet by identification of the types of units, their interconnections and the optimal values of the parameters. Improvement of the performance of process flowsheets must be based on the changes in the characteristics of the chemical process, such as chemical and physical properties, the topology structures, etc. The changes in the process characteristics concerned always result in changes in other process characteristics because of design constraints and specifications. The design activities need to handle the conflicts among the improved characteristics and the correspondingly changed ones. The handling of the conflicts in the early design stage is the precondition for effective process synthesis. The objective is to minimize the number of the conflicts as early as possible in order to facilitate the detailed process design and control. More conflict exist more difficult optimization and operation of the system could be.

Therefore it is an important issue to develop a strategy to handle the conflicts for process synthesis and design in order to achieve the optimal solutions.

This work presents a conflicts-based approach for dealing with the conflicts of the process synthesis. The conflict model is proposed for the representation of the design targets and problems. It allows the decomposition of design targets and the organization of design knowledge. The design tool, the contradiction matrix, is constructed. A design paradigm is formulated based on the hierarchical classification of the conflicts It supports, in a systematic way, the generation of possible design alternatives or solutions space for the detailed design stage. The method is illustrated by the synthesis of the reactor-separator system.

The Methodology Background

The work is carried out based on design paradigm adapted from Theory of Inventive Problem Solving methodology (TRIZ) (Altshuller, 1998). Mann (2000) has concluded that TRIZ currently offers the most useful foundation for a systematic creativity model in terms of its relevance to primarily scientific, engineering, and business applications. TRIZ is claimed to be a 'systematic creativity' framework thanks to its knowledge based and evolutionary-directed nature. It is an approach to identify the system's conflicts for solving the inventive problems. The main idea of TRIZ consists in the modification of the technical system by overcoming its internal contradictions. Therefore, it is an efficient method for modifying the solution space and early screening the alternatives by the conflict-based analysis.

Process synthesis is a complex problem solving process based on qualitative, semi-qualitative and quantitative information as well as multiple objective design criteria. Chemical process synthesis problems are open-ended and under-defined, often with the existence of conflicts. The synthesis task is to remove or decrease the occurrence of the conflicts through the proper decision-making process. The following is a definition for process synthesis in the context of conflicts:

Process synthesis is the decision-making process of identifying and handling the conflicts in design in order to satisfy the multi objective requirements.

The conflict model

There are mainly two groups of conflicts encountered during the design process: one is the conflict among the multiple objectives; the other is the conflict among the process characteristics, such as process parameters (operating parameters and process structure elements). It is clear that the two groups of conflicts are related to each other: The former is the effect or function of the latter. However their interactions are difficult to describe precisely because of the complexity and combinatorial nature of chemical process synthesis. In order to bridge the gap and simplify the functionality between the two abstract levels of the design targets and the process parameters, a medium level of conflicts is proposed - the conflicts among the process properties. The process properties are the performance of the process blocks or process phenomena, such as the reaction conversion, reaction selectivity, separation efficiency, etc. The process properties are the combination or function of the operating parameters. So the conflicts among design objectives are the effect of conflicts among the process properties, which are the function of the process parameters. Therefore the conflict model for process design is made up of three functional levels. It is proposed for the representation of the design targets and problems. It allows the decomposition of design targets and the organization of design knowledge.

Figure 1 shows the proposed conflict model. From the outer level to the inner level, it illustrates the decomposition of design targets or tasks. To handle those conflicts, the sub design tasks which are essential for the design target are identified. The process properties are related to the process blocks and phenomena. The conflicts of the process properties are originated by the trade-offs among the values of the process parameters. So the conflicts are moved to the level of the process parameters. They are directly influenced by design knowledge and heuristics. As a result, the transfer of the conflicts from outer to the inner level is carried out with the decomposition of the design tasks into the subtasks. The conflict chains are formulated to represent the design tasks at different levels of abstraction.

From the inner level to the outer level, the model shows the way the design knowledge is organized and analysed. First, applying the design knowledge and heuristics will directly affect the process parameters. It identifies the conflicts among the process parameters; then the changes of the parameters will result in conflicts among the process properties. Consequently, conflicts of design objectives occur because of the changes of the process properties. The affected design objectives and the implicit information behind the design knowledge are extracted. It is an approach to the structuring of conflicts-oriented analysis for the organisation of the design knowledge. It is also the main idea behind building the conflict-based tools that will be discussed in the next section.

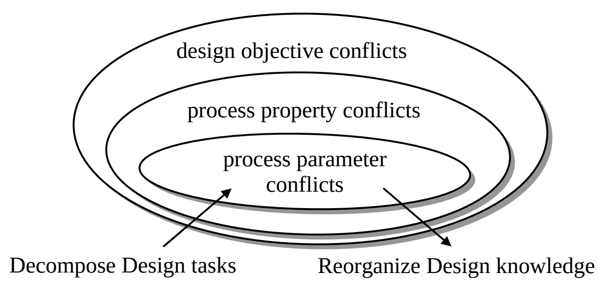

Figure1. Three-level conflict model

For synthesis of reactor-separator system, the conflicts transfer is shown in Figure 2. According to TRIZ (Savransky, 2000), system conflicts cannot be eliminated directly. Handling of system conflicts is aimed at identification of the essential elements which control the competing attributes. Through modifying these elements the system conflicts will be transferred to physical conflicts. The conflicts transfer in a reactor-separator system design and synthesis can be seen in Figure 2. The detail description, for design objectives, process properties and parameters of reactor-separator system, can be found in Li (2003). The hierarchy for identifying and handling conflicts is determined by the levels of the conflict model: first, the conflicts among the design objectives; then the conflicts among process properties; and finally the conflicts of process parameters such as streams and thermodynamic properties.

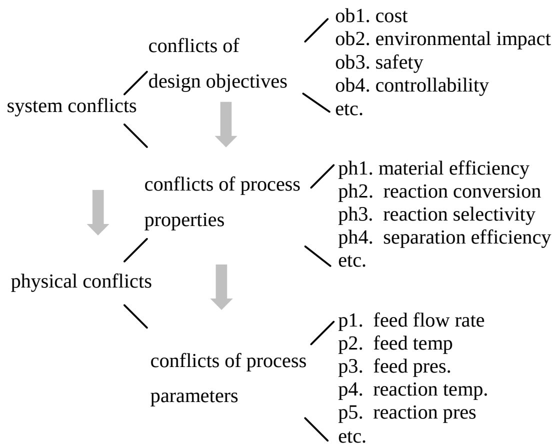

Figure 2. Conflicts in a RS system

Conflict-based Tool

The development of TRIZ tools is based on revealing similarities and common patterns between design problems and solutions published in patents (Altshuller, 1998). After studying 200,000 patents, there are identified 39 characteristics of technical systems that generate contradictions and 40 universal principles for any technical system. With the principles and characteristics, a contradiction matrix is built that could be used to solve contradictions generated by any technical system.

Similarly, based on the available literature in a specific domain, the process characteristics and design heuristics for building the design tool – the contradiction table – are extracted. The procedure for constructing the design tools is composed of the following 5 steps:

Step 1: define the problem domain where a large amount of design heuristics, experiences and cases studies exist.

Step 2: extract the design heuristics from available literature which has been proven to be critical for the conceptual process design.

Step 3: identify the characteristics of the studied system which usually generate conflicts among the characteristics.

Step 4: analyse the design heuristics via the conflict-based model. First, identify the affected characteristics when applying the design heuristics. The indicators could be used to express the influence of the applied heuristics to the characteristics of the studied system. Then group the design knowledge and heuristics which contribute to the same conflicts among the characteristics identified.

Step 5: formulate the contradiction table by putting the grouped design heuristics into the table cells corresponding to the concerned characteristics.

For reactor-separator system, the formulated contradiction matrix is composed of 8 design objectives, such as economic criteria, product quality, safety, environmental impact. The design objectives form the rows and columns of the matrix. There are 86 design heuristics P_k, k= 1-86 extracted from the available literature (Douglas, 1988 and Smith, 1995). They constitute the matrix elements. If the design heuristics P_k influences the objectives i and j, then it is positioned at the intersection of the row i and column j (see Table 1). Every heuristics is characterized by so-called influence coefficient $I_{i,}$ i=1- 4 and flowsheet phenomena indicator S_j, j= 1-6. The influence coefficient I_i represents the character of the influence on the two concerned objectives when applying the heuristics. The flowsheet phenomena correspond to the region of the flowsheet structure in which the given heuristics should be applied (Li et al., 2002).

The matrix reorganizes the available design heuristics based on their possible influence on the design objectives. It is used for identifying the conflicts among the objectives and handling them by selecting the suitable heuristics considering the concerned objectives. As a result, the design alternatives are screened and preselected to generate the efficient superstructure and useful information for detailed process design and synthesis.

Table 1. A fragment of the contradiction table

	1.captial cost	2.operation cost	3.product quality	4.environ. impact	…	8.controlla -bility
1	**	p2 (1, s1) ...	p1(1,s3) ...	P4(1,s6) ...	…	p7(1, s2) ...
2		**	p4(2,s6) ...	p4(4,s6) ...	…	p13(3,s3) ...

Conflict-based Design Paradigm

For chemical process synthesis, based on the concept of the conflict, the design paradigm is formulated by combining the TRIZ strategy (Savransky, 2000) and the general process design paradigm (Siirola, 1996). The procedure consists of three steps for the whole conceptual process design as illustrated in Figure 3: conflict-based analysis, process analysis and process simulation and optimisation.

First, the conflicts among the objectives present the design tasks, such as the conflict between process profitability and environmental impact. To handle the conflicts of the objectives, the sub design task or possible major structural issues are identified For example, by-product treatment is one of the important issues concerned with the above conflict. Then the sub design tasks are described by the conflicts among the process properties. For the by-product treatment, this brings out conflicts such as the conflict between the recycle ratio and raw material utilizing efficiency. Next those conflicts are transferred to the conflicts among the process parameters, which involve stream properties and thermodynamic parameters. To handle the conflicts between recycle ratio and raw material utilizing efficiency, it is essential to trade off those parameters like the stream parameters of the recycle flow, the parameters of the raw material, and the operating parameters of reaction. The conflicts among these parameters are handled by selecting the suitable heuristics based on the design tools and design strategies. As a result, promising process alternatives are generated which are subject to process analysis in the second step. The methods of thermodynamic analysis or qualitative reasoning are proposed to further modify the solution space. The solution space is the basis for searching of the optimal solutions in the final step through simulation or optimisation. This procedure is iterated until no further improvements to the generated flowsheet can be made.

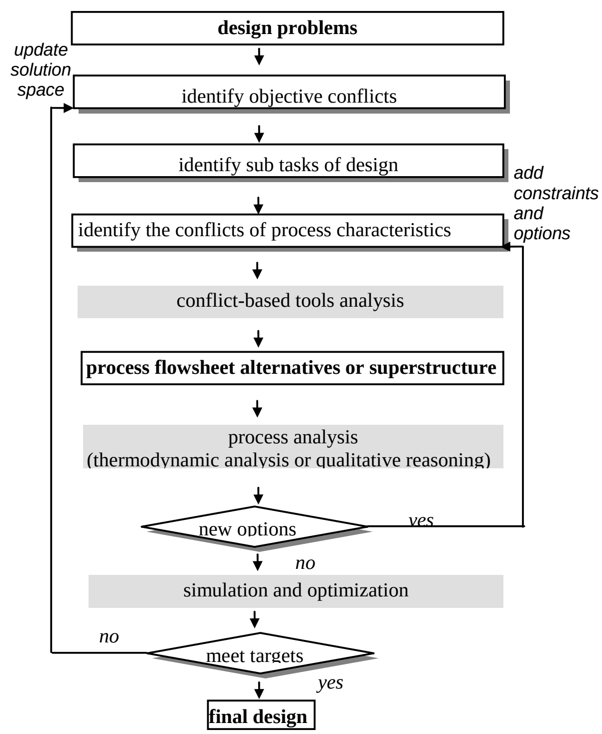

Figure 3. The paradigm of conflict-based method for chemical process synthesis

The conflict-based method is used for generating and screening promising alternatives at the early stage of conceptual design. It can overcome the limitation of inappropriate decisions for multi objective design caused by the limited design space or insufficient design knowledge. The multi objective requirements are considered at the early design stage. Decision-making is based on the minimization of the number of the conflicts during the design process. It can facilitate the later design activities. The solution space from the conflict-based method builds the foundation for the process analysis via thermodynamic analysis tools or qualitative reasoning. Process analysis could provide the useful information to bridge the gap between the qualitative knowledge and quantitative techniques. It assists the simulation and optimisation stages when searching for the optimal solutions.

Conclusions

The conflict-based method presents a new paradigm for representing and solving process synthesis and design problems. The conflict model is proposed for the representation of the design targets and problems. It is made up of three functional levels to allow the decomposition of design targets and the organization of design knowledge. The design problem is represented through the conflicts among the interrelated design objectives or the characteristics of the process. The conflicts among the objectives are transferred to ones among the process properties and operating parameters. It is a new strategy of evolving conflicts to carry out the design process. The conflict-based method, based on selecting the design heuristics through the contradiction matrix, exemplifies the generation of design alternatives at the early stage of process synthesis. The proposed design paradigm combines conflict-based analysis in the early stage design and process analysis and evaluation in the detailed design stage. Conflict-based analysis is applied at the early design stage for screening and evaluating process alternatives. It minimizes the number of conflicts among the multi objectives and supports the generation of an efficient and compact solutions space for the detailed design and optimisation stage.

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