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Volume 2

NATURAL GAS SWEETENING

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Preface

Natural gas, with its abundance, cleanliness, and economic advantages, has emerged as a crucial energy source that is extensively utilized worldwide. Composed mainly of methane, natural gas can be found in underground reservoirs or associated with crude oil. The exploration, production, transportation, and utilization of natural gas require multidisciplinary efforts and technological advancements to ensure efficient and sustainable operations. To fully exploit the potential of natural gas, a thorough understanding of its properties, extraction, processing, transportation, storage, and applications is essential.

The *Advances in Natural Gas* book series serves as a comprehensive and up-to-date reference for researchers, engineers, professionals, students, and academics involved in the natural gas industry. It provides a valuable resource for those interested in delving into the realm of natural gas science and technology.

Natural gas sweetening is a crucial step in the processing of natural gas that ensures the removal of unwanted impurities, such as hydrogen sulfide (H_2S) and carbon dioxide (CO_2), that can cause corrosion, decrease the heating value of the gas, and pose health and safety risks. Sweetening technologies have evolved over the years, ranging from absorption and adsorption techniques to membrane technology. The selection of a suitable sweetening technology depends on various factors, including the composition of the feed gas, the desired product specifications, the availability of resources, and the economic and environmental considerations.

This volume of the *Advances in Natural Gas* series, titled *Natural Gas Sweetening*, offers a comprehensive overview of the recent advances in sweetening technologies. It comprises a collection of chapters that provide insights into the concepts, standards, policies, and regulations associated with natural gas sweetening. It also explores the economic assessments and environmental challenges of natural gas sweetening technologies.

The volume is structured into four sections, each delving into different aspects of natural gas sweetening technologies. The first section serves as an introduction to natural gas sweetening, covering the basic concepts and technologies involved in sweetening processes. It highlights the importance of sweetening technologies in ensuring the quality and safety of natural gas for various applications. This section also provides an overview of the economic and environmental considerations associated with sweetening technologies.

The second section of the volume explores absorption techniques for natural gas sweetening, including the use of amines, physical and hybrid solvents, and solvents modified with nanoparticles. The section also delves into the use of encapsulated liquid sorbents and cryogenic-fractionation for natural gas sweetening. Additionally, it provides an overview of the absorption processes for CO_2 removal from CO_2-rich natural gas.

The third section of the volume focuses on adsorption techniques for natural gas sweetening, including swing technologies and the use of zeolite sorbents, nanosorbents, metal oxides, and silica-based sorbents. This section also explores the adsorption processes for CO_2-rich natural gas sweetening.

The fourth and final section of the volume addresses membrane technology for natural gas sweetening, including the use of polymeric membranes, ionic liquid membranes, dense metal membranes, and electrochemical membranes. This section also explores membrane technology for CO_2 removal from CO_2-rich natural gas.

In summary, this volume of the *Advances in Natural Gas* series provides a comprehensive overview of natural gas sweetening technologies. It not only highlights the potential of sweetening technologies in ensuring the quality and safety of natural gas but also addresses the challenges associated with their production and extraction. This volume is structured to provide valuable insights to researchers, engineers, professionals, students, and academics involved in the natural gas industry. We invite you to delve into the fascinating world of natural gas sweetening and explore the immense potential of these technologies for sustainable energy practices.

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Membrane technology for CO_2 removal from CO_2-rich natural gas

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1. Introduction

Gas separation is required to remove contaminants, hazardous gases, and CO_2 in order to produce gas that meets consumer demands. Membrane gas separation is a typical gas separation method. Membrane gas separation processes, such as absorption, distillation, and adsorption, provide various benefits, including minimal cost, simplicity of handling, higher selectivity, and the potential to connect with other operations [1]. Presently, the primary emphasis is on developing technology and polymer manufacturing for improved selectivity and permeability in order to meet demand. Numerous studies are being conducted to separate CO_2/CH_4 and O_2/N_2 from air and natural gases [2]. Membrane performance is determined by its manufacture and material structure, as well as separation mechanism [3].

Benchold started the voyage of membrane gas separation in 1907 [4]. He was a pioneer in the development of nitrocellulose membranes with varying pore sizes. Collodion membranes with microparticle sizes first appeared on the market on a small scale in 1930s, when more refined membrane manufacturing procedures were devised [5,6]. Various polymers, such as cellulose acetate,

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mixture and discards others [15,16]. Membrane has shown a remarkable performance over conventional methods and it is used in many petroleum chemicals, water purifiers, and other industries today [15,16]. There are many advantages of membrane like its small size, diversity, maintenance, and simplicity. The separation of gas by membrane is used in several industries to enrich the quality of gas. In separating at least one gas from a feed combination and producing a pure gas-rich pervades, a membrane works as a "filter" that permits the special section of specific substances. Specifically, a membrane will separate if a few components from the combination can pass through the membrane more quickly than others [15,16]. Further, motion of the gas that passes quickly separates from the mixture.

There are mainly two types of membrane: porous membrane and nonporous membrane [15,16]. Mechanisms of the two types of membranes are different. Porous membrane separates gases through small pores based on molecular size. Diffusivity and solubility are nonporous membrane mechanisms of separating gases. Solution diffusion, surface diffusion, Knudsen diffusion, facilitated transport, molecular sieving, and capillary condensation are the mechanism for both porous and nonporous membrane gas separation [17–22]. For polymeric membrane, solution-diffusion is the most suitable procedure for removing CO_2 [22]. Gas transport depends on a solution dispersion system and results in particular separation of gases and, subsequently, their purification.

3. Membrane processes for efficient CO_2 removal

Membrane-based separation technology is widely used for gas purification, desalination of water, toxic metal removal, and recovery of valuables. The whole process depends on the membrane nature and manufactures from several materials among them polymeric, ceramic, and zeolites are common. Each membrane has a separate filtering property. Filtering property mainly depends upon the change of surface, different pore sizes, the morphology of membrane, and hydrophobicity characteristics [23].

Organic membrane partial pressure gradient is one method of gas separation. It is mostly the result of mole function and total pressure. Several gas transportation techniques have been suggested. It is mostly determined by the membrane's material qualities [24]. Poiseuille (viscous) flow, Knudsen diffusion, molecular sieving, capillary condensation, and solution–diffusion mechanisms are the common mechanisms that are proposed for gas transportation [25]. Table 18.1 shows gas transport regimes and their selectivity based on the pore size, and Fig. 18.1 is about the several gas separation mechanisms.

3.1 Hagen–Poiseuille (viscous flow in wide pores)

Hagen–Poiseuille technique is applicable when the pore width is enormous contrasted with the mean freeway of gas particles (λ) and transport is by mass liquid course through the huge pores [26].

Permeability and gas viscosity are proportional inversely in the Poiseuille regime [25] shown on Eq. (18.1).

$$P_e = \frac{\varepsilon \eta r^2}{8\mu RT} P_{av}\left(\text{mol m}^{-1}\,\text{s}^{-1}\,\text{Pa}^{-1}\right) \tag{18.1}$$

Here, ε is the porosity
η is the structural factor
μ is the viscosity
p_{av} is the pressure, Pa

3.2 Knudsen diffusion in narrow pores

Kundsen diffusion is a gas transportation technique in which pore size is larger than the size of the molecule but smaller than the gas path molecules. Instead of friction between gas particles, collision occurs between the pore divider and gas atoms in this system [27]. Although the bearing of bounce back is uneven,

Table 18.1 Main gas separation regimes and their selectivity based on the pore size in the membrane [25].

Separation mechanism	Turbulent flow	Laminar flow	Surface diffusion	Knudsen diffusion	Solution diffusion	Capillary condensation	Molecular sieving
Diameter of the pore	>50	>20	1–3	2–50	0	2–10	0–2
Selectivity	×	×	√	$\sqrt{m2/m1}$, $m2 > m1$	√√√	√√	√√