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*Editorial*

# Process Intensification in Chemical Reaction Engineering

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Process Intensification (PI) is a modern trend in Chemical Reaction Engineering (CRE) science. The main concept is to develop sustainable and cost-effective chemical process systems, driven by the reduction of the equipment size, energy consumption, or waste generation. Several efforts were made, focusing on different kind of technologies:

- microreactors and micromixers
- static mixers
- alternative sources of energy: microwave and ultrasound
- two-unit operations in one apparatus: reactive chromatography/reactive distillation
- alternative fluids: supercritical fluids, ionic liquids, SILCA
- structured catalysts, foams, monoliths, 3D-printed structures

The development of Process Intensification requires the deep understanding of several aspects which comprise CRE, spreading from reactor modeling/design to the investigation of microfluidics, treating with rigor the physical and chemical phenomena occurring in the reaction network. The Special Issue on “Process Intensification in Chemical Reaction Engineering” (https://www.mdpi.com/journal/processes/special_issues/process_intensification_chemical_reaction, accessed on 24 May 2022) aims to illustrate novel trends in CRE to demonstrate that with the right approach, it is possible to aim the PI of a chemical process.

First, a review article was published by Haase et al. to collect the main and most recent efforts within Process Intensification, analyzing the strategies and drawing the main guidelines when facing with PI [1].

The interest on Process Intensification can be verified by considering the information extracted from Scopus database, related to the number of publications per year, see Figure 1A. The Special Issue allowed the collection of nine papers, which could be framed within different macro areas, whose distribution is depicted in Figure 1B. As revealed, the trend in Process Intensification interest is exponentially increasing, proof of the effective scientific interest of the selected topics. Moreover, the distribution is well balanced along three different macro areas, namely: (i) novel reactor; (ii) novel unit operation; (iii) multipurpose unit. In the following sections, the main efforts published on the SI are reviewed and summarized, highlighting the point of novelty per each macro area.



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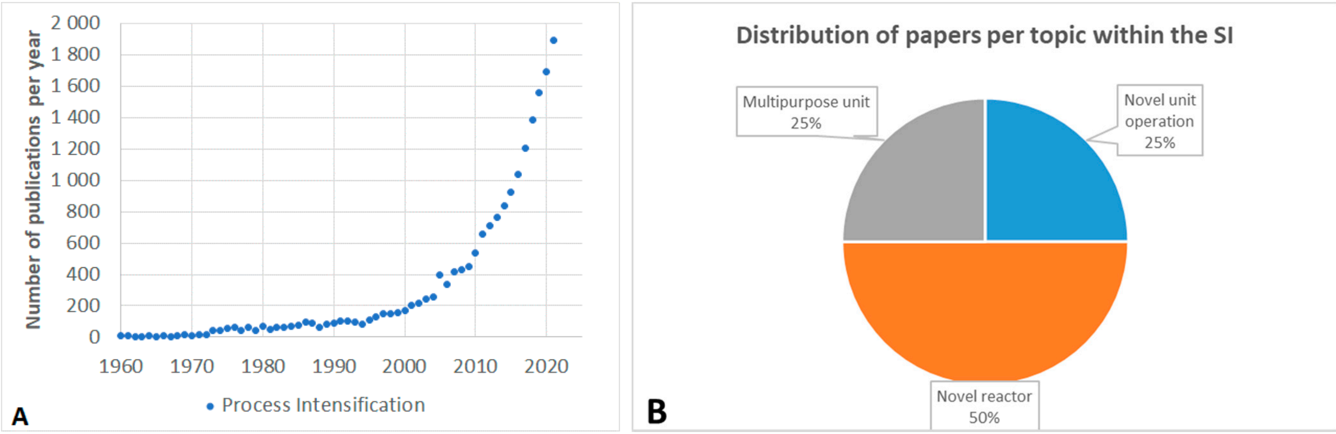



**Figure 1.** Statistical information related to the Special Issue "Process Intensification in Chemical Reaction Engineering". (**A**) Number of publications per year related to Process Intensification (Scopus Database). (**B**) Distribution of papers per macro area.

Four articles devoted to the use of novel reactors were published in the Special Issue. The first article published by Nico Jurtz et al. proposed how to enhance the thermal performance of a slender packed bed reactor by means of internal heat fins [2]. The authors published an in-depth CFD modeling paper coupling the modeling results with the experimental data. The authors demonstrated that by using heat fins (Figure 2A), it is possible to obtain an increase of roughly 30% of the heat transfer coefficient within the adopted Reynolds number range, leading to an increase of the effective thermal conductivity. This is a clear strategy of improving existing technologies to intensify heat transfer phenomena, clearly in line with Process Intensification principles. Thomas Eppinger et al. investigated how packed beds characterized by small tube-to-particle-diameter ratios can influence both fluid-dynamics and heat transfer (Figure 2B) [3]. The authors demonstrated by CFD computations that using the mentioned device, the thermal performance could be improved by up to 120% depending on the wall structure and flow regime. The improvement is the highest for industrial relevant Reynolds numbers. In addition, in this case, a novel reactor was demonstrated to be very effective to improve heat and mass transfer problems, allowing working in safer conditions.

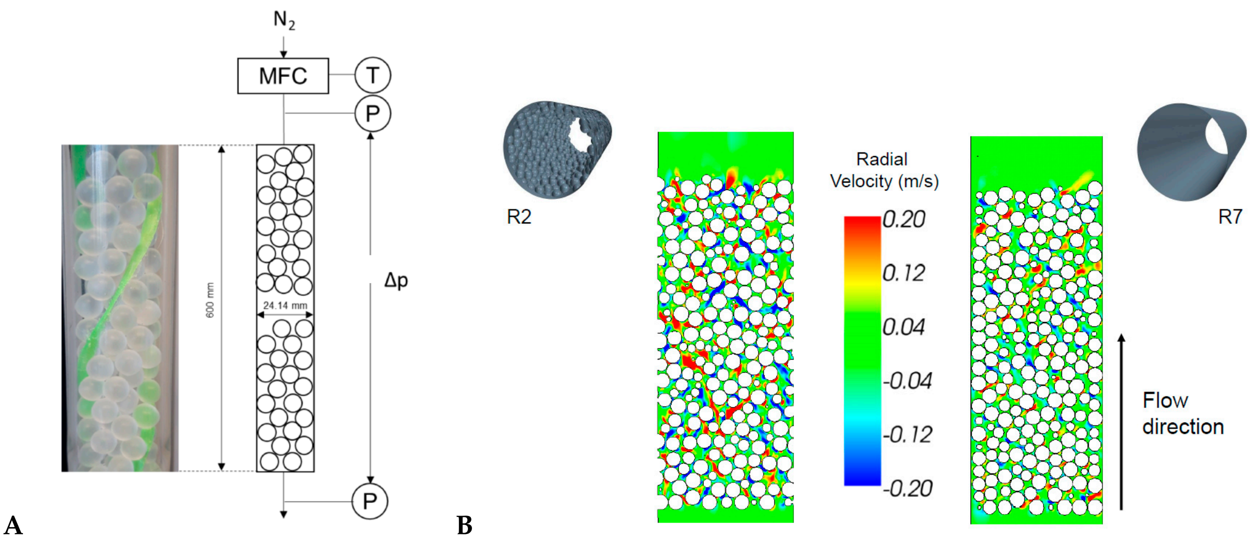



**Figure 2.** (**A**) Packed bed reactors filled with heat fins [2]. (**B**) Comparison of the local radial velocity between configuration R2 with wall structure and R7 for a $D/d_p$-ratio of 8.8 [3].

Two papers were published on microreactors. Musavuli et al. investigated, both experimentally and theoretically, the effect of the use of microdevices on the CO oxidation adopting Ru-Cs/$Al_2O_3$ catalyst [4]. The work demonstrated that microchannel reactor technology, supporting an active catalyst for CO PROX, is well suited for CO abatement in a $H_2$-rich gas stream at moderate reaction temperatures and high space velocities (Figure 3A). Haase et al. published a paper that help the reader to choose the right reactor to upgrade hemicellulose, making a comparison between classical and miniaturized reactors for hydrogenation reactions (Figure 3B) [5]. In particular, the results demonstrated that minichannel packings, either with the deposited catalyst at the channel wall or with catalytic internals, outperform the traditional and miniaturized packed beds. Considering flow conditions for maximum productivity, the replacement of a conventional trickle-bed by a wall-coated foam-packed minichannel reactor will provoke an about 5- to 10-times larger space-time yield, although the energy spent per converted molecule is similar.

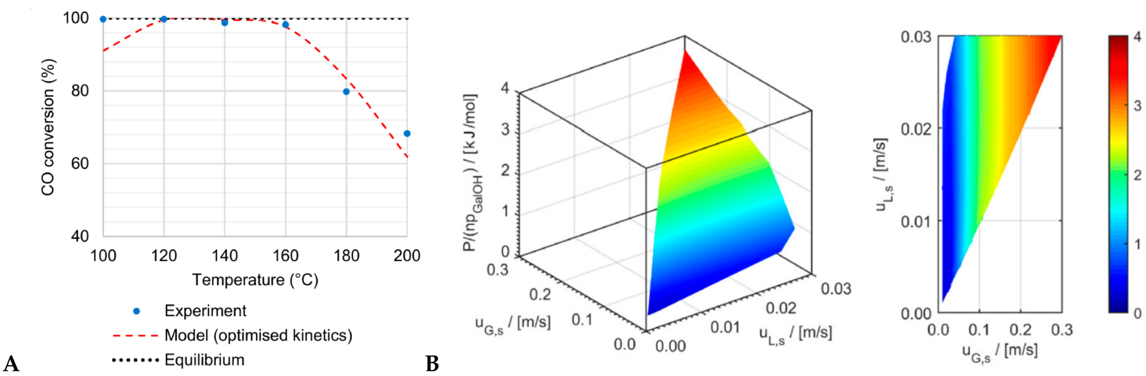



**Figure 3.** (**A**) CFD model validation to experimental data of CO conversion, in the temperature range 100–200 °C, and for space velocities of 32.6 NL/($g_{cat}$ h) [4]. (**B**) Specific energy consumption of mini trickle-bed reactors operating at different gas and liquid superficial velocity [5].

Two articles of the Special Issue were devoted to the use of novel unit operations. Dmitry V. Gradov et al. studied the effect of a auto-aspirated DAF sparger on the hydrodynamics properties of the equipment [6]. Such equipment demonstrated the allowance of a superior gas dissolution compared with conventional technologies (Figure 4A). Sana et al. investigated the effect of the spinning disc mixer on starch nanoparticle precipitation [7]. By using high shear rate on starch nanoparticle precipitation, a reduction in nanoparticle size was observed with an increase in starch concentration, although agglomeration, thus leading to good performances (Figure 4B). It is clear that with the latest two cases, using non-conventional unit operations, it is possible to improve mass and heat transfer properties.

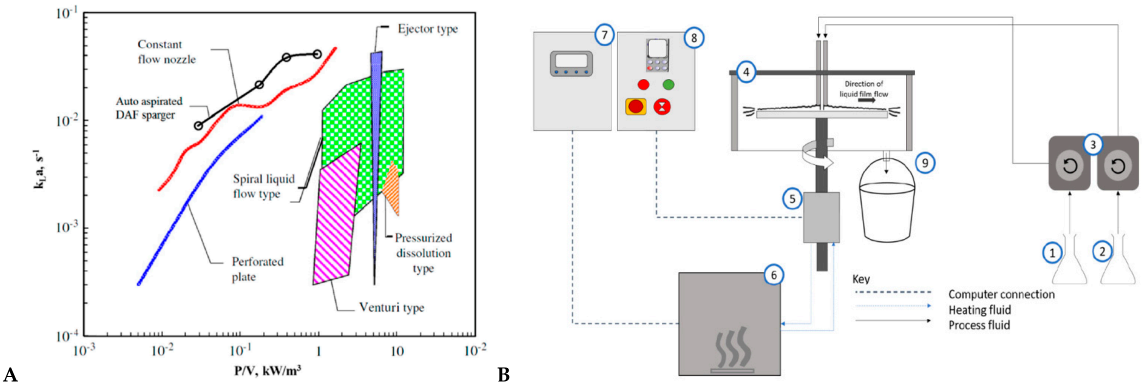
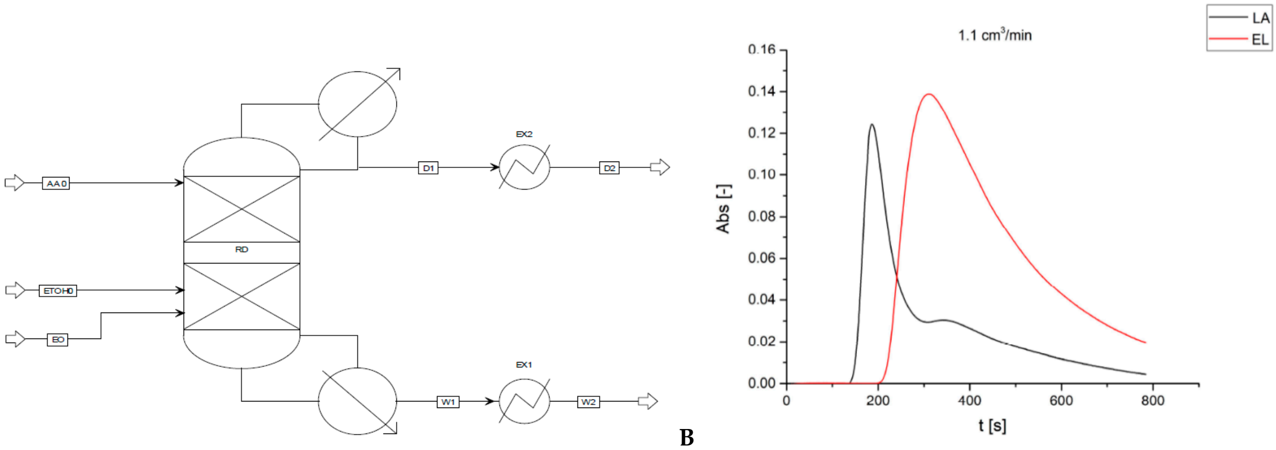



**Figure 4.** (**A**) Specific power requirement for water aeration of various sparger types [6]. (**B**) Schematic of experimental set-up for spinning disc reactor (SDR) [7].

Finally, two articles of the Special Issue were published on the use of multipurpose units, both on esterification reactions, exploring the use of reactive distillation and chromatography. Branislav Šulgan et al. investigated the effect of reactive distillation to ethyl acetate synthesis [8]. Three different points of view were applied to evaluate the selected process benefits and drawbacks. Process energy, economy, and safety were assessed. As a result, a reactive distillation column with an auxiliary chemical reaction was proven to be the most suitable pathway for ethyl acetate production assuming all three evaluated aspects. Carmelina Rossano et al. demonstrated the feasibility of the application of reactive chromatography to ethyl levulinate synthesis [9]. By investigating a wider range of operation conditions, in terms of both temperature and flowrates (e.g., Figure 5B), the authors drew the root for the optimization of reactive chromatography to overcome the thermodynamic limitation of the esterification reaction, obtaining in some cases full conversion of levulinic acid.




A B

**Figure 5.** (**A**) Sketch of the reactive distillation unit for ethyl acetate synthesis [8]. (**B**) UV spectra of levulinic acid (LA) and ethyl levulinate (EL) 6 M at $T$=303 K and imposing a volumetric flowrate of 1.1 $cm^3$/min [9].

As it can be seen, despite their high quality, the works published in this first edition of the Special Issue on Process Intensification in Chemical Reaction Engineering are rather heterogeneous for their contents. This is due to the large possibility of different options that can be obtained when facing with Process Intensification.

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