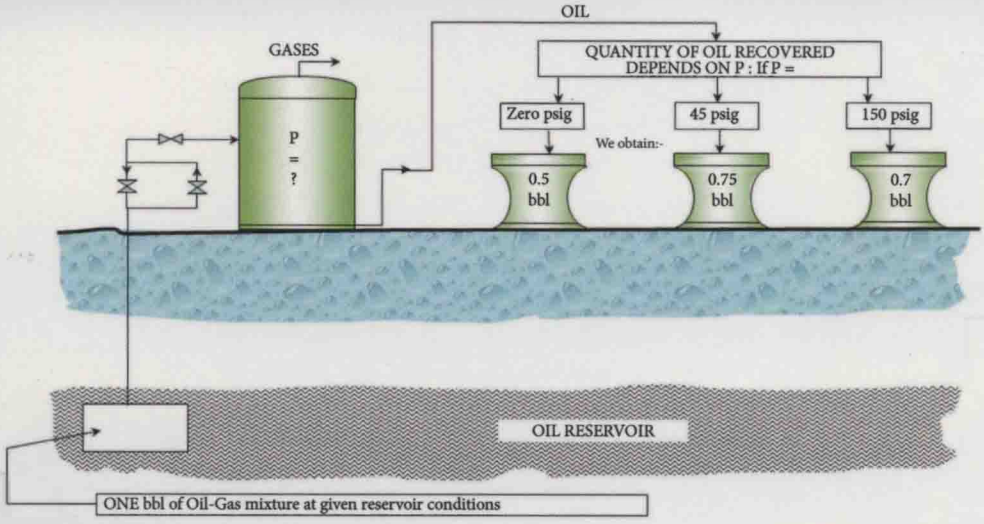
CHEMICAL INDUSTRIES/141

Petroleum and Gas Field Processing

Second Edition



Hussein K. Abdel-Aal
Mohamed A. Aggour
Mohamed A. Fahim

CRC Press
Taylor & Francis Group

Petroleum and Gas Field Processing

Second Edition

Hussein K. Abdel-Aal
Mohamed A. Aggour
Mohamed A. Fahim

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Printed on acid-free paper
Version Date: 20150817

International Standard Book Number-13: 978-1-4822-5592-8 (Paperback)

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the CRC Press Web site at
http://www.crcpress.com

Petroleum and Gas Field Processing

Second Edition

CHEMICAL INDUSTRIES

A Series of Reference Books and Textbooks

Founding Editor

HEINZ HEINEMANN
Berkeley, California

Series Editor

JAMES G. SPEIGHT
CD & W, Inc.
Laramie, Wyoming

MOST RECENTLY PUBLISHED

Petroleum and Gas Field Processing, Second Edition, Hussein K. Abdel-Aal, Mohamed A. Aggour, and Mohamed A. Fahim

Handbook of Refinery Desulfurization, Nour Shafik El-Gendy and James G. Speight

Refining Used Lubricating Oils, James Speight and Douglas I. Exall

The Chemistry and Technology of Petroleum, Fifth Edition, James G. Speight

Educating Scientists and Engineers for Academic and Non-Academic Career Success, James Speight

Transport Phenomena Fundamentals, Third Edition, Joel Plawsky

Synthetics, Mineral Oils, and Bio-Based Lubricants: Chemistry and Technology, Second Edition, Leslie R. Rudnick

Modeling of Processes and Reactors for Upgrading of Heavy Petroleum, Jorge Ancheyta

Synthetics, Mineral Oils, and Bio-Based Lubricants: Chemistry and Technology, Second Edition, Leslie R. Rudnick

Fundamentals of Automatic Process Control, Uttam Ray Chaudhuri and Utpal Ray Chaudhuri

The Chemistry and Technology of Coal, Third Edition, James G. Speight

Practical Handbook on Biodiesel Production and Properties, Mushtaq Ahmad, Mir Ajab Khan, Muhammad Zafar, and Shazia Sultana

Introduction to Process Control, Second Edition, Jose A. Romagnoli and Ahmet Palazoglu

Fundamentals of Petroleum and Petrochemical Engineering, Uttam Ray Chaudhuri

Advances in Fluid Catalytic Cracking: Testing, Characterization, and Environmental Regulations, edited by Mario L. Occelli

Advances in Fischer-Tropsch Synthesis, Catalysts, and Catalysis, edited by Burton H. Davis and Mario L. Occelli

Preface

As oil exploration and production (E&P) activities over the world continue to grow, we academicians and engineering professionals must fully grasp the technology and processes involved within their function to proactively support oil and gas field operations. A competent understanding of technology and various processes that drive E&P also provides an overall appreciation of the role played by surface production operations.

In addition, the very high cost and risk involved in E&P demands the reevaluation of all operations encountered in handling the oil–gas mixture from well head all the way to quality petroleum oil and gas products. Many oil production processes present a significant challenge to the oil and gas field processing facilities and equipment design. The optimization of the sequential operations of handling the oil–gas mixture can be a major factor in increasing oil and gas production rates and reducing operating costs.

Fully revised and updated to reflect major changes over the past 10 years or so, this second edition offers thorough coverage of every sector in the field processing of produced crude oil along with its associated gas. We intend to go forward to continue building on our foundation success attained in the first edition. Our mission remains unchanged: to deliver an expanded and updated volume that covers the principles and procedures related to the processing of reservoir fluids for the separation, handling, treatment, and production of quality petroleum oil and gas products.

Adding new information about field facilities to this edition, this book contains 18 chapters (compared to 13 in the first edition) grouped into five sections. Section I presents a broad background that covers the production of oil and gas (Chapter 1), a preview of principal field processing operations (Chapter 2), composition and types of crude oil and products (Chapter 3), composition and characterization of natural gas (Chapter 4), and the role of economics in oil and gas field operations (Chapter 5). Section II handles two-phase and three-phase gas–oil separation (Chapters 6 and 7, respectively). Crude oil treatment is detailed in Section III, which covers emulsion treatment and dehydration of crude oil (Chapter 8), desalting (Chapter 9), stabilization and sweetening of crude oil (Chapter 10), and other treatment options (Chapter 11). Gas handling and treatment, covered in Section IV, includes sour gas treatment, gas dehydration, and separation and production of natural gas liquids (NGLs), Chapters 12, 13, and 14, respectively. Section V, on the other hand, is devoted to surface production facilities, a new addition to the second edition. It includes four chapters covering the topics of produced water management and disposal (Chapter 15), field storage tanks, vapor recovery units (VRUs) and tank blanketing (Chapter 16), oil field chemicals (Chapter 17), and piping and pumps (Chapter 18).

This second edition takes advantage of recent publications with immense knowledge in the area of surface petroleum operations by the inclusion of new subjects, in particular natural gas, economics and profitability, oil field chemicals, and piping and pumps. These additions contribute new features to our book, especially when it comes to the dollar sign in an economic study.

The concept of unit operation, which is discussed in the "Introduction" of this book, is presented in many surface operations in this new edition. Unit operations are identified in crude oil field treatment and natural gas processing. Distillation, mixing, and absorption are typical examples.

An all-inclusive guide to surface petroleum operations, the text provides a comprehensive and visionary approach to solve problems encountered in field processing of oil and gas. It contains examples and case studies from a variety of oil field operations. Example step-by-step exercises are worked out. This book is arranged so that it can be used both as a text and as a reference. As a textbook, it would fit nicely for courses on surface petroleum operations taught in many schools all over the world. It would be suitable for use in a one- or two-semester course for students majoring in petroleum engineering, chemical engineering, and allied engineering. On the other hand, it would be invaluable for experts, engineers, and practicing professionals working in the petroleum industry.

The authors are indebted to the many oil organizations and individuals who have provided information and comments on the subject materials presented in this edition. As far as the production and the publication of this edition, we feel a deep sense of gratitude to Barbara Glunn, Robert Sims, and Kari Budyk of Taylor & Francis, and Adel Rosario of MTC.

Hussein K. Abdel-Aal
Mohamed A. Aggour
Mohamed A. Fahim

Authors

Prof. Hussein K. Abdel-Aal is an emeritus professor of chemical engineering and petroleum refining at NRC, Cairo, Egypt, and KFUPM, Dhahran, Saudi Arabia. He worked in the oil industry (1956–1960) as a process engineer in Suez oil refineries before working on his graduate studies in the United States.

From 1971 to 1988, Prof. Abdel-Aal was with the Department of Chemical Engineering, KFUPM, Dhahran, where he was the head from 1972 to 1974. He was a visiting professor with the Chemical Engineering Department at Texas A&M in 1980–1981. In 1985–1988, Prof. Abdel-Aal assumed the responsibilities of the head of the solar energy department in NRC, Cairo.

Prof. Abdel-Aal has contributed to more than 90 technical papers and is the main author of the text book *Petroleum and Gas Field Processing* (Marcel Dekker Inc., 2003); he is also the editor of *Petroleum Economics & Engineering, Third Edition* (CRC Press, 2014).

He is a fellow and a founding member of the board of directors of the International Association of Hydrogen Energy, Miami, Florida. He is on the honorary editorial board of *International Journal of Hydrogen Energy.*

Dr. Mohamed A. Aggour is a professor and former chairman of the petroleum engineering program of Texas A&M University at Qatar. Prior to this, he was a professor of petroleum engineering at the Petroleum Institute, Abu Dhabi, and King Fahd University of Petroleum and Minerals, Saudi Arabia.

Dr. Aggour was the leader of the Production Technology Research Group of Esso Resources Canada and a staff production engineer at the East Texas Division of Exxon Company. He has more than 48 years of combined academic, industry, and research experience. He has numerous publications and three patents.

He received 19 departmental and six university-level Distinguished Teaching Awards, and three Distinguished Research Awards. He was the recipient of the 2012 Best Petroleum Engineering Faculty from the Institute of Academic Excellence and the 2013 Society of Petroleum Engineering Regional Award for Distinguished Achievement by the Petroleum Engineering Faculty.

Dr. Mohamed A. Fahim was a professor and the chairman of the Chemical Engineering Department for 40 years at the University of Kuwait and the University of United Arab Emirates.

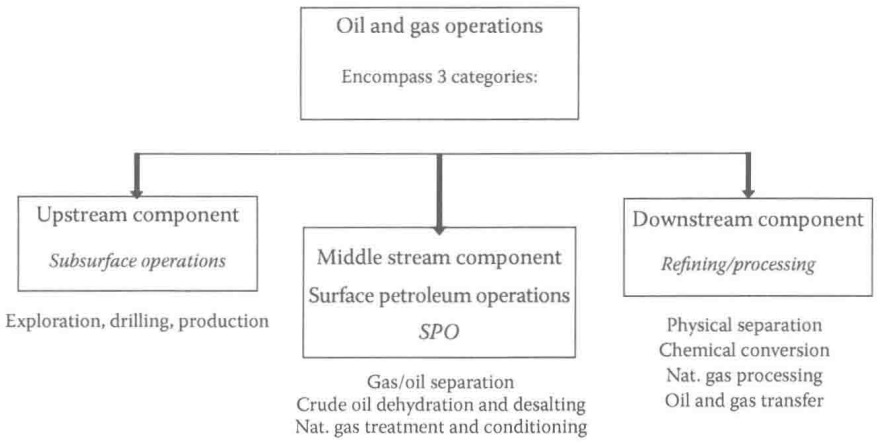
Dr. Fahim published more than 150 papers in the field of petroleum refining and gas processing.

Prof. Fahim is the main author of *Fundamentals of Petroleum Refining* (Elsevier, 2010) and a coauthor of *Petroleum and Gas Field Processing* (Marcel Dekker Inc., 2003).

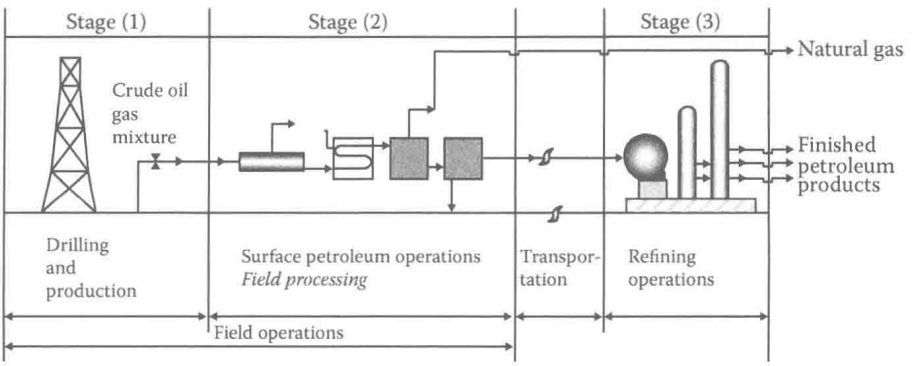
Introduction

This new edition of *Petroleum and Gas Field Processing* comes at a time when oil producers are taking a close look at the economy of oil field operations to improve the ultimate recovery and to maximize the yield of oil and gas obtained during the surface processing operations.

Oil field operations in general encompass three main phases, as shown in the following block diagram.



This is illustrated further by the following flow diagram:



Petroleum and gas field processing operations, referred to as surface petroleum operations (SPO), cover the myriad procedures required to handle the crude oil mixture between the well head and the delivery points for refining operations and other usages.

Crude oil is far from being one homogeneous substance. Its physical characteristics differ depending on where the crude oil is found, and those variations determine its usage and price as well. As the U.S. Energy Information Administration (EIA) puts it succinctly, "not all crude is created equal" (U.S. Energy Information Administration, 2015). It is worth mentioning that more than 40,000 oil fields are scattered around the globe, on land and offshore. The largest are the Ghawar Field in Saudi Arabia and the Burgan Field in Kuwait, with more than 60 billion barrels (9.5×10^9 m^3) estimated in each. Most oil fields are much smaller. According to the EIA, as of 2003 the United States alone had more than 30,000 oil fields. More than half the United States' oil reserves are located in its 100 largest fields. According to a new EIA report, these massive fields account for 20.6 billion of the 36.5 billion barrels of oil, or 56 percent of the total ("List of Oil Fields," 2015).

Many oil production processes present a significant challenge to oil and gas field processing facilities. This applies to the design and operations of the processing equipment. A typical example is the fact that the nature of crude oil emulsions changes continuously as the producing field depletes. Therefore, conditions change as well.

In this new edition, we attempt to introduce the concept of unit operations used by chemical engineers to provide the readers with tools for creating a *surface* process system that will economically separate and treat oil–gas mixtures as they exit the wellhead into quality salable oil and gas products.

What Is a Unit Operation?

A unit operation represents a basic physical operation in a chemical or petroleum process plant. Examples are distillation, absorption, fluid flow, and heat and mass transfer. Fundamentals pertaining to a given unit operation are the same regardless of its industrial applications. This is how pioneers came up with the term *unit operation.*

Unit operations deal mainly with the transfer and the change of both materials and energy primarily by physical means, arranged as needed by a given petroleum or chemical industry. The following is a partial list of some important unit operations:

- Fluid flow—Deals with the principles governing the flow and transportation of fluids.

- Heat transfer—Deals with the principles underlying the heat transfer by different modes.
- Distillation, absorption, extraction, and drying—Known as diffusional mass transfer unit operations. Separation of petroleum hydrocarbons, by these unit operations, is accomplished by the transfer of molecules from one phase to the other by diffusion. Typical examples are distillation and absorption.

The significance of introducing the unit operation concept in understanding the processing surface operations in an oil field will be apparent to readers when it is realized that most of these surface operations are *physical operations*, or *nonreacting processes*. They deal mainly with the transfer and the transformation of *energy*, and the transfer, separation, and conditioning (treating) of *materials* by physical means. Three modes of transfer that take place in oil field processing operations are recognized as follows:

1. Momentum transfer (gained by fluid flow)
2. Heat transfer of oil using heat exchangers and furnaces
3. Mass transfer in distillation columns, absorbers, and others that lead to enrichment and separation (transfer is due to the diffusion of the molecules that separates the light from the heavy)

These three modes of transfer are usually covered under the topic of transport phenomena.

Examples of some common unit operations that take place during oil and gas field processing are listed next along with their specific applications.

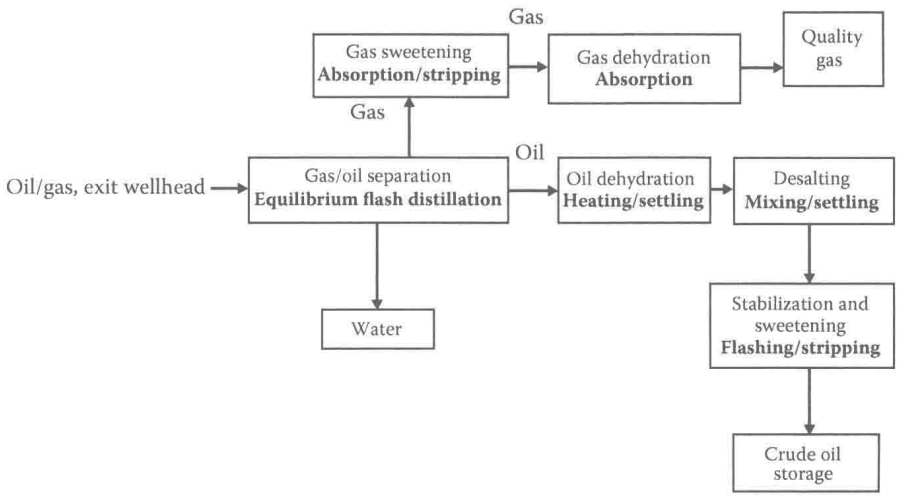
Unit Operation	Application
Equilibrium flashing	Gas–oil separation
Distillation/stripping	Crude oil stabilization/sweetening
Absorption	Treatment of natural gas
Fluid flow	Most of field operations
Heat transfer	Most of field operations

The proposed treatment of the subject matter of petroleum and gas field processing will follow a chronological sequence of field operations in transient. Each is described with the unit operation concept when applicable as the oil–gas mixture proceeds from the wellhead until the crude oil is finally separated, treated, and stored ready for shipping or refining. The same is true for the associated gas, passing through its journey until it is finally a quality sale gas.

Process System

A process system is a collection of equipment that affects the required separation or treatment through physical methods or chemical changes. For example, by means of a properly designed processing system, crude oil desalting is accomplished by intimate mixing of the crude oil with dilution water.

By applying the unit operation concept, we are able to identify the process system that handles crude oil–gas mixtures all the way through as shown next.



Following the order of events using this flow sheet, one can determine the function of every piece of equipment involved in an oil field process design, highlighted in bold. The immediate next step is the determination of the size and the type of equipment needed to carry out the physical changes, using the unit operations principle underlying this process. Remember that the fundamentals pertaining to a given unit operation are the same regardless of its application, hence unit operation.

Contents

Section II Separation of Produced Fluids