Modern Technologies for Optimised Speciality Chemicals Production Processes

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1 Abstract:

This paper describes, from a strategic point of view, the efforts of two parties working towards the sustainable and successful industrial application of precisely micro-structured chemical reactors. For this, a strategic alliance was formed between Clariant Competence Center for MicroReactionTechnology (C³-MRT), a user of such devices, and the Heatric division of Meggitt plc, who model, design and manufacture compact Printed Circuit Heat Exchangers (PCHEs) and Printed Circuit Reactors (PCRs). The concept of using PCHEs as chemical reactors, comparable to an array of miniaturised tubular reactors and, thus, an example for one type of a microreactor, was first proposed in the mid 1980-s [1]. Subsequent development has resulted in the evolution of a broad family of PCRs, including products embracing micro reaction technology (MRT).

Recognition of the benefits of MRT, and increased user acceptance, has led to a multitude of devices available today. Furthermore, the technical and operational feasibility of successful and reliable pilot scale operation of such devices, in an industrial environment, has been demonstrated recently [2]. Therefore, micro reactors are of great interest for chemical, pharmaceutical and biotechnical applications today [3]. These devices with channel dimensions in the micrometer range are a state of the art tool for R&D [4], [5]. This explains why many textbooks have been published on this innovative R&D technology e.g. [6], [7], [8].

The use of micro reaction technology in chemical synthesis has the potential to deliver products with improved yield, higher selectivity and with economies that were previously not possible. In the practical world of commercial chemical synthesis, these features deliver a wide range of benefits which will also be discussed in the paper.

Nevertheless, a conclusive break-through in MRT, especially in industrial production processes, has yet to come. From the viewpoint of a process operator, it appears that complete production processes based on MRT devices can only be realised through a synergistic combination of chemistry, process operations, and industrial equipment design and manufacturing know-how. Therefore, Heatric and C³-MRT have formed a strategic alliance and now follow together as equal partners the path towards production scale MRT processes. This alliance combines a deep knowledge in the field of speciality chemicals, technologies and production processes with proven capabilities of producing large-scale micro structured heat exchangers as well as customised micro structured devices for chemical reactions.

2 Introduction: Clariant's MRT Roadmap to establishing Heatric as Preferred Supplier

At the end of the 1990-s, Clariant recognised the potential of micro reaction technology (MRT) for modern state of the art processes and development of chemical specialty products. As MRT was a rather immature technique for R&D and process development, it was decided to start initially with an external experimental feasibility study in the field of pigments synthesis, before commencing practical in-house MRT investigations.

This approach minimised the financial risk of investing in an as yet unproven, but highly interesting and promising technology. Subsequent to the suitability of MRT as an alternative R&D tool having been demonstrated in principle, milestones for implementation of MRT at Clariant were established as follows, see *figure 1*.

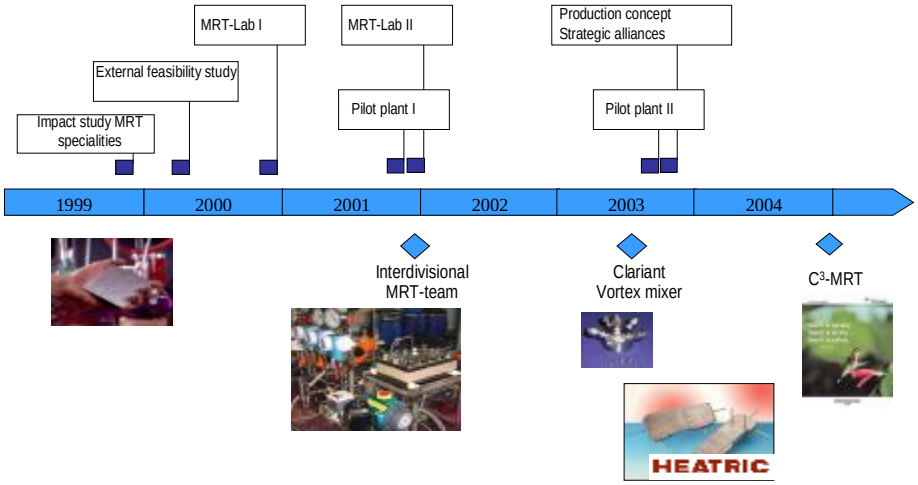


Figure 1: MRT roadmap at Clariant and steps towards a cooperation with Heatric as preferred supplier.

After successfully completing the model feasibility study in 2000, Clariant set up in-house MRT resources and subsequently started the first lab dedicated solely to MRT related R&D-investigations, including process development in Clariant's Pigments & Additives Division. The reason for this was that only demonstrators and prototypes of micro devices, rather than reliable standard equipment, i.e. no plug-and-play-solutions, were available in this young research field at the time. Specifically, the task of technical development with respect to adapting MRT to the Clariant environment was assigned to an interdisciplinary team of process and chemical engineers as well as chemists.

At the end of 2001, a second MRT lab in the Life-Science-Chemicals Division was established. At the same time, a pilot plant based on micro reactors was successfully completed based on modern production scale process technologies for Division Pigments & Additives. This MRT plant was designed for the three-step synthesis of an azo-pigment and, thus, consists of three serialized reaction stages, of which the core component was a stack of three parallel micro reactors.

These MRT lab and pilot plant capacities were used between 2001-2003 in a network of an interdisciplinary and interdivisional MRT team. Work covered typical exothermic and/or mass transfer limited reactions like air-oxidation, nitration, side-chain-chlorination, acetoacetylation and coupling of azo-pigments including diazotation and the laking-step.

One benefit of MRT supported R&D was very quickly established. For example, critical reaction parameters need to be validated only once in continuously operated micro devices and remain valid during subsequent pilot and scale-up phases. Unlike batch processes, optimum reaction parameters, for example constant temperature and ideal mixing, are established much more quickly and can be more accurately controlled.

However, MRT cannot and will not fully replace a traditional batch production plant. The devices have their advantages in the reaction step and in the preparation of reaction components that require efficient mixing, but MRT cannot substitute all reactions and preparation steps of a chemical reaction and subsequent product isolation. However, MRT certainly offers a quick and inexpensive alternative to replace steps of the manufacturing process wherever appropriate.

Inspired by this important conclusion, the Clariant Competence Center MicroReactionTechnology (C^3-MRT) was founded at the beginning of 2004, to ensure availability of the generated MRT expertise within the whole Clariant Corporation. It enables the interdivisional MRT team access to further promising reactions with optimization potential and needs, which require process intensification through micro devices.

This all-embracing application know-how led - among other things - to the design of Clariant's vortex-mixer and, according to the principle of multi-scale approach [2, 8], to a second pilot plant based on this special Clariant mixer. Moreover whilst screening micro devices available on the market (as well as a first future-oriented concept for a production plant based on micro reactors) it was discovered that there was no reliable supplier, who could potentially deliver micro structured production scale reactors in future.

3 Switching from Batch to Continuous Synthesis in Micro reactors – an Example of Process Intensification in the Field of Pigments Synthesis

Switching from a batch pigment synthesis to a continuous synthesis in a micro reactor requires

- a complete survey of, as well as re-thinking about, the synthesis and - especially challenging -
- a solution for de-bottlenecking of potential fouling and blocking phenomenon, which may arise, when suspensions have to be handled in small structures such as in reaction channels of a micro structured device.

For a classic batch process, at least 2-3 tank reactors are needed for operational steps such as dissolving, precipitation or clear filtration of raw materials and, obviously, for the reaction itself. After pigments synthesis, filters are also used for preparing the pigment suspension generated, see *figure 2*.

Figure 2: Continuously stirred tank reactor for coupling-reaction of an azo-pigment and filter press used for separating pigment press cake from coupling suspension.

For a better understanding of the difficulties faced, when transferring an azo-pigment synthesis from a batch to a continuous process, the complexity of the reaction mechanism is described in more detail below.

Azo-pigments are generally synthesised in a 3-step reaction, i.e. diazotation, coupling and laking. Diazotation is a reaction of a primary aromatic amine with a nitro sating agent such as sodium nitrite. The resulting diazo-suspension/ solution is then

mixed together with a coupling agent for the coupling-step according to equation 1 [10].

$$Ar\text{-}N^{\oplus}\,N^{\ominus}Y + RH \rightarrow AR\text{-}N \;\backslash\!\backslash\; N\text{-}R + HY$$

Ar : (Hetero)aromatic group
R : Coupling component residue
Y : Cl, HSO_4

(equ. 1)

The coupling reaction itself is an exothermic electrophilic substitution of a diazonium compound ($Ar\text{-}N^{\oplus}\,N^{\ominus}Y$) with a coupling component (RH). The free acid produced (HY) has to be buffered by additional feeding of a solution of sodium hydroxide or by using an internal buffer. In the final laking-step the pigment's colouristic properties are adjusted in a special treatment under pressure and at elevated temperature. The synthesis is then followed by processes like separating the pigment from the yielded suspension, washing the press cake free of chloride, drying and milling.
Apart from the essential procedure for preparing the raw materials and also the final preparation of the pigment, the complete 3-step synthesis was transferred into three separate micro reactors operated in series. figure 3 shows the principal set-up of a first pilot plant based on micro reactors and a picture of the complete 2nd reaction stage. (A magnification of the core of one reaction stage and the housing, in which three parallel micro reactors are embedded, is shown in figure 1 bottom, centre.)

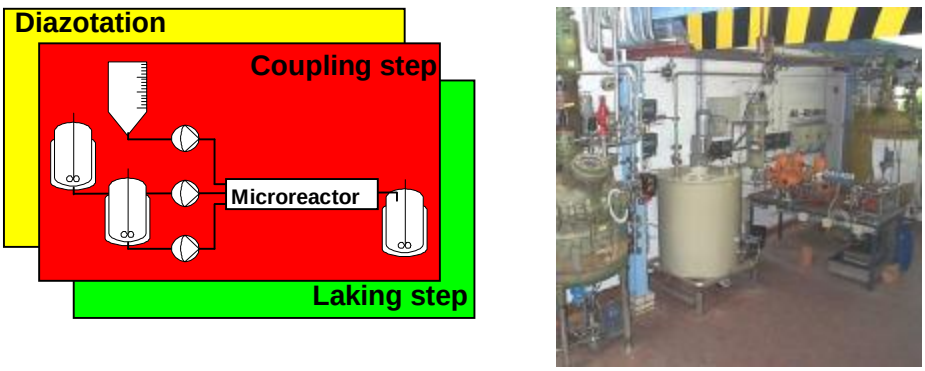


Figure 3: Principal set-up of a micro reactor pilot plant (left) and picture of the coupling-stage (right).

Before and after each reaction stage, conventional vessels or tanks (reactors) made of plastic, steel glass or enamel (glass-lined) are used. They are dedicated to storing or preparing raw materials as well as collecting intermediates from the previous reaction stage, respectively. For example, the storage tank for the diazo solution/ suspension at the outlet of the diazotation stage is, at the same time, one of the three feed vessels for the following coupling stage. In doing so, all three reaction stages are connected and are operated in series.
Before discussing the trend-setting results generated with the 3-stage micro reactor pilot plant, one very important issue has to be highlighted: In order to ensure steady-state conditions of the continuous synthesis in terms of reliability, as well as reproducible results, a technique had to be established for how to avoid potential blockages of the micro channels due to settling and/or adhesion of solid particles on surfaces of the inside of the micro channel. In some cases particles are fed as insoluble component of a raw material into the micro reactor, but in the end all produced pigments are in-soluble colorants with adhesive properties which vary from pigment to pigment.

It soon became apparent that blockages due to raw materials in suspended form can be totally excluded by use of specially-dedicated in-line dispersing machines, which are operated at the suction inlet of the dosing pumps. But finding a solution to overcome difficulties due to adhesive pigment suspension needed a completely different approach.

3.1 Handling of Pigment Suspension in Micro Structured Devices

Synthesis of pigments is synonymous with handling suspensions. Some pigment syntheses require handling of raw materials in suspended form from the first step onwards - be it a diazo-suspension or a suspension of the coupling component or even both of them in suspended form. Each pigment's synthesis generates a pigment suspension with varying properties concerning the extent of adhesion to surfaces.

Bearing in mind that this can be a bottleneck or even a knock-out criterion when using micro devices in R&D, and probably an insurmountable hurdle for production scale applications in general [11], Clariant deliberately decided to choose a pigment synthesis to be a first model reaction for investigations by use of MRT. The philosophy behind this was the belief, that if one finds a solution for clogging-free operation of micro devices with respect to the challenge of handling pigments suspensions in general, then one would be in a position to also overcome fouling problems, when working with non-suspended reaction systems like homogeneous liquid-liquid or heterogeneous gas-liquid systems.

In the end, in the framework of daily process development for specialty pigments using micro reaction technology, a method and device for process-attendant cleaning of micro- and mini-reactors was developed [12]. Indeed, when synthesising pigments in micro channels a pressure increase was observed *figure 4 (1),* which is due to crystallisation of pigment particles on the surfaces of the structures. This can lead to a total blockage, initially of a single passage and in the long run of all parallel reaction channels, when the thickness of the coating fills the complete flow cross section.

But a micro reactor breakdown can be avoided by use of the following technique: A pressure indicator mounted at the inlet of the micro reactor continuously measures the pressure loss in the micro reactor and controls an automatically controlled valve at the outlet. If a certain pigment-specific, maximum working pressure is exceeded, a pressure cleaning process is initiated. The micro reactor's valve at the outlet is closed for a few seconds to attain peak pressure, which is at least ten times higher than the average working pressure at steady state conditions of the synthesis. Then the valve is suddenly opened. Through the rapid change of flow rate - from zero to a maximum effluent speed corresponding to the peak pressure – the correlated change of surface shear forces, the pigment coating is removed almost completely and, thus, the working pressure drops back down to the desired steady-state operation value according to flow rate and viscosity of the pigment suspension. In a continuous 2-week campaign to produce 125 kg of a specialty pigment it was shown, that this technique allows unlimited and, most importantly, clogging-free operation. *Figure 4* shows, what would happen without taking any measurements as well as the positive effect of the pressure cleaning process, respectively.

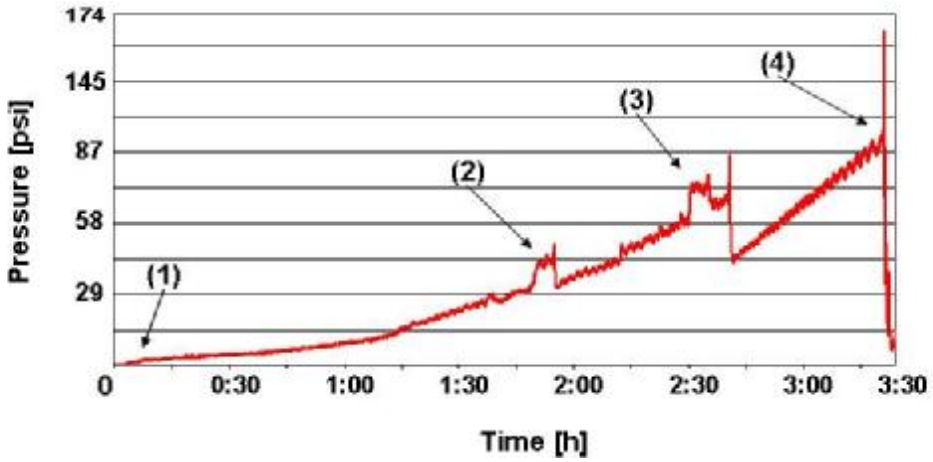


Figure 4: Demonstration of the pressure cleaning working principle.

A pigment synthesis in a micro reactor is normally started by changing the feed from water to the reactants, e.g. diazo and coupling compound as well as sodium hydroxide solution in the coupling step. Due to the instant formation of pigment, the viscosity and, thus, pressure increases, see *figure 4 (1)*. In turn, the pressure loss inside the micro reactor rises due to growth of the pigment coating on the reaction channel surfaces - in the beginning nearly linearly, later on with a slight tendency to an exponential drift.

Temporary pressure peaks without any external impact can be observed, sometimes followed by no pressure drop *(2)*, sometimes with a slight pressure drop *(3)*. But in both cases, the pressure immediately starts rising again rapidly. It is clear from *figure 4* that the pressure would increase further exponentially, until the maximum pump pressure is reached or the micro reactor is totally blocked. Both would result in an end to the steady-state synthesis conditions. Fortunately, this can be prevented by activating the pressure cleaning procedure described above *(4)*, after which the pressure can be decreased almost to the level of the pressure at the beginning of the operation *(1)*.

Figure 4 fundamentally describes the working principle of the pressure cleaning process. Automating this procedure and transferring all the operation know-how, partially pigment-specific, from several process development routines of various specialty pigments, enables Clariant to maintain the operating pressure in a very narrow gap between 15 and 30 psi. This ensures nearly steady-state reaction conditions with respect to flow speed, residence time and pressure.

3.2 Properties of Micro Reactor Pigments, e.g. PV-Fast Yellow H2GR

All results of the synthesis of azo-pigments in micro reactors have already been discussed in detail in a previous paper [13], therefore, only the most important features of pigment synthesis in micro reactors are shown. *Figure 5* shows corresponding particle size distribution of a MRT derived yellow pigment (1), namely PV-Fast Yellow H2GR (which is one of Clariant's pigments for plastic applications) compared to that one of a former batch standard (2). Additionally, Transmission Electron Microscope (TEM) pictures give a rough idea about the significant difference between particle sizes of micro-reaction and batch-wise synthesized pigments, respectively.

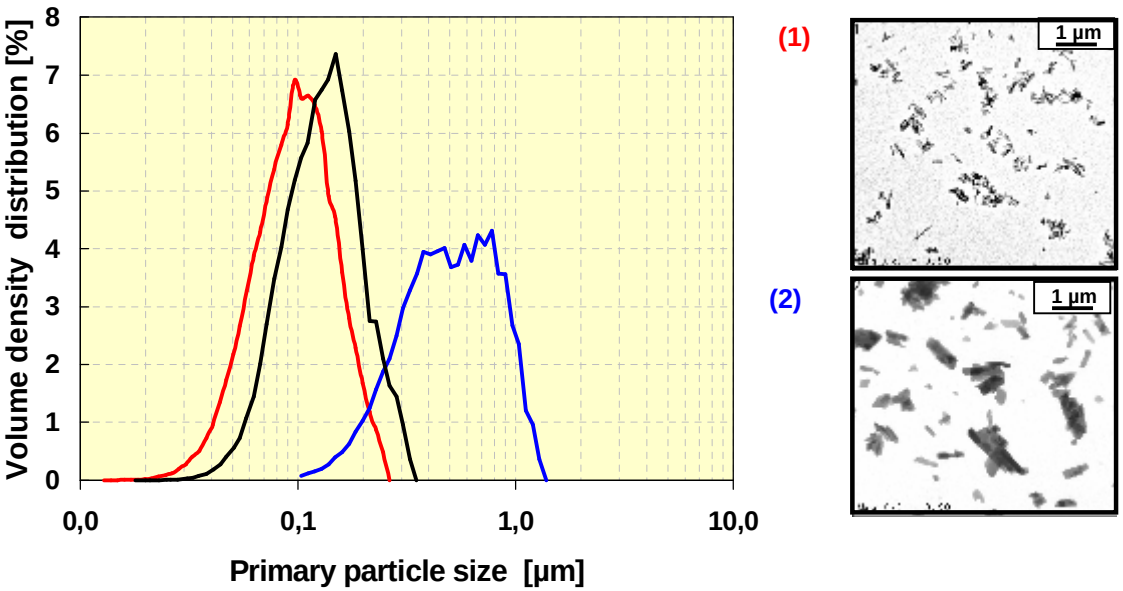


Figure 5: Comparison of a micro reactor pigment produced in a three-step micro reactors synthesis (1) with a former batch pigment standard (2).

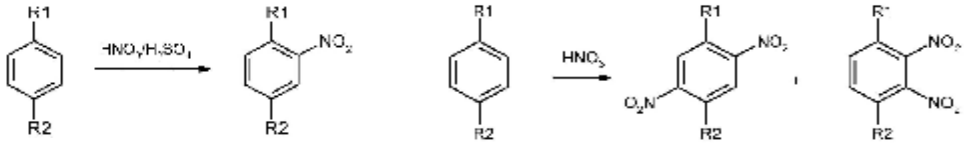
Obviously, by continuous, as well as process-intensified, synthesis of an azo-pigment synthesis in a micro reactor, the particle size distribution of the micro reactor pigment *(1)* is significantly narrower than that of the conventionally produced pigment *(2)* (standard deviation is s = 1.5 and s = 2, respectively). Also, the corresponding values for the average particle size (D_{50}) differ by a factor of 6: Micro reactor pigment has a D_{50}-value of 90 nm, the D_{50}-value of the standard batch pigment amounts to nearly D_{50}= 600 nm.

These improved physical properties lead to a dramatic improvement of colouristic properties such as colour strength and transparency [10] and are primarily due to reaction engineering in small volumes without any back-mixing. Nevertheless, Clariant later succeeded in transferring some of the process intensification know-how into the batch-production *(3)*. Therefore, PV-Fast Yellow H2GR is among the first examples of a Clariant product optimised by MRT.

4 Review of Further Examples of Continuous Micro Reactor Processes

The following examples schematically demonstrate the potential advantages being achieved by using MRT for other applications.

In a typical nitration reaction (see example *(A)* in *figure 6*) results of a short optimisation program demonstrated almost identical product purity at dramatically reduced residence time (MRT: 1.2 s vs. batch: 15 minutes). This can be explained by the extremely high surface-to-volume ratio and shorter path-ways in micro devices, which lead to accelerated mass transfer rates. Besides this improved overall process effectiveness concerning reaction time, it must be pointed out, that compared to conventional technology the detailed process information was achieved in a shorter time period. Rapid parameter-screening was demonstrated.

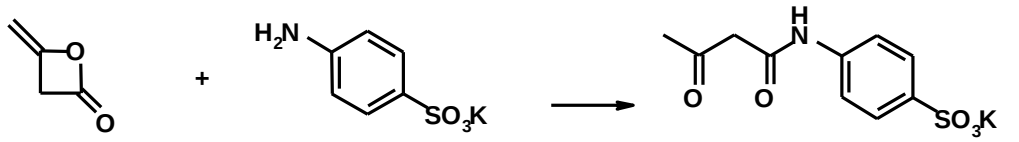


Experiment A: **Example B:**

Figure 6: Continuous nitration of toluene derivatives.

second example *(B)* for another nitration reaction, it shown, that MRT processes can achieve improved selectivity, as can be seen by the desired shift of the isomer ratio from 1:5.7 (batch) towards 1:2.5 (MRT) of the target isomer (2-5-position of the nitro-group). One explanation for this can be the narrow and short residence time inside a continuously operated micro reactor, which reduces competing side reactions.

In another study, initiated by need of process improvement in saving hazardous raw materials, i.e. diketene, the continuous acetoacetylation of an aromatic amine (see *figure 7)* yielded complete conversion as in the batch synthesis. But through continuous processing under well-defined reaction conditions in a micro device with especially high heat exchange capacities, the excess of diketene could be reduced by 50% compared to batch process. At the same time the level of by-products decreased.



Diketene **[Sulphanilic acid aq.]** **AE-Sulphanilic-acid-K-Salt**

Figure 7: Continuous acetoacetylation of an aromatic amine with diketene.

The final example (see *figure 8*) also shows clear operational relevance of micro reaction technology: For the synthesis of phenyl boronic acid it could be demonstrated, that almost regardless of the temperature regime the level of the by-product boronic acid could be reduced significantly with the effect of significantly increased selectivity compared to the batch process. This example also revealed that due to the superior heat exchange properties of micro devices the MRT process could be transferred easily from cryogenic range to ambient temperature. This is a good example for increased process effectiveness of energy consumption, as firstly the costly investment in low temperature equipment and, secondly, the high operating expenses of a process at temperatures below – 15° can be avoided.

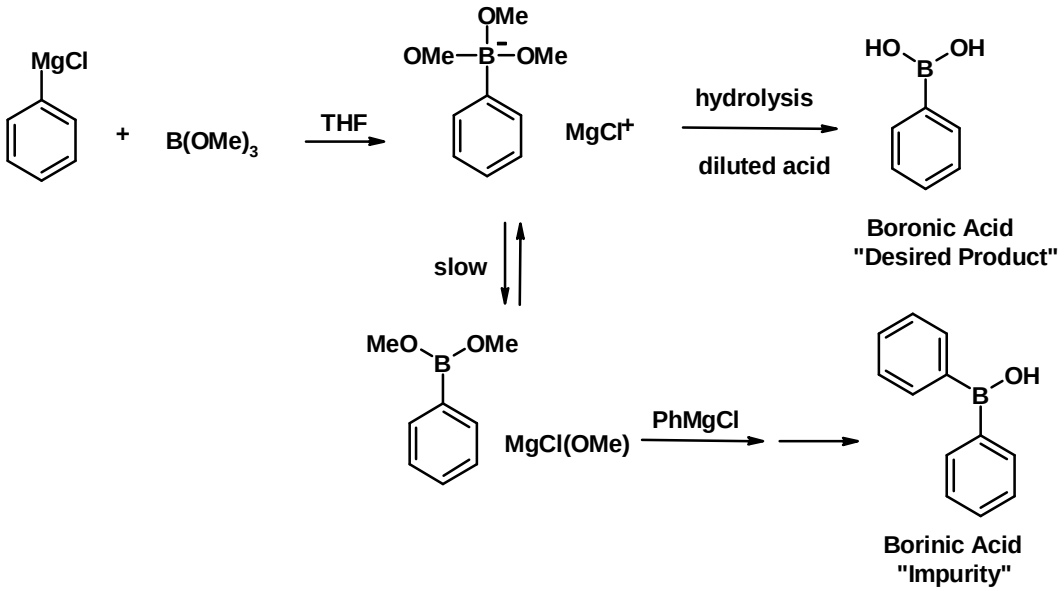


Figure 8: Continuous Synthesis of phenyl boronic acid.

To summarize, this micro reaction technology can offer profound advantages in commercial applications that require rapid scale-up and those that have safety issues at traditional scale as well as reactions that require an uncommonly high temperature, concentration and dosing control of very high purity.

5 Practical Experience with Micro Devices used

In the past three years, Clariant has established MRT application know-how in an industrial environment. According to the concept of simultaneous engineering and parallel processing, the development activities of this technology were rapidly expanded from lab to pilot plant scale, and even a first concept for a production plant based on micro reactors was planned at a very early stage.

While screening various devices[1] made of stainless steel, titanium, Hastelloy as well as glass it was apparent that more or less appropriate equipment is already commercially available for almost every application. This is especially true for R&D applications, where manufacturers are willing to adjust, improve or even modify the devices to user's requirements.

As soon as the hurdle of a pilot scale application is skipped, the performance evaluation of such devices changes somewhat as technical requirements rise. To be prepared for production scale MRT applications, the operator and plant manager expects already for pilot scale application more standardised, handier, more reliable and more sustainable equipment and, most importantly, equipment, which satisfies design regulations of the ASME BPV Code and EC declaration of conformity issued in accordance with the pressure equipment directive (PED 97/23/EC).

According to the philosophy, that the supplier, who meets these demands already for pilot plant application, is the first addressee for an engineering order for a potential MRT production plant, Clariant C³-MRT identified Heatric as a preferred supplier for

[1] Offered by e.g. Coming Incorporated (USA, Coming, NY 14831), Cellular Process Chemistry Systems GmbH (CPC/D-60343 Frankfurt), Ehrfeld Mikrotechnik AG (D-55234 Wendelsheim), Heatric (GB-BH16 6LT Poole), Insitut für Microtechnik Mainz GmbH (D-55129 Mainz), Little Thing Factory GmbH (LTF/D-98693 Illmenau), Mikroglas Chemtech GmbH (D-55129 Mainz), Synthesechemie (D-66265 Lenbach).

process intensification equipment manufactured in steel. Over the past 15 years, Heatric has built up a remarkable and acknowledged know-how in the field of large scale heat exchangers for petrochemical applications. Here, the same accuracy for manufacturing of small scale structures as well as for bonding platelets together to form compact stacks is needed and used for so called printed circuit reactors (PCR), which are – like micro reactors - comparable to an array of miniaturised tubular reactors.

5.1 Heatric's "Printed Circuit" Technology

Heatric was established in 1985 to commercialise the design and manufacture of "micro/milli" scale heat exchange core matrices called Printed Circuit Heat Exchangers (PCHEs), following several years of developmental work at the University of Sydney. PCHEs incorporate single-material (usually metal) matrices manufactured by diffusion bonding together plates into which fluid flow passages have (usually) been formed by photo-chemical etching. Complex fluid circuitry is readily implemented with this technique, and minimum passage dimensions are generally dictated by the cleanliness of the fluids and allowable pressure drops.

PCHEs are "compact" relative to conventional heat exchangers, and passage dimensions are typically 1-2mm diameter, but they are not necessarily "small": single units of up to 100 tonnes have been manufactured, and clearly these are only "compact" in comparison to the 500 tonne alternatives.

Since moving from Australia to the UK in 1990, Heatric has supplied over 3000 tonnes of such matrix in hundreds of services - many of them arduous duties on offshore oil and gas platforms where the size and weight advantages of compact structures are of obvious major benefit. Other applications include LNG, ethylene oxide, sulphuric acid, naphtha reforming, and caustic soda plants. Whilst these matrices are predominantly involved in thermally simple two-fluid heat exchange, albeit at pressures up to 500 bar, there also is a long history of their application to more complex integrated fluid processing applications. Indeed even in the development stage of PCHE technology at the University of Sydney operations such as multi-stream counterblow heat exchange, rectification, stripping, mixing, absorption, boiling, condensation and separation were incorporated into compact integrated process modules. The potential for application of PCHEs to temperature control in chemical reaction has also been long recognised, with potential benefits anticipated in areas such as compactness, operability, efficiency, safety and cost.

5.2 Printed Circuit Reactor (PCR) Concepts

Heatric has developed a family of reactors derived from the established PCHE product, collectively known as Printed Circuit Reactors (PCRs). These may incorporate one or more of a range of concepts, a selection of which are described below.

In Passage Reaction

The potential for using a PCHE as a plug flow reactor was recognised by Heatric at an early stage [1]. For heterogeneous catalytic processes this concept may be extended to include:

- Catalyst packed passages
- Catalyst coated passages
- Catalyst coated inserts
- Entrained catalyst.

These concepts are illustrated in *figure 9* below.

The concept of coating a heat transfer surface with catalyst has been quite widely discussed. However, one of the big challenges is how to provide sufficient catalyst surface at reasonable capital cost. The PCHE offers the desired high surface density at demonstrably competitive cost, over a range of operating conditions far exceeding that offered by any other type of compact heat exchanger.

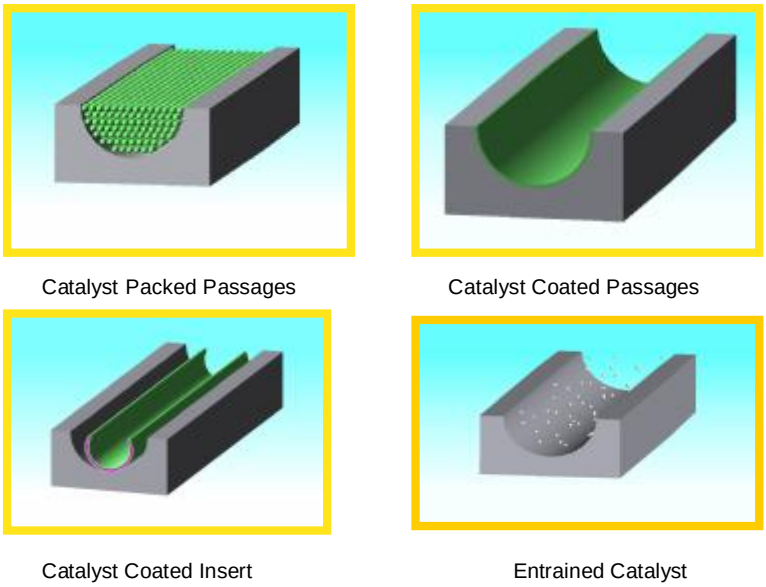


Figure 9: In-Passage Catalyst Options.

Multiple Adiabatic Beds

Inevitably it will not always be possible to match (at least approximately) the required catalyst surface with the required heat transfer surface. In this case the PCHE risks simply becoming a rather expensive catalyst support, and an alternative approach is needed.

Where the required catalyst surface area is very large, and substantially exceeds the required heat transfer area, a better balance between capital cost and performance may be achieved by approximating the in-passage reactor with a large number of shallow adiabatic beds, with heat exchange between each bed. Hitherto the feasibility of such an approach has been constrained by the cost of successive reactor vessels, heat exchangers, and interconnecting piping. Even in the most sophisticated integrated reactor designs, the number of reaction and heat exchange

steps rarely exceeds 3 or 4, since the volume required for conventional heat exchange within a reactor vessel becomes increasingly costly with increasing overall reactor vessel size. However, by making use of the very compact nature of PCHEs it is possible to devise cost-effective reactor layouts with many adiabatic beds, with intermediate heating or cooling between each.

The concept is illustrated in *figure 10* below.

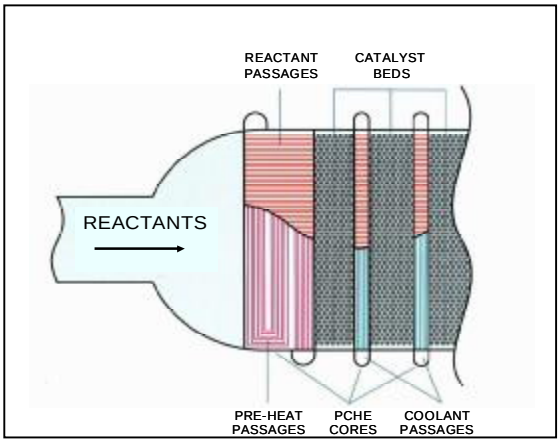


Figure 10: The Multiple Adiabatic Bed Concept.

Reactant Addition and Mixing

Heatric's well-established and proven technique for distributing two-phase streams into PCHEs, and for injecting glycol into offshore gas coolers, can be extended to admix reactants into a process stream on a passage-by-passage basis. Further, it is possible to conveniently achieve staged reactant addition (differential side stream reactor) and mixing. The concept is illustrated in *figure 11.*

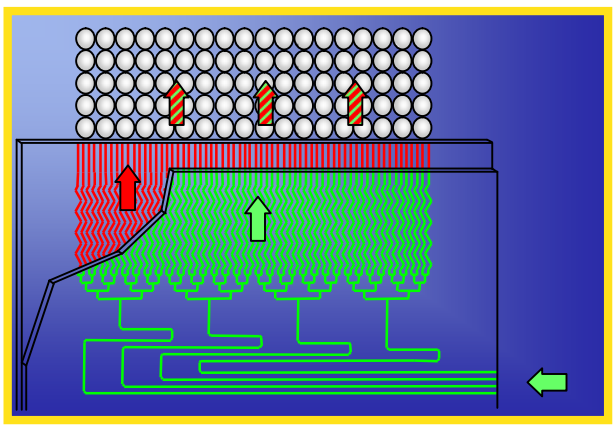


Figure 11: Passage-by-passage reactant addition.

The small hydraulic diameter of typical PCR passages often gives rise to very low Reynolds numbers. Satisfactory design for mixing under such conditions relies on a proper understanding of fluid flow (as well as heat transfer) in serpentine channels: Heatric benefits from the invaluable work being performed in this field at the University of Sydney, Australia [14].

5.3 Industrial Implementation

By using the inherent flexibility of Heatric's Printed Circuit Technology it is possible to combine features such as those described above, together with other special or innovative features, to produce a reactor tailored to specific process requirements. Reliable scale-up from laboratory or pilot scale to full industrial production may be confidently undertaken, based upon Heatric's demonstrated understanding of fluid flow and heat transfer - both within the flow passages formed into individual plates, and in flow distribution manifolds, and the repeatability achieved in the manufacturing process.

A key capability is design and manufacture in conformance with internationally recognised design codes and standards: Heatric has held the ASME U-stamp since 1999.

A commonly encountered objection to the industrial use of process equipment featuring narrow fluid flow passages is the potential for fouling and blockage: PCHEs and PCRs are no exception in this regard, and known fouling duties should normally be avoided. However, practical experience has demonstrated that in many duties fouling is not observed. In those duties where fouling does manifest itself, very successful cleaning procedures have been developed. These procedures include chemical cleaning, hydrokinetic cleaning, and so-called "gas puffing" – although performed off line, hydrokinetic cleaning and gas puffing are not dissimilar in principle to the procedures developed by Clariant for handling pigment suspensions in PCRs. *Figure 12* shows a PCHE undergoing a gas puffing cleaning procedure, photographed at the moment of bursting disk rupture. *Figure 13* illustrates the effectiveness of chemical cleaning

Figure 12: Gas Puffing of a PCHE.

Before After

Figure 13: The Effectiveness of Chemical Cleaning.

Whilst PCHEs are firmly established in the industrial landscape, the industrial adoption of PCRs is still in its infancy. Heterogeneous catalytic reactor applications are currently being pioneered for continuous processes, primarily focussed on steam reforming [15] and other hydrocarbon processing reactions. Clariant is an enthusiastic early adopter of PCR technology for what are traditionally considered batch processes.

6 Conclusion and Outlook

By bringing together expertise and industrial experience that embraces both process chemistry and a phenomenally flexible approach to reactor design and manufacture, we aim to open up a refreshingly new view on chemicals manufacture. By replacing the “one size fits all” approach of batch reaction with reactors that are specifically tailored to the needs of individual processes, a significant commercial advantage can be obtained.

Central to this new approach is the proper understanding of process chemistry as it relates to reactor design – something that is so often absent, even in the case of long established products. By teaming Clariant’s expertise in chemical syntheses, and laboratory and pilot-scale studies, with Heatric’s proven ability to provide bespoke reactor solutions at both laboratory or pilot scale and full industrial production scale, we believe we can effectively bridge the gap from the research laboratory to commercialisation.

Literature

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