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IS FLEXIBLE CONTINUOUS MANUFACTURING AN OXYMORON?

Global competition is pushing the industry towards faster Time-To-Market and more efficient and flexible processes. Modular plants are seen as potential bridges between the flexibility of batch plants and the efficiency of continuous processes, which could improve the competitiveness of the chemical industry. A modular plant system is presented in this document.

Introduction: Batch vs Continuous Manufacturing

Batch manufacturing has been the main technology used in fine chemical production, where high flexibility is desirable. Continuous processes are more efficient than batch and generally not flexible. On the other hand, competition has been pushing towards more efficient productions and continuous manufacturing has been reshaped in modular plants in order to be more competitive [1].

The benefits of continuous manufacturing have been identified in the past such as better heat transfer, improved mixing, higher temperature, automation and smaller equipment [2]. Process intensification has improved the overall efficiency of continuous processes [3].

From a business perspective, costs are one of the main drivers for decision making and therefore it is always needed to create a business case, in order to compare the economic benefits of batch vs continuous processes. In Tab. 1, a general overview of some case studies is presented.

Shifting batch to continuous manufacturing leads to smaller equipment and more efficient processes in general. In some cases, higher costs might be reported. Continuous processes need to be optimized before a comparison and economic analysis can be made toward optimized existing batch processes.

Modular Plants

Modular plants are functional units or sections which are usually preassembled in a skid representing a

unit operation e.g. dosing, chemical reaction, crystallization etc. Units could be standardized or they could represent unique and customized engineering systems, which can be easily run together. These sections can be used, exchanged or numbered up depending on the production necessities. Modularity allows to be flexible in fast changing markets. These standard sections or skids can be combined in different setups depending on the process requirements. Standardized modules present advantages such as faster ROI (Return on Investment), shorter lead time, reduced installation time, faster market access and reduced initial investment [14-17].

Even though modular plants present advantages, they cannot compete with economies of scale, if they were to be used in bulk production, where production capacities are much higher [14].

These new systems, due to the advantages in process performance and safety, start to outclass classic batch processes in fine chemical industry regarding economic efficiency. Modular plants would potentially have a learning curve, during the first period of implementation and it needs to be considered that batch processes have been known and optimized for decades, consequently potential problems during production are better understood and solved.

Control System and Standard Modules

One of the essential aspects of the modular plants is having a control system capable of identifying and intercommunicating between the modules. An au-



Process	Capital costs	Operational	Total Cost Reduction	Source
API synthesis and formulation	-	-	From -9 % up to -40 %	[4]
Distillation	-19% up to +36% CAPEX expenditure depending on the configuration	Energy consumption in continuous processes is up to 50% lower	Highest cost reduction: -28%. Some configurations increased the production costs up to 5%	[5]
API synthesis	-19.6% up to -57%	-29.3% up to -51.6%	-20.1% up to -54.5%	[6]
Nitration, Hydrogenation	-35% up to -43% (defined as plant depreciation)	Lower energy, waste, labor, water, solvent and catalyst	Capital and operational costs were lower in both case scenarios	[7]
Hydrogenation	Reduced (amount not described)	Reduced (amount not described)	-	[8]
Biodiesel production	+20.19% increased	-0.66%	-	[9]
Biopharm: Downstream processing (500 kg/h)	-39%	-33%	-	[10]
Biogas - Modelling	-	-	Batch is better than continuous. Cost per unit volume 6 times lower	[11]
Micro / Millicontinuous Writing ink	Capital costs continuous process are 2.8 times higher	Production costs continuous process are 2.7 time lower	Continuous manufacturing costs are ~1/3 of the batch manufacturing costs	[12]
Pharma - LLE	Cost reduction 25.6-36.3%	Cost can increase or decrease depending on method	Cost savings 1.6% up to 37.4% (depending on method)	[13]

Tab. 1 - Cost Comparison: Batch vs Continuous Processes

tomation system for modular plants ideally allows changes to be done by the operator without modifying the control program itself. A desktop computer could be used as an analogy (physical connection without the need to update the operating system).

There are some guidelines/recommendations which have already been introduced in order to apply the modularity approach such as the NE 148 from NAMUR [19]. Fig. 1 shows a general overview of the automation concept based on the work of Ladiges *et al.* [21]. Each unit has its own automation system (PLC) and the addition and/or removal of any of the modules does not require to modify the automation for the whole system, in other words each section is independent with its own alarm management, process controls, HMI, etc. The interaction and communication between modules could be performed by the use of the OPC UA architecture [21].

Standardized approaches offer many advantages, such as easier and faster integration of modules even if they are provided from different suppliers. The most important aspect is the reduced time regarding

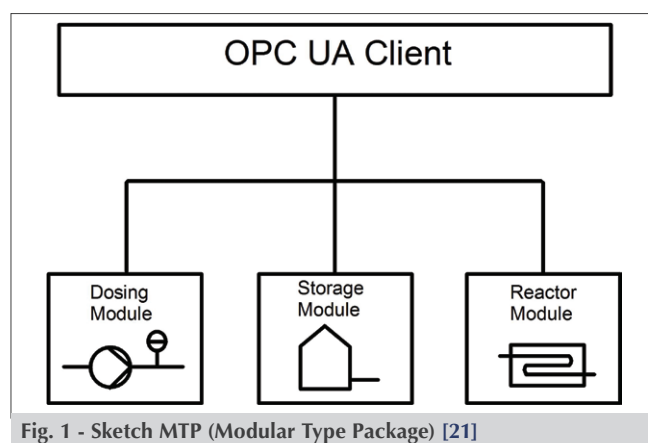


Fig. 1 - Sketch MTP (Modular Type Package) [21]

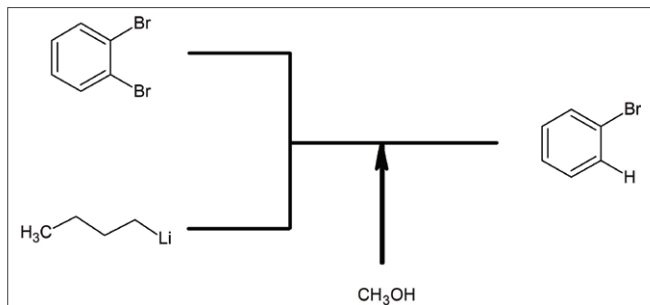


Fig. 2 - Organometallic reaction [20]

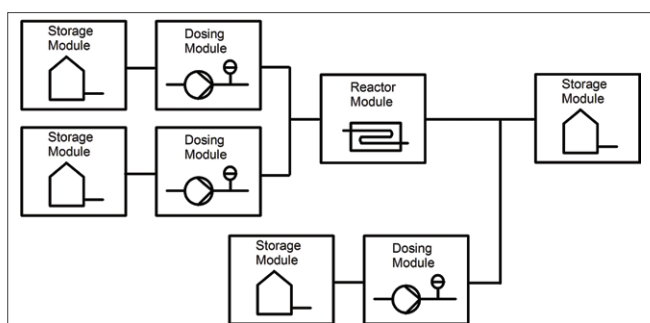


Fig. 3 - Sketch modules for an organometallic reaction

setting up a new plant or modifying an existing one, where the need to update the control system whenever a change is done is avoided.

Although modular plants offer many advantages, there are still some aspects which need to be addressed such as how to integrate this new approach with old production plants. On top of that, processes would need to be redesigned and standardization of modules should be implemented across the industry [18]. Many of these disadvantages could be easily addressed once the acceptance and operation of the system increases.

Study Case:

An Organometallic Reaction

In order to exemplify how a modular approach could be applied, an organometallic reaction was used. The reaction is based on lithium-halogen exchanged reported by Gioello *et al.* [20] (Fig. 2).

Based on the process requirements a total of 3 liquid dosing units, 1 reac-

tor module for high exothermic processes, including a quench mixer and 4 storage modules would be needed. As it can be seen from Fig. 3, the plant is split up in different functional sections and each of these sections works as an independent equipment with its own control system. Changing the module configuration or the recipe is a simple configuration task which can be done by the operator (with the proper user rights). The biggest advantage relies on not needing to reprogram the control system and only the physical modification taking place simply by doing the fluidic and utility connections.

Having predefined functional sections means that for a specific step, such as a high pressure liquid section (dosing module), most of the effort on the design can be avoided, which saves money and time. Consequently, these sections can be utilized for different processes, depending on the requirements of the process.

This methodology is applicable where flexibility is fundamental, e.g. to fine chemical production, where productions in campaigns are usual. Actually capacities up to 100 t/y are achievable with available systems. The same concept has been used for different projects built on site, which can be seen in Figs. 4 and 5.

In Fig. 4 two modules used for API production are represented. The modules are used in a cryogenic solid/liquid reaction with additional quench step

and the starting material is HF at high concentration. The upper section is a liquid dosing unit in stainless steel used for quenching and the lower section is a metal-free liquid dosing module (metal-free due to HF). Fig. 5 represents three different modules for crystallization in COBC/R. The complete plant is composed of a total of five modules and the three sections represented in the figure starting from the right side of the image are: liquid dosing module, seed slurry module and the crystallizer module, the remaining modules are the heating/cooling module and a storage module under controlled conditions for the crystals. Additionally, if needed a separation and filtration module

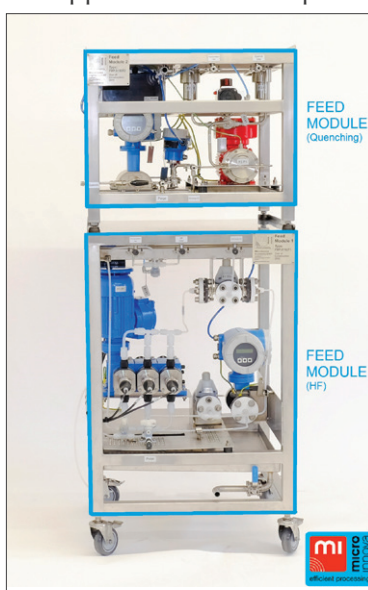


Fig. 4 - Example of two modules for API production



could be added to the plant from Fig. 5 (Flexible approach).

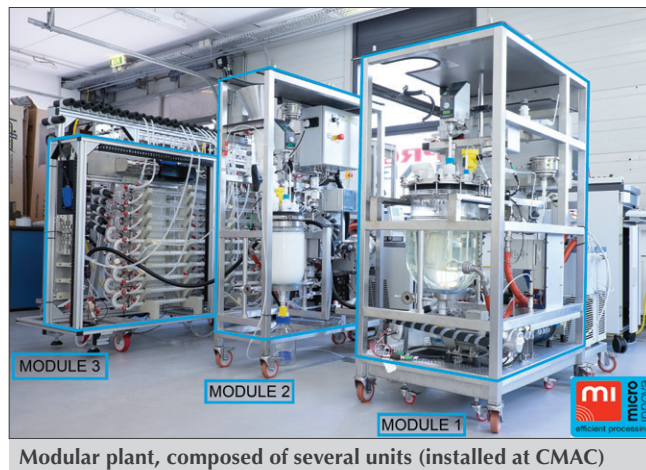
Conclusions

Modular plants have the potential to improve the efficiency and flexibility of fine chemical production. They offer several advantages and are technically feasible. The biggest challenge still remains an overall implementation and standardization across the industry, which would ease the transition from batch to continuous and flexible manufacturing.

Acknowledgments: This project has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement No. 721290. This publication reflects only the author's view, exempting the Community from any liability. Project website: <http://cosmic-etn.eu/>

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Modular plant, composed of several units (installed at CMAC)

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La produzione flessibile in continuo è un ossimoro?

La competizione globale sta spingendo l'industria chimica verso tempi sempre più rapidi per arrivare sul mercato e processi più efficienti e flessibili. Gli impianti modulari sono visti come un potenziale ponte tra la flessibilità degli impianti batch e l'efficienza dei processi in continuo, che potrebbero migliorare la competitività dell'industria chimica. Un sistema di impianti modulari è presentato in questo documento.