Introduction

Anil K. Pabby, Syed S.H. Rizvi, and Ana Maria Sastre

Focusing on the recent advances and updates, this section addresses new development in chemical and pharmaceutical industries and in the conservation of natural resources. Included in this edition are newer practices and technologies and their applications or trends for future applications with relevant references that have appeared in the literature since the first edition was published. Several new chapters on emerging areas such as membrane separation in petrochemical oil refinery, chitosan as new material for membrane preparation, new membrane material for ultrafiltration (UF) and nanofiltration (NF), and potential application of reverse osmosis (RO) in chemical industry have been added in the second edition.

As a new strategy, process intensification is gaining paramount importance and slowly becoming part of already established and newly developed technological processes. Drioli et al. [1] define process intensification as the strategy to bring drastic improvements in manufacturing and processing by decreasing capital cost, equipment size, energy consumption, waste production, environmental impact, etc. In this context, membrane operations have the potential to replace conventional energy-intensive techniques, accomplish the selective and efficient transport of specific components, improve the performance of reactive processes, and, ultimately, provide reliable options for sustainable growth [2]. In addition, membrane processes can be beneficially integrated at different levels because of their several advantages over conventional processes: compactness, easy scale-up, and automation [3–4]. Pressure-driven processes such as UF, NF, and microfiltration are already established, and various applications have been commercialized in the fields of food, pharmaceutical, and biotechnology. The development of a means of characterizing, controlling, and preventing membrane fouling has proven vital in recent years. Engineering tailored membranes, fouling prevention, and optimization of chemical cleaning will ensure a high level of membrane process performance. In the last 5 years, developments of new techniques for membrane characterization and improvements in existing techniques have increased our knowledge of the mechanisms involved in membrane fouling. The advanced techniques used for membrane fouling detection will not only provide useful insights into the fouling mechanism but also augment our understanding of the factors that affect membrane fouling.

In the new developments, a novel method for CO$_2$ separation from the gas phase by applying nanofluids of nanosilica and carbon nanotube as absorbents was achieved in a gas–liquid hollow fiber membrane contactor. Nanofluids of silica and carbon nanotubes (CNT) were prepared first from their nanoparticles and were fed into the lumen side of the membrane module [5]. Similarly, development of a different and potentially advantageous geometry for membranes called microcapillary film (MCF) was recorded by Bonyadi and Mackley [6]. MCFs are films with embedded multiple hollow capillaries and can be considered as a hybrid geometry between flat sheets and hollow fibers. Compared to flat sheet membranes, MCFs are self-supported and provide a higher surface area per unit volume. Compared to single capillary membranes, MCFs offer several advantages including improved mechanical strength, ease of handling, and more efficient module fabrication.

The extraction of metals based on a membrane contactor system with conventional solvents is a process widely studied using different configurations, extractants, and extraction solvents. One of the upcoming applications of membrane contactors is supercritical extraction. This process is called porocritical extraction. Porocritical process or porocritical extraction is a commercial supercritical fluid extraction (SFE) technique that utilizes an hollow fiber membrane contactor (HFMC) to contact two phases for the purpose of separation. As an improvement, the extraction of Cu$^{2+}$ from aqueous solutions by means of dense gas extraction was achieved by using a hollow fiber membrane contactor device [7]. The authors
claimed that the use of dense CO₂ as extraction solvent of Cu(II) ions reaches extraction efficiencies of up to 98.7%. This process offers several advantages over the conventional contactor devices generally used in SFE in which one fluid phase is dispersed in another in a column. In this case, the modularity of the membrane contactor application is very important, considering that in a typical porocritical extraction application large and expensive vessels are not used.

Membrane materials are continuously undergoing modifications for achieving better performance. In this direction, the extra high free volume glassy polymer poly[1-(trimethylsilyl)-1-propyne] (PTMSP) is a perspective membrane material for two inherently different applications: (1) organic solvent NF (OSN), when a high solvent flux through the membrane is expected, and (2) high-pressure membrane contactors for CO₂ capture that requires the absence of liquid permeation (no liquid leakage) through the membrane. A successful application of this single polymer for two different membrane systems has been reported in the literature [8].

The combination of molecular separation with chemical reactions (membrane reactors) offers important opportunities for improving the production efficiencies in biotechnology and in the chemical industry. With regard to the future of biotechnology and pharmaceutical processes, the availability of new, high-temperature-resistant membrane contactors offers an important tool for the design of alternate production systems appropriate for sustainable growth.

A few recent publications [5–8] outline the very latest advancements in the field of membrane science and technology. Since these are only updates and the systems are yet to be established on large scales, no dedicated chapter in these fields was included in this edition. This section of the book outlines several established applications of membranes in the chemical and pharmaceutical industries, reviews the membranes and membrane processes available in the field, and discusses the huge potential of these technologies. In addition, other important topics dealing with conservation of natural resources (zeolite membranes) are also presented in this section. Each chapter has been written by a leading international expert with extensive industrial experience in the field.

This chapter presents an overview of different membrane processes and a description of all of the chapters presented in this edition. Chapter 2 focuses on updated information of utility to UF and NF membrane research and development, particularly in the preparation of new types of UF/NF membranes with improved performances. Chapter 3 presents a comprehensive review on RO membrane, the latest developments in the field, important installations demonstrating this technology, and future scope of RO processes. Chapter 4 presents the potential of membrane contactors, especially hollow fiber contactors in the field of chemical and nuclear industry along with their applications, performance, and current challenges faced by industry. This chapter also gives an introduction to membrane contactors, their principles of operation and associated mechanisms (where chemical reactions are involved), and future scope of these contactors. Chapter 5 presents the latest advances in membranes processes for refinery and petrochemical fields. This chapter describes the important applications, current status of technology, and future perspectives. Chapter 6 deals with membrane and monolithic convective chromatographic supports. This chapter discusses the latest developments in membrane-based stationary phases (affinity membranes and mixed matrix membrane adsorbers) and monolithic separation media (organic and inorganic). It also provides information on new types of chromatographic support, focusing on membrane materials, properties, and preparation. Finally, it considers possible applications of chromatographic membranes under various process conditions. Chapter 7 focuses on the important aspects of membrane applications in gas separation. It deals with the subject comprehensively, providing an introduction and discussing transport mechanisms, different membrane materials for gas separation, module design, current and potential applications, and novel developments in the field. Chapter 8 presents new developments in pervaporation (PV). It first gives a brief introduction to the theory of PV and then discusses sorption thermodynamics in polymers, the solution diffusion model, the criteria for membrane polymer selection, and the important latest applications of PV in different cases of aqueous and organic separations. Chapter 9 focuses on advances in the field of ceramic membranes, covering interesting applications in this area. Chapter 10 presents the various methodologies or techniques for improving the membrane performance of liquid-phase membrane processes by improved control of concentration polarization. Chapter 11 describes some of the main characteristics of the use of zeolite membranes in separation applications. Zeolite membranes separate molecules according to differences in their adsorption and diffusion properties in the mixture. They are, therefore, suitable for separating gas and liquid-phase mixtures by gas separation and PV, respectively. This chapter reviews the basic mechanisms of gas separation and PV through zeolite membranes and presents examples of industrial applications. Chapter 12 focuses on membrane fouling and the strategies used to reduce it relative to pressure-driven processes. This chapter highlights recent strategies for minimizing membrane fouling. In particular, it discusses the latest literature on the fouling phenomena in pressure-driven membrane systems, analytical techniques employed to quantify fouling, preventive methods, and membrane cleaning strategies. Specific recommendations are also made on how membrane users may find it helpful to improve the performance of these systems by minimizing the membrane fouling phenomena. Chapter 13 describes membrane extraction and its use in preconcentration, sampling, and trace analysis. Chapter 14 provides an introduction to membrane applications and recent advances in the pharmaceutical industry, its current status, and future potential in this very important area. Chapter 15 is devoted to membrane applications and its recent advances in the drug delivery field with emphasis on the mechanisms governing mass transport to modulate
Membrane Applications in Chemical and Pharmaceutical Industries and in the Conservation of Natural Resources

the release kinetics. Chapter 16 presents studies in emerging area dealing with new materials for developing membranes, that is, chitosan and its derivatives as potential materials. This chapter also elaborates on the latest applications, current status, and future challenges in this field.

REFERENCES
