17th European Symposium on Computer Aided Process Engineering – ESCAPE17
V. Plesu and P.S. Agachi (Editors)

Systematic retrofit design of batch processes using an indicator and model based framework

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Abstract

The contribution of this paper presents a systematic, indicator and process heuristics based retrofit method for batch processes. The developed framework considers the identification of improvement opportunities in a generic batch plant by considering also the product market situation. The evaluation of retrofit actions is performed using dynamic batch models.

Keywords systematic batch retrofit, indicators, heuristics, dynamic models

1. Introduction

All existing chemical processes have to be continuously retrofitted in order to improve their efficiency. The retrofit projects are triggered, among other, by increased competition, increasing energy costs, patent expiration and new emission regulations. The goals of the retrofit project are various: capacity expansion of the production capacity, incorporation of new technology, reuse of surplus equipment units, product quality and energy efficiency improvement, operation cost and waste volume reduction.

2. Paper approach

2.1. Methodology

2.1.1. The batch retrofit method structure

The developed systematic batch retrofit methodology has a top-down structure and is presented in Figure 1. The batch plant retrofit is started by gathering information about the production plant layout and recipes. Additional information is collected about the market situation in order to decide upon the business case.

The evaluation of the product market is an important step to be carried out and will shape the path of the retrofitting. From this point of view the market can be limiting or non-limiting. The limited market means that the product cannot be sold in larger amounts than a certain quantity while in the situation of a non-limiting market more product can be sold to the customers. These considerations lead to different retrofit incentives: for the first business case, the same amount should be produced cheaper or with increased quality, while for the second business case, production and sales should be as high as possible, price the cheapest and quality within acceptable limits.

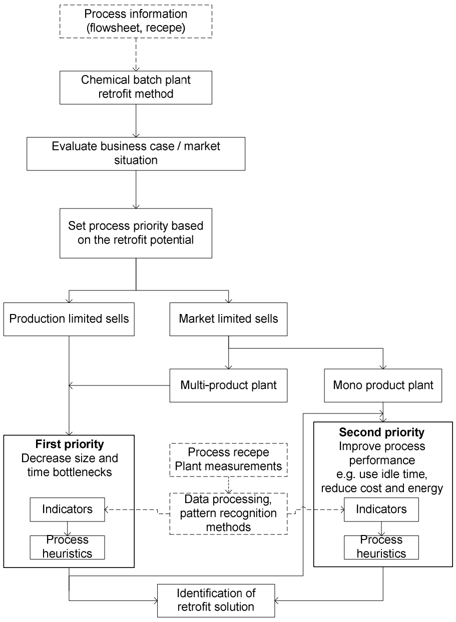

Figure 1 The systematic batch chemical process retrofit framework (continuous line), dashed line represents chemical process information sources and routes

Batch process de-bottlenecking has to be carried out in the case of production limited sells of mono- and multi-product batch plants. When the market limits the sells, the production de-bottlenecking should be carried out for multi-product plants. By this, equipment and resources are made available for other production lines. The goal of batch process de-bottlenecking is to increase the product throughput by increasing the batch size or reducing the cycle time of the bottleneck equipments. It is recommended that first the batch size limitation should be tackled because volume changes might have an influence on operation times.

In the case of a mono product plant operating under market limited sells conditions production increase is not meaningful; however under these conditions, process performance improvement should be done, e.g. equipment idle time usage, cost and energy demand reduction. This improvement step can be carried out additionally to the de-bottlenecking efforts, as shown in Figure 3.

2.1.2. Indicators in the batch framework

The indicators used in this framework are virtual concepts used to monitor the operation or the state of a system. The indicators in their nature are of two types: quantitative and qualitative. One of the most frequent quantitative examples in the chemical engineering field are the dimensionless numbers which show a relation between two phenomena. Qualitative indicator is the reaction quality which shows if a chemical substance has a positive or negative impact on the reaction yield. The type of indicators used for continuous processes [1] are not enough to describe a batch process in detail, due to the difference in their nature. For a batch process several other indicators are needed expressing the time related characteristics of a process such as cycle and batch times; size related indicators are the batch size, filling degree. Additionally to the set of indicators presented above, indicators are needed to describe the unit specific operations in detail and the unit operation variability.

The set of indicators proposed for this batch process analysis framework are the process performance -, unit operation specific -, and path flow indicators, Figure 2.

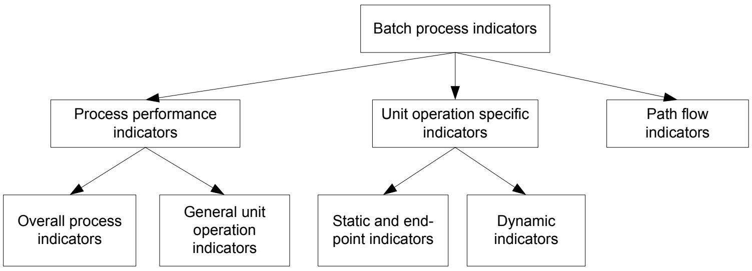

Figure 2 Indicators in the systematic batch process retrofit method

The general unit operation indicators can be calculated for any of the batch processing unit and are time and volume utilization related. Also in this category belong indicators which assess the batch to batch variability of parameters. The unit operation specific group of indicators consists of static and dynamic indicators. The static indicators comprise the parameters which are constant or are measured only at the beginning and at the end of the processing and the dynamic indicators capture process states at different moments during the batch processing. The last category of indicators is the path flow related class and is part of the path flow based process analysis method developed by Uerdingen et al. [1]. Often dynamic batch models [2] are used to calculate some of the indicators.

2.1.3. Process heuristics

The selected process heuristics, Table 1, are used to find retrofit actions.

Table 1 The unit specific heuristics

Indicator	Heuristics
Reactor	
Initial and end point indicators	
Selectivity	In order to increase the selectivity for an intermediate component an optimal temperature or feeding profile should be calculated, depending on the reaction scheme [3] (difference in activation energy or reaction order). If unwanted products are formed in concentrations below 1-3% then check for main product thermal decomposition, decrease operating temperature or reaction time, and check the catalyst selectivity. If unwanted products are formed in concentrations significantly higher the reaction selectivity is low
Conversion	Maximize conversion by shifting equilibrium
Vapor rise speed (VRS)	Optimize reaction rate under swelling constraint, using temperature and pressure as control variables in optimal control strategy
Heat transfer area change (HTA)	Increase heat transfer area by considering direct heating or an additional heat exchanger in an external loop

2.2. Case study

The production site is a mono-product batch plant with parallel production lines. The processing sequence starts with the reactor where the fine chemical is produced and continues with the crystallizer. After this, centrifugation is performed and the processing is ended with the product drying. The first buffer tank can be found between the reactor and crystallizer in order to eliminate the down-stream processing waiting time and to homogenize the reaction product. The two reactors operate out of phase which means there is a continuous feed to the buffer. The second set of buffers can be found between the crystallizer and the centrifuges and their role is to free-up the crystallizers after crystallization is finished. With the same goal the third set of buffers can be found between the centrifuge and dryer.

2.3. Results and discussions

2.3.1. Evaluation of the market situation and the retrofit potential

After the evaluation of the product business case it was concluded that the market is not limiting and more final product could be sold. This means that the primary retrofit goal of this fine chemical case study is the production capacity expansion. The retrofit potential from capacity expansion point of view is calculated by assuming that the current productivity bottleneck is eliminated.

2.3.2. Retrofit actions

The retrofit actions are generated systematically one-by-one by relating the indicator values to the list of heuristics and this procedure will be demonstrated below. Based on the assessment results for the fine chemical batch process this section discusses in order of descending improvement potential, which retrofit actions are found to be applicable. In order to increase the plant throughput the overall process productivity de-bottlenecking actions are proposed, see Table 2.

Table 2 Overall process productivity de-bottlenecking and path flow retrofit actions

	Retrofit actions and ranking	**Effect on**	**Implementation difficulty**	**Estimated retrofit potential / batch [%]**
1.	Add a second dryer or a larger one	Time, productivity, equipment cost	High	43
2.	Divide drying and cooling down in separate units	Productivity, equipment costs	High	30
3.	Install an alarm to show the end point of drying	Time variations, productivity, equipment costs	Low	15
4.	Decrease utility temperature	Time, productivity, utility costs (brine)	Medium	13

The proposed retrofit actions tackle the first productivity bottleneck, namely the dryer and the realization of these actions might increase the plant productivity between 13 - 43 %. The first productivity bottleneck is considered the unit with the lowest productivity of all units. The first action in this class is the addition of a second dryer or a larger one. By this the dryer productivity is doubled; however now the process productivity bottleneck would be the crystallizer and closely followed by the reactor. The second retrofit action has a retrofit potential of around 30% productivity increase and implies the separation of the drying and cooling processes performed in the dryer. The third retrofit action is suggested by the heuristics for the variability indicator and considers the introduction of an alarm which signals the termination of a dryer batch. It is concluded that if the drying time variation is reduced by half then a productivity increase of 15 % can be achieved without any major investment. Similar retrofit potential is shown by the fourth retrofit action which indicates the reduction of the cooling utility temperature; therefore the dryer mass is cooled faster. This retrofit action is concluded based on the heuristics for the task share indicator calculated for the dryer; the implementation of this retrofit action implies the change of the cooling media and cooling capacity.

3. Conclusions

A systematic indicator, heuristics and process model based framework for retrofitting chemical batch processes and its application to a fine chemical case study was presented. The developed framework considers the identification of improvement opportunities in a batch plant by considering first the product market situation. The batch plant analysis is structured on three levels: the plant, the process, and the unit operation level, respectively. The analysis of these levels is based on indicators which are of various types and specific for each analysis level. These indicators are linked to heuristics which are used to identify the retrofit actions. Finally, for each identified retrofit action the improvement potential is calculated using process models in order to assess its importance. The developed method was successfully applied to a fine chemical batch production facility and it was able to identify in a systematic way several retrofit actions with significant improvement potential.

The benefits of the proposed framework are that it guides the decision maker in a systematic manner through the process analysis towards the generation of retrofit actions. Thus, the method is capable to identify improvement opportunities which are not straightforward and might be neglected.

References

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