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Process Synthesis, Design and Intensification. An integrated approach

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Abstract

Process design has four main objectives: process synthesis or generation of process alternatives; process analysis; process evaluation; and the selection of the best process to achieve a desired goal [1]. According to Westerberg [2] the overall improvement of a process, new or existing, may be achieved by considering the original design as the base case, performing flowsheet optimization to further improve the design and through analysis of the real time process operation. Possible improvements are identified and are generally, where economically feasible, implemented during plant retrofits. Process intensification (PI) is a means by which processes, whether conceptual or existing, can be designed or redesigned to achieve a more efficient and sustainable process through the improvement of key process parameters, for example energy efficiency and waste generation. PI is defined as the improvement of a process at the phenomena level which ultimately has an impact at the higher levels of a process, for example the functional and unit operations levels. More specifically it is the enhancement achieved through the integration of unit operations, functions and/or phenomena. Therefore incentives exist for the inclusion of PI within the overall concept of process design and in particular as part of the process synthesis and design methodology.

With the inclusion of PI into process design, not only can a process be synthesised, analysed and evaluated but it can also be further analysed for the potential use of intensified equipment within that process, whether novel or mature. In order for this paradigm shift to occur the intensified process should be better than the original design. An example of PI was achieved by Eastman Chemical [3] which in 1983 intensified a process for the manufacture of methyl acetate by replacing with one single reactive-extractive distillation column a multi-step process which had consisted of a reactor, extractor, decanter, several normal and azeotropic distillation columns, and two mass separation agents.

For achieving PI via a systematic approach different methods exist, for example, the task-based means-ends analysis developed by Siirola [1]. However, there is a need for not only a more systematic, efficient and flexible PI method covering a wider range of applications, but also for one that is able to find truly innovative and predictive solutions, using not only the knowledge of existing methodologies at the unit operations level but also at a lower phenomena level, where new unit operations can be designed.

The objective of this work is twofold: (1) The further development of a phenomena based PI synthesis and design algorithm (PBS algorithm) and (2) To incorporate the PBS algorithm as part of an overall process synthesis/design framework that includes both task-based means-ends analysis and thermodynamic insights [4]. Within the overall synthesis/design framework this PBS algorithm is employed to generate, screen and analyse many possible alternatives. A first version of the PBS algorithm has been developed and consists of a six steps.

The starting point of the PBS algorithm is the base case design, which can either be the final design based on the current state of the art of process design or the design of an existing process. In Step 1 the problem is defined together with the objective function. In Step 2 a decomposition approach is applied where the process is represented in terms of tasks and process phenomena respectively and the process is then analysed using thermodynamic insights for example analysis of pure component and mixture properties. In Step 3 the limitations/bottlenecks (LBs) of the process can then be identified together with the desirable and accompanying phenomena to overcome these LBs. In Step 4 phenomena are connected to form

simultaneous phenomena building blocks (SPBs) which are screened for the most feasible connections using for example connectivity rules. An example of a connectivity rule is heating and cooling cannot exist within the same SPBs. The SPB's are then connected to form operations which are then connected to form flowsheets. In Step 5 these flowsheets are first screened using for example logical constraints and performance metrics. In Step 6 the feasible flowsheets from Step 5 are optimized with respect to the objective function defined in Step 1 with the end result being the identification of the best intensified process candidate. The emerging flowhseet consists of either novel or existing equipment. Through the combined synthesis and design framework, the results of the means-ends analysis and thermodynamic insights methodologies are used in defining the problem (Step 1), in decomposing the problem (Step 2), and in evaluating the results from Step 4.

In the proposed presentation the overall process synthesis and design framework together with its supporting algorithms and tools will be illustrated by a re-examination of the methyl acetate process. It will be shown that the framework is able to generate a wider range of solutions, including those that have been reported earlier.

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