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Book Review
Hollow Fiber Membrane Contactors: Module Fabrication, Design and Operation, and Potential Applications

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ABSTRACT

The latest developments and applications of hollow fiber membrane contactors (HFMCs) were discussed in this recent published book. Membrane contactor provides gas–liquid or liquid–liquid contact without dispersion of one phase in another, which gives a higher mass transfer coefficient compared to the conventional contactors. Using a microporous hydrophobic or hydrophilic membrane, one of the fluids is immobilized in the pores where the mass transfer is occurred based on the concentration gradient. HFMC technology has been implemented in various applications including gas separation, fermentation, pharmaceuticals, wastewater treatment, chiral separation, semiconductor manufacturing, carbonation of beverages, metal ion extraction, protein extraction, VOC removal from waste gas, and osmotic distillation.

1.0 BOOK SUMMARY

In the current book [1], chapters were classified by different categories based on different ways of contacting phases, as gas–liquid contacting, liquid–liquid contacting, supported liquid membrane, supported gas membrane and fluid–fluid contacting. There are 19 chapters that were written by the membrane experts covering advances in design and fabrication of membranes, fundamentals and applications, challenges, transport phenomena, CFD based mass transfer modeling, process intensification and scaling up. The chapters of this book are summarized in Table 1.

Table 1 Summary of the chapters

Chapter	Summary
1	• Introduction to HFMCs • Chapters outlook
2	• Membrane contactor processes • Review of HFMC

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Chapter	Summary
3	• Membrane contactor module configuration • Flow distribution
4	• Gas absorption and stripping • Membrane materials and module design • Incorporation of additives and nanomaterials • Surface modification
5	• Operation principles of membrane contactor • Various applications
6	• CFD-based modeling • Non-dispersive solvent extraction • Mass transfer and boundary conditions
7	• Treatment of metal-bearing aqueous solutions • Acidic, basic, solvating and ionic liquid extractants
8	• Process intensification • Case studies of Hollow Fiber Contactor-Based Processes
9	• Hollow fiber dispersion liquid membrane process • Mathematical modeling • Bench scale membrane contactor system for uranium recovery
10	• Membrane emulsification • Membrane nanoprecipitation
11	• Liquid membrane separation • Mechanism of transport in liquid membranes • Liquid membrane techniques at the back end of nuclear fuel cycle
12	• Hollow fiber-based liquid-phase microextraction (HF-LPME) • Principles, configuration and recent developments of the HF-LPME
13	• Air dehumidification • Mechanisms of water vapor transport through the membrane
14	• Gas filled membrane pores • Membrane materials and modules • Mass transfer phenomena • Various applications
15	• Liquid–liquid membrane contactors • Fundamentals, mechanisms and mass transfer of ammonia removal • Case study of ammonia recovery from zeolite regeneration streams
16	• Gas–liquid absorption • Mass transport and physico–chemical mechanism • Olefin/paraffin separation, CO_2 capture and SO_2 removal

Chapter	Summary
17	• Membrane distillation (MD), membrane assisted crystallization and membrane assisted condenser • The transport principles and the applications
18	• Hollow fiber membrane contactors in fermentation and enzymatic transformation • Chiral separation
19	• HF membrane contactors for application in food, pharmaceutical, and biotechnological separations • Advantages, disadvantages and future consideration

In Chapter 1, an introduction to HFMCs and outlooks of all the chapters in this book were presented. A comprehensive review on developments in hollow fiber membrane contactors was presented in Chapter 2, which deals with novel processing configurations and novel membrane structures. For gas–liquid membrane contactor systems, the authors have briefly deliberated novel ways of operation, different configurations, pressure-swing membrane absorption, temperature-swing membrane absorption and novel membrane structures. The gas–liquid membrane contactor systems were extensively studied for greenhouse gas capture. Figure 1 presents a schematic of CO_2 absorption through gas–liquid membrane contactor.

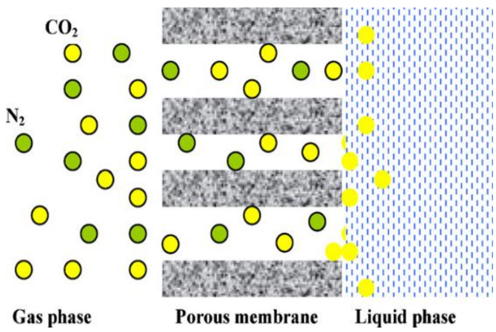

Figure 1 Schematic of CO_2 absorption in gas–liquid membrane contactor [2]

In Chapter 3, the authors presented the improvement in design and fabrication of HFMCs covering the membrane module engineering, the type of membrane and flow distribution in the modules.

Gas absorption and stripping using HFMCs were described in Chapter 4, where the advances in the fabrication and modification of the membranes were discussed in view of the incorporation of nanomaterials, silanization and amination. The flow diagram of CO_2 absorption/stripping in a hollow fiber membrane contactor system is shown in Figure 2.

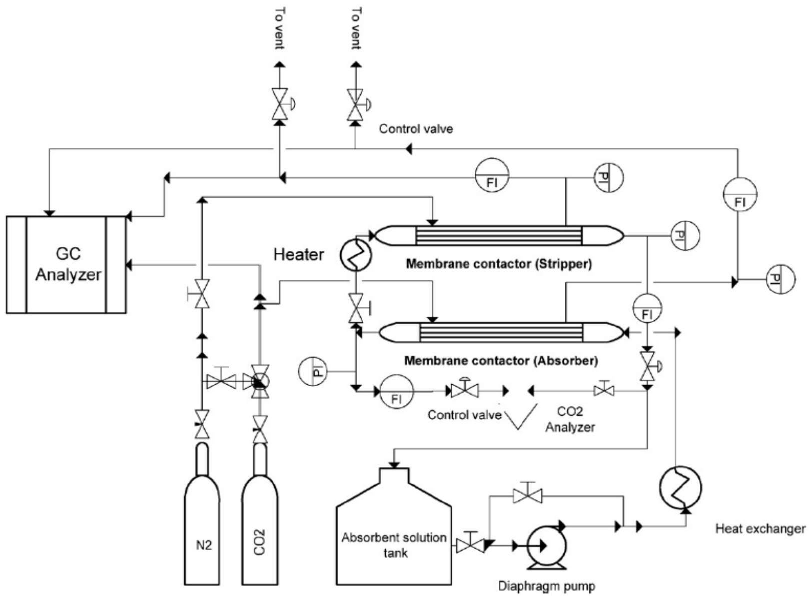

Figure 2 Schematic diagram of CO_2 absorption/stripping in a hollow fiber membrane contactor system [3]

Chapter 5 demonstrated the applications of HFMCs in oil and gas, microelectronics and beverage industries. The authors presented CFD based mass transfer modeling in HFMCs for extraction-separation processes in Chapter 6. In addition, recent investigations on the treatment of metal-bearing aqueous solutions (particular environmental area of interest) via a HFMC are summarized in Chapter 7.

Chapter 8 presented the role of process intensification in integrated use of liquid membranes, non-dispersive solvent extraction and strip dispersion membrane, while describing some of the case studies. The schematic of sparkling water production by a membrane contactor system is shown in Figure 3.

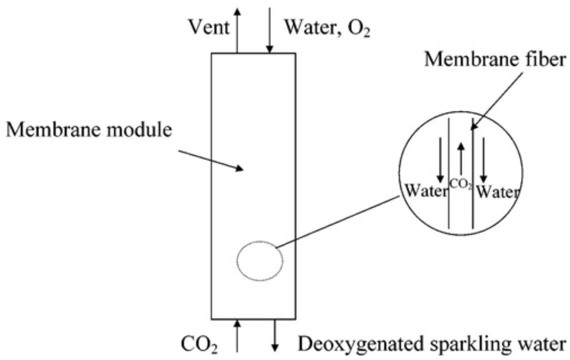

Figure 3 Schematic of sparkling water production by membrane contactor [4]

Scaling up of the HFMC for uranium recovery from lean effluents presented in Chapter 9, where the authors discussed the challenges and the methodology of a continuous bench scale membrane contactor set up with a real stream of uranium production plant. Figure 4 presents the bench scale membrane contactor system for recovery of uranium from lean acidic raffinate stream of a uranium purification plant (700–1,000 ppm of uranium in 1M nitric acid medium). The results showed a good stability in terms of flow through the module, dispersion, and efficiency of uranium transport.

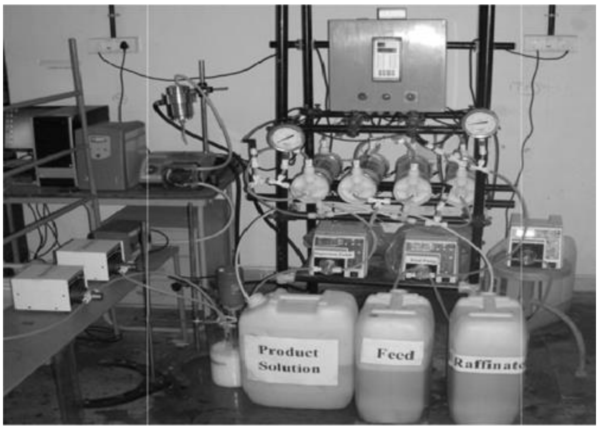

Figure 4 Bench scale membrane contactor system for uranium recovery: Four PP2 HF modules in series [1]

Chapter 10 highlighted the advances in membrane emulsification and nanoprecipitation covering important applications and current perceptions with regard to production of nanoparticles. In membrane emulsification process, a porous membrane controls the contact, the interaction, and the distribution of an immiscible fluid into another (gas/liquid or liquid/liquid). However, in membrane nanoprecipitation, a porous membrane is used for the interaction between two miscible phases in order to produce nanoscale particles by nanoprecipitation. Figure 5 shows a representation of membrane nanoprecipitation.

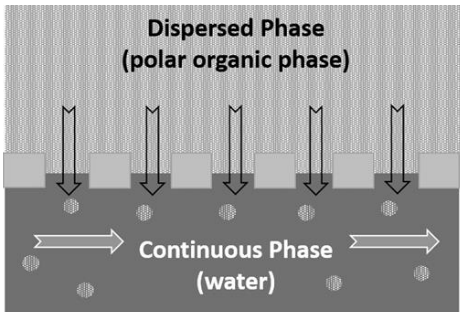

Figure 5 The illustration of membrane nanoprecipitation [1]

Liquid membrane separation and its mechanism of transport were presented in Chapter 11. A review on liquid membrane-based separation works, mainly related to radionuclides as a long-term environmental hazard, was also presented. Figure 6 shows a schematic of hollow fiber supported liquid membrane (HFSLM) for solvent extraction. The application of HFSLMs at the back end of a nuclear fuel cycle was demonstrated.

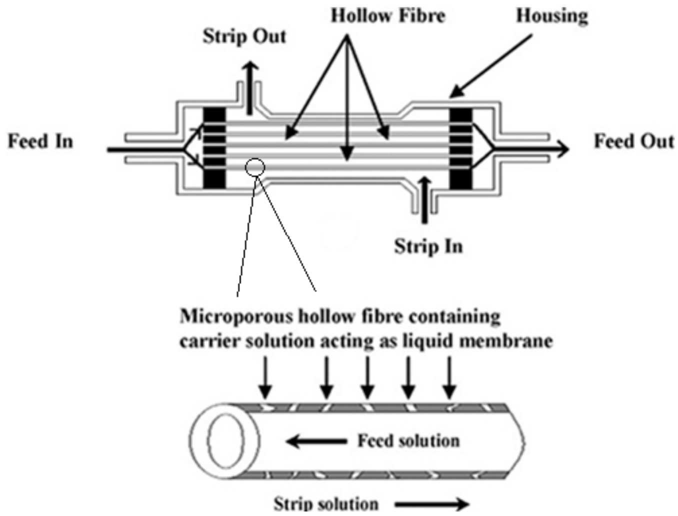

Figure 6 Schematic of the hollow fiber supported liquid membrane system [1]

Chapter 12 exhibited the progresses in hollow fiber based liquid-phase micro-extraction (HF-LPME) in analytical applications. In HF-LPME, the organic solvent is immobilized in the pores of a porous hydrophobic hollow fiber membrane by capillary forces. Using a micro-syringe, the acceptor phase is flowed into the lumen of the hollow fiber. At that moment, the membrane system is placed in the sample solution container, where the mass transfer is improved by a magnetic stirrer in the container. Figure 7 shows the illustration of HF-LPME.

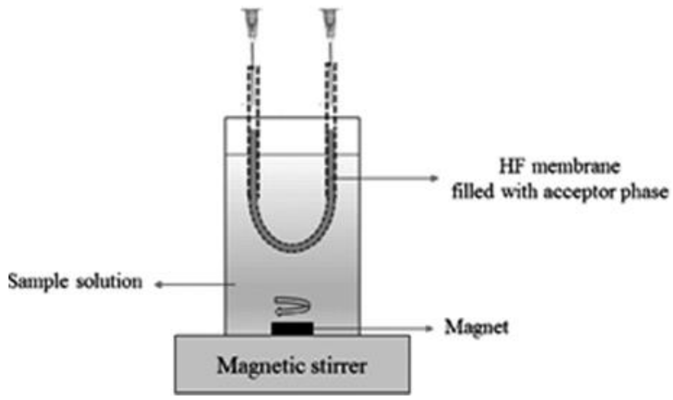

Figure 7 The illustration of HF-LPME [1]

The new concept for dehumidification of air and industrial gas mixtures by HFMC was described in Chapter 13. Gas-liquid membrane contactors using liquid desiccants have been applied for air dehumidification as a new alternative technology compared to the conventional dehumidifiers. In this case, problems related to the desiccants' corrosive nature and complexity of design can be avoided.

HFMCs with gas filled membrane pores were discussed in Chapter 14. In this type of membrane contactor, the membrane pores are filled with gas. The gas might have a special affinity to the components to be separated or it can be inert. Membrane distillation, osmotic distillation, and gas absorption/stripping are the main operations. Figure 8 shows schematic of osmotic distillation and water activity profile with mass transfer resistance.

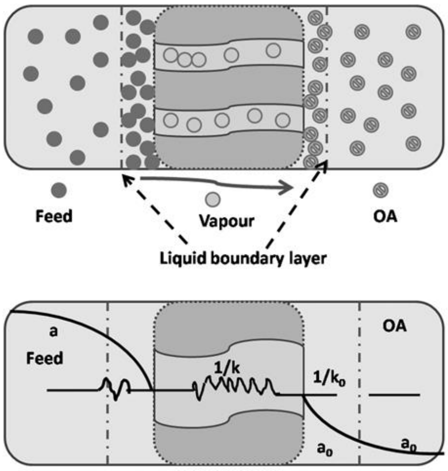

Figure 8 Schematic of osmotic distillation and mass transfer resistances [1]

Chapter 15 described fundamentals, mechanism and mass transfer of the liquid-liquid membrane contactor (LLMC). Figure 9 demonstrates ammonia transport through a hydrophobic hollow fiber LLMC. An industrial case study on ammonium valorization from urban wastewaters (as liquid fertilizers) by using HF-LLMC was also presented in this chapter.

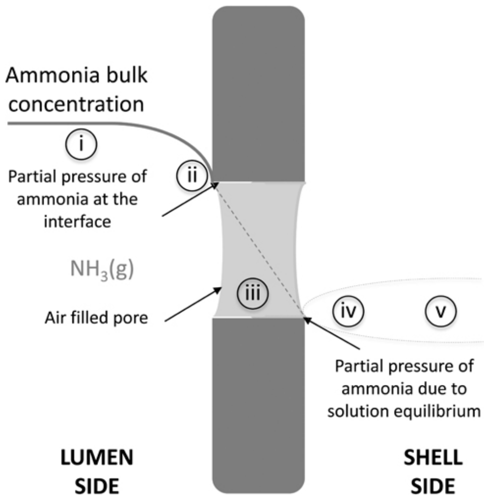

Figure 9 Ammonia transport through a hydrophobic hollow fiber LLMC [5]

Facilitated transport based separations using HFMCs were presented in Chapter 16. The fundamentals, physico-chemical mechanism and mass transport of gas-liquid absorption were presented. The different applications such as olefin/paraffin separation, CO_2 capture and SO_2 removal were also discussed in this chapter. In Chapter 17, three different membrane contactor processes as membrane distillation, membrane crystallization, and membrane condenser were discussed. The principles, fundamental concepts and the transport phenomena through microporous hydrophobic hollow fiber membranes were elaborated.

The challenges and growing applications of HFMCs in fermentation and enzymatic transformation in industry and in chiral separation were given in Chapter 18. The authors also presented the advantages and disadvantages of the used HFMC systems. Figure 10 presents the diagram of the lipase-catalyzed hollow fiber membrane reactor.

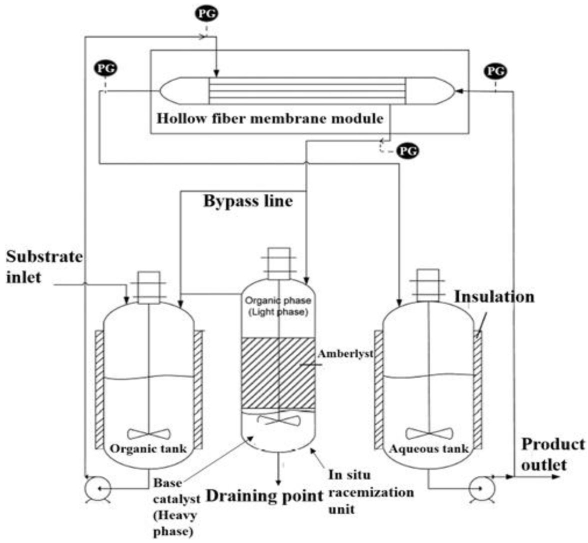

Figure 10 Diagram of the lipase-catalyzed hollow fiber membrane reactor [6]

FINAL REMARKS

Not only the advantages of HFMC technology, but also the severe environmental regulations have led to an accepted unit operation for various separation processes. Therefore, different aspects of HFMC technology including membrane structure, module configuration and applications have been investigated, in recent years. This book has been written by the membrane experts which provides an insight of recent advances and potential progress on membrane contactor technology. This book can be a dynamic reference for future research and development for researchers, students, membrane technologist, membrane manufacturer and academicians. Some critical issues need to be overcome and much research efforts are required to industrialize the membrane contactor technology. To minimize the membrane mass transfer resistance, high surface porosity with small pore size are the key factors. To prevent channeling and bypassing in the shell side of the hollow fiber membrane module, an upgraded design can be an advantage, especially for large scale modules. The energy assessment and techno-economic analysis of a membrane contactor process is required to achieve the commercialization level. Integration of membrane contactor process with other separation units or membrane processes, waste heat and renewable energy sources can be studied to achieve new sustainable technical solutions. To preserve the membrane reliability for a prolonged operation, the real feed condition and membrane fouling can be important factors which have been rarely investigated.

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