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EDITED AND REVIEWED BY
Eric Favre,
Université de Lorraine, France

*CORRESPONDENCE
Jimoh K. Adewole,
jimoh@imco.edu.om

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Editorial: Membrane engineering and process intensification

Jimoh K. Adewole[1]*, Anteneh M. Yeneneh[1], Mohd Yusuf Khan[2] and Md. Jashim Uddin[1]

[1]Membrane Science and Engineering Lab, Process Engineering Department, National University of Science and Technology, Sohar, Oman, [2]Interdisciplinary Research Center for Hydrogen Technologies and Carbon Management, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia

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Editorial on the Research Topic
Membrane engineering and process intensification

Process intensification (PI) has been found to be a design approach that offers a solution which leads to substantial reduction in the size of process equipment or plant, energy saving, cost reduction, increased safety, and reduced environmental impact. The four principles of PI include maximizing the effectiveness of intra- and intermolecular events, giving each molecule the same processing experience, optimizing the driving forces/resistances at every scale and maximizing the specific surface areas to which these forces/resistances apply, and maximizing the synergistic effect from partial processes. PI can be achieved through the functional, spatial, thermodynamics, and temporal domains. This editorial discusses process intensification with respect to process in the pharmaceutical industry, hybrid process of reactive-extractive distillation, intensified separation technique for CO separation from industrial gas streams, and recovery of value-added products from wastewater.

One of the methods of achieving intensified process is by converting batch to continuous processes (Boodhoo and Harvey, 2013). This is inline with the second principle of PI which requires that each molecule should be given the same processing experience. It has been reported that the pharmaceutical industry produces far more by-products than useful products (Cushman-Roisin and Cremonini, 2021). This is partly because batch processes are predominantly used in the pharmaceuticals industry. Process such as organic salt crystallisation is a very crucial process in pharmaceutical industry since most of pharmaceutical products are marketed as salts. Unfortunately, the predominant method of performing salt crystallisation in the pharmaceutical industry is a batch process. Although batch technology has some merits in pharmaceutical industry which may include flexibility, and the suitability for small production volumes, however, batch technology faces challenges ranging from difficulty in scale up, poor yield, and variation in compositional and temperature over the entire vessel which negate one of the principles of PI which require that each molecule is given the same processing experience. Switching the salt crystallization process from batch to continuous was investigated by McGinty et al. The idea of intensifying the salt crystallization process will lead to a reduction in waste generation, lower energy consumption, increase in yields, and reduction in equipment size. It addition, the process can be carried at reduced costs. The authors evaluated semi-batch and continuous crystallisation processes with the use of continuous mixing approaches for the crystallisation of the polymorphic organic salt of ethylenediammonium 3,5-dinitrobenzoate (EDNB). The use of continuous process allowed for a greater control of the crystallization process to produce seeds of a consistent polymorph and particle size for a polymorphic organic salt. The overall results revealed that the continuous process approach has better potential to produce salt of controlled particle properties compared to current batch salt crystallisation technique.

The fourth principle of PI is about maximizing synergistic effect from partial processes. This principle emphasizes the exploration of synergistic effects whenever possible and at all possible scales. This may include the use of hybrid separation in which two or more separation techniques are combined to realise a more energy efficient and cheaper separation. Reaction and separation can be combined using reactive distillation, membrane reactor, extractive distillation, and reactive-extractive distillation (Novita et al., 2018; Li et al., 2023). Extractive distillation column (EDC) is one of the well-known methods usually implemented in the separation process for the separation of the azeotropic mixtures. A comprehensive review of the recent progress on hybrid reactive-extractive distillation for azeotropic separation was conducted by Kong et al. The authors elaborated on the advantages of reactive-extractive distillation as compared to conventional reactive or extractive distillation processes. The review was structured in a chronological order starting from the initial three column reactive-extractive distillation to the most recent technology of dividing wall reactive-extractive distillation and their applications in azeotropic separation. This was done in a way to identify the existing gaps and pave way for future work that need to be conducted on this technology. The review showed that the technology of reactive-extractive distillation has the potential to provide significant improvement in energy consumption, total annual cost, and CO_2 emission. The authors also recommended potential areas for future work which include analysis of the sustainability of reactive-extractive distillation, combination of different process intensification strategies to improve the energy efficiency and separation performance, and further exploration on the control and dynamic simulation studies of the systems.

Process intensification was explained by Stankiewicz and Moulijin in 2000 in terms of a "toolbox" view which divided the toolbox into two sub domains (Stankiewicz, 2020): PI Equipment, and PI Methods. Membrane separation was named as an example of PI methods. The use of innovative technologies such as membranes in achieving the goals of PI has remained a hot topic in recent years. Membrane technology can substantially reduce the energy consumption of many industrial processes, as well as reduce waste, making separation processes more cost-effective, safer, and more sustainable (Adewole and Sultan, 2019; Adewole et al., 2022). Membrane gas separation is one of the membrane separation techniques which has been investigated worldwide because it is well-aligned with PI practices. A systematic review on the use of four different separation processes for direct carbon monoxide recovery from nitrogen-containing industrial streams (such as H_2, CO_2, CH_4, and N_2) was carried out by James et al. The authors reviewed cryogenic purification, absorption, adsorption, and membrane separation with specific attention to industrial applications. The review showed that membrane processes are most promising for CO/N_2 separation. Cryogenic processes are not suitable for this separation. Moreover, absorption can be promising with developments of new set of ionic liquids to replace the current solvents. Similarly, adsorption processes require the development of new materials that do not require vacuum regeneration.

One of the fundamental benefits of PI is the reduction in the costs of raw materials and generation of less waste which invariably imply the a reduction in the costs of waste-stream processing (Reay et al., 2013). Waste reduction can be achieved by valorisation of industrial wastes. A review of most novel approaches for treatment and recovery of value-added products from wastewater valorisation was conducted by Kathi et al. The authors examined the recovery of value-added products such as biofuels, biofertilisers, biopesticides, biopolymers, vitamins, enzymes, dyes, pigments, and phenolic compounds as possible products from wastewater using various separation methods. Biopolymers and natural polymeric materials are very useful products that can be used in various industrial applications (Adewole, 2016; Smith et al., 2016; Krebsz et al., 2017; Adewole and Muritala, 2019). The approaches described in the review include membrane technology, enzymatic catalysis, and microalgae cultivation. The authors also addressed the life cycle assessment and made a critical overview of the barriers to the large-scale application of the resource recovery strategies. The concerns (economic, environmental, and social) that are associated with using waste-derived products were also addressed in this review. This review actually calls for a change in the current non-sustainable utilization of Earth resources. Sludge and wastewater should be considered sources of valuable products that can be harnessed to the benefit of mankind. The realization of this concept will require the development of cutting-edge technologies to ensure efficient treatment of wastewater. To extract nutrients in high quantities and desired quality, traditional approach needs to be integrated with intensified technology such as membrane technology. The use of advanced analytical tools for accurate qualitative and quantitative analysis of wastewater cannot be over emphasizes. All these coupled with political will from governments (in the form of relevant legislation, policies, and regulations) will promote the technological viability and lower operational expenses of the approaches discussed in the review.

Overall, the concept of process intensification is gaining a lot more attraction in the academia as well as in the industry. Membrane technology has become a widely accepted technology that can be used to achieve the goals of process intensification. The global market of membrane technology is expected to witness a significant growth in the coming year. The growth and public acceptability of process intensification is expected to be highly impacted by the growth in membrane market size.

Author contributions

JA: Writing–original draft, Writing–review and editing. AY: Writing–review and editing. MK: Writing–review and editing. MU: Writing–review and editing.

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Conflict of interest

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