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Rodrigues, Fabricio

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Fabrício Rodrigues, Department of Chemical Engineering, Federal University of Uberlândia, Uberlândia, Brazil

A new formulation of the Means-Ends Analysis for Process Intensification

Fabrício Rodrigues[1*]

farod@student.dtu.dk

[1]*Department of Chemical and Biochemical Engineering, Technical University of Denmark (DTU), DK-2800, Kongens Lyngby, Denmark*

Process intensification (PI) is a new paradigm in chemical engineering that aims for more efficient and sustainable designs of chemical processes. PI can be defined as the improvement of a process at three different levels: operational, functional and phenomena. Intensified equipment, such as reactive distillation, divided wall column and reverse flow reactors, are all examples of well-established technologies existing within the industrial sector with clear advantages, however the means by which a process, new or existing, can be systematically intensified is still challenging [1]. Different systematic methodologies to achieve PI exist [2] and here the task-based means-ends analysis by Siirola [3] is highlighted using two characteristics: (1) A higher degree of freedom is provided for synthesis and design by going beyond unit operation-based flowsheets to task-based flowsheets and (2) the modifications in the means-ends analysis to fit in an hierarchical environment and include strategic operations, in addition to opportunistic operations [4], provides some sort of using a hierarchal approach that when applied to process synthesis and design, provides some sort of look-ahead for process synthesis.

In this work a new means-ends analysis formulation for PI is proposed consisting of two segments. In segment 1 a base-case design is proposed following an evolutionary approach for a given reaction path and segment 2 a systematic methodology constituting of five steps is applied as follows: Step 2.1: Problem definition, Step 2.2: Screening of base-case design process bottlenecks, Step 2.3: Tasks-based representation of the base-case design, Step 2.4: Means-ends approach to hierarchically overcome the process bottlenecks, Step 2.5: Task integration. In applying the method different methods and tools are used for example, ProCAMD [5] and SustainPro [6], depending on the characteristics of the possible corrective tasks at each step. To accomplish all the five steps, five tasks are defined: Task 2.1: An objective function is set, Task 2.2: Use of the sustainability analysis/SustainPro developed by Carvalho et al. [7] as a tool to systematically find the process bottlenecks, Task 2.3: Correct representation of the unit operations in tasks defined by the type of operation and the property/phenomena exploited, Task 2.4: Means-ends formulation to hierarchically overcome the process bottlenecks. Task 2.5: the final tasks-network needs to be translated into equipment→flowsheet. Some advantages of the methodology are as follows: In Step 2.2, the sustainability analysis only requires steady state data, to screen the process bottlenecks of the process, therefore it is a powerful link for the integration of PI into process design. In step 3, the degrees of freedom are increased by going beyond unit operations to tasks, this is essential to enhance the goal-oriented approach to overcome the bottlenecks in the next step. In the same way that Siirola used the Means-Ends Analysis to go from raw material to products, in step 4, the means-ends is formulated for PI, the goal here is to move from the current tasks-network (base-case design) to a new/modified tasks-network (design) that overcomes the maximum number of bottlenecks given a set of feasible strategic and opportunistic operations. The hierarchy to be followed has the same basic idea as the one applied by Siirola that “methods which change properties lower in the sequence are less likely to also alter properties higher in the sequence” [4]. For example improvements in reaction-related tasks are more likely to also overcome bottlenecks related with the separation than the opposite situation. It is assumed that, at this point, the corrective tasks to be proposed just need to be reasonably feasible. In the last step the degrees of freedom provided by the task-based representation are once again exploited in order to integrate the tasks which can lead to either new or existing unit operations; it can be notice that this step might require further experimental validation of the idea generated, however it is believed that the suggested designs will be better than the existing base case design because all the options generated from this step have a higher performance than the existing options.

Future developments are to complete generate and retrieve the different feasible strategic operations to overcome the several possible bottlenecks in a knowledge base. Different methods such as thermodynamic insights [8] can be used to rank the feasibility of the possible operation and a new computer tool can be created to include PI in the synthesis and design of chemical processes. In this poster the method will be presented and its application highlighted through a case study related to the intensification of production of methyl-acetate, starting from a base-case design given in the literature [9]. It will also be shown that using different strategic operations, for example Le Chatelier’s principle, will ultimately lead to the intensification option of reactive distillation.

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