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Integration of ecological aspects during process development and design – A case study of batch to continuous production

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Abstract

Sustainability has become a major topic in product and process development strategy for many companies. Development and design of resource-efficient processes are key factors and represent a substantial contribution to the improvement. The transfer of manufacturing processes from batch to continuous operation may contribute considerably to this goal. The basis for process redesign are experimental trials and the development of suitable equipment. In a case study, such a transfer has been conducted accompanied by technological, economic and ecological assessments. An analysis of the existing batch process supported by material flow modelling generated a reference point for the developed production process.

Keywords: ecological assessment; batch to conti; process development; energy efficiency; micro process engineering

Nomenclature

Eq.	equivalents
UO	unit operation
DCB	dichlorobenzene

1. Introduction

In 2007, the Federal German Government has stated their goal to reduce the German greenhouse gas emissions by 40 % until 2020 in comparison to the international reference year 1990 [1]. A big contribution to reach these goals are expected from the material-conversion industries with their high energy and resource demand. For instance, the implementation of heat integration measures can lead to a significant increase in the energy efficiency and thus to the reduction of CO_2 in production processes [2].

Most of the products in the process industry, such as fine chemicals, aromatic or pharmaceutically active substances, are produced batchwise or semi-continuously. This means, the individual process steps are carried out in succession, often in the same apparatus such as stirred tank reactors with jacket heating or cooling capacity. These processes frequently show disadvantages in regards to the energy input for mixing, heating and reaction due to the limits of the equipment. Additionally, the discontinuous mode of operation requires numerous cleaning and rinsing steps to eliminate the possibility of a cross contamination after a product change in the same apparatus. As a result, large quantities of water and utilities are required and have to be disposed properly afterwards. Additionally, rinsing and cleaning steps are usually accompanied by product losses. These disadvantages are expected to be diminished through the transfer of a batchwise to a continuous mode of production, leading to higher energy efficiency and cost reduction, for example through the possibility of heat integration and thus strengthening the competitiveness [3].

In an industrial case study in the framework of the research project *μKontE*, funded by the Federal Ministry for Economic Affairs and Energy, the transfer of a batch to continuous production process of a binding agent emulsion has been

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investigated. The existing batch process as well as the newly developed continuous production process have been assessed in regards to their technological, economic and ecological performance. Based on the initial analysis of the batch process, measures for improvement of the energy and resource efficiency were determined and taken into account in the design of the continuous process. This contribution will give an overview of the analyses and their results with focus on the ecological point of view. The results will be compared to existing investigations of Kralisch et al. [4], who investigated the transfer of a chemical synthesis from a macro-scale batch to continuous micro-scale setup as well as Grundemann and Scholl [5], who reported a significant reduction of the environmental impacts of a writing ink production through the transfer from batch to a continuous campaign production.

2. Case study

The investigated batch process was provided by AURO Pflanzenchemie AG [6], a paint and coating manufacturer based in Braunschweig, Germany. The original batch process was performed in a stirred tank vessel in which the solid-containing and highly viscous natural reactants were added consecutively. Under constant stirring, the production mix underwent several heating, cooling and reaction steps.

2.1. Process modeling

The processes were depicted in material flow models with the software umberto® [7]. Material flow modelling enables the generation of consistent mass and energy balances as well as a detailed depiction of the process. This way, the mass and energy flows can be assigned to their actual location of consumption.

For a detailed balancing and assessment of a production process, Wesche et al. [8] proposed the classification of the inputs and outputs into reactants, auxiliaries, utilities and energy on the input side as well as the product, emissions and residual materials on the output side. Furthermore, the expenditures related to the equipment should be detected. Based on this information the consumption data and economic as well as ecological impacts can be evaluated. Focus analyses and sensitivity studies support the investigations to identify efficiency potentials achievable through the implementation of new technologies, e.g. microfluidic equipment, or process redesign, e.g. transfer of batch to continuous production. Afterwards, the technical feasibility of the identified potential alternatives has to be verified.

To support the design of a new production process during research and development, the process analysis has to be carried out in different levels of detail. At first, the process section with highest energy and resource consumption as well as economic and ecological impact has to be identified and afterwards the values have to be assigned to the process steps or apparatuses. A systematic assessment and the identification of potentials can be supported by a suitable modelling approach such as the 3-Level-Model [8], see fig. 1.

The approach follows a modular concept and is oriented towards a typical depiction of manufacturing processes which are structured as a sequence of unit operations (UO). This sequence is presented in the second level of the model. In the first level single UOs are modelled in detail. This comprises the depiction of the single process steps as well as the operated apparatuses and equipment. The third level reflects the operating infrastructure.

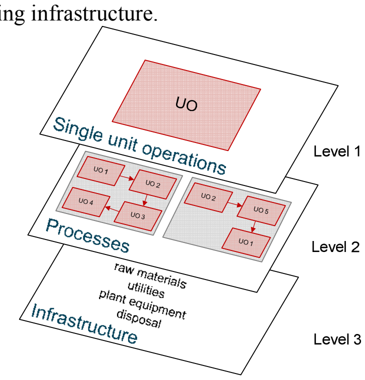

Fig. 1. 3-Level-Model, adapted from Wesche et al. [8]

This modelling structure enables balancing as well as focus and sensitivity analyses in different level of detail. Through the integration of costs and ecological factors a holistic process assessment can be achieved.

For the batch process, the modelling was structured as follows: On the second level, the combination of UOs (mixing, mechanical disintegration, reaction, separation) was modelled, complemented by cleaning procedures, stand-by operation as well as internal transports. The individual UO was modelled with all process steps, e.g. heating, stirring, cooling, pumping, etc. in detail on the first level. The modelling of process was then integrated into the existing infrastructure of the AURO production site on the third level. This included for example the supply of heating media and water as well as external transports and the residue disposal.

For the continuous process, the modeling of the third level displaying the infrastructure as well as the second level with the sequence of UOs remains unchanged. Only the operation of the UOs on the first level had to be modified to reflect the investigated process alternatives.

2.2. Analysis and assessment

Recording and modeling of the existing batch process provided a benchmark for the process assessment. Therefore, appropriate system boundaries had to be defined for the batch production which were also applicable for the continuous process to enable a conclusive comparison between both of them. A "cradle-to-gate" approach was chosen for the assessment considering all expenditures directly related to the individual production processes. Neither the use phase, nor the distribution or the disposal of the product or produced intermediates were considered since they would not be affected by a process change and thus have no impact in the comparison. Focus of the assessment was on the energy and resource consumption and production related emissions.