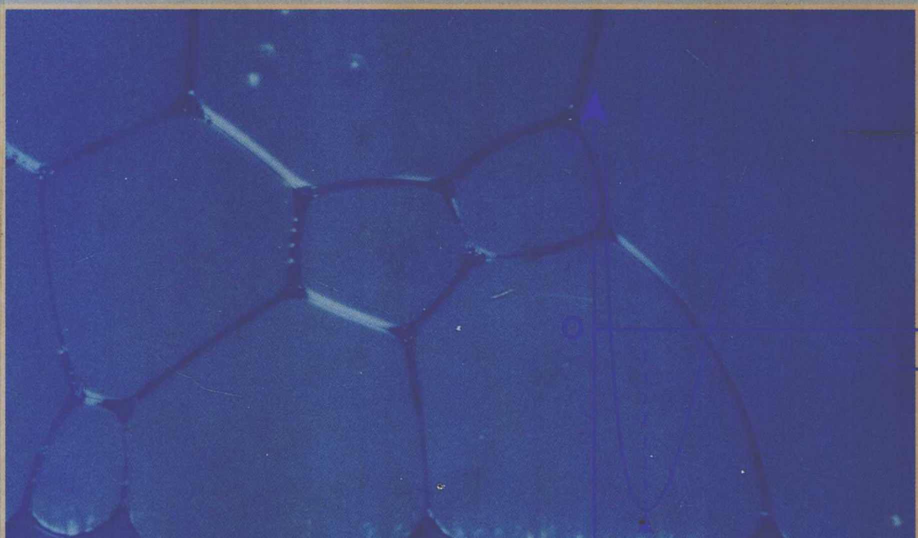
Advances in Chemistry Series 242

FOAMS

Fundamentals and Applications in the Petroleum Industry



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Foams: Fundamentals and Applications in the Petroleum Industry

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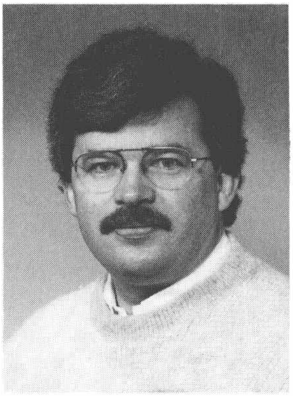
FOREWORD

The ADVANCES IN CHEMISTRY SERIES was founded in 1949 by the American Chemical Society as an outlet for symposia and collections of data in special areas of topical interest that could not be accommodated in the Society's journals. It provides a medium for symposia that would otherwise be fragmented because their papers would be distributed among several journals or not published at all.

Papers are reviewed critically according to ACS editorial standards and receive the careful attention and processing characteristic of ACS publications. Volumes in the ADVANCES IN CHEMISTRY SERIES maintain the integrity of the symposia on which they are based; however, verbatim reproductions of previously published papers are not accepted. Papers may include reports of research as well as reviews, because symposia may embrace both types of presentation.

ABOUT THE EDITOR



LAURIER L. SCHRAMM is a senior staff research scientist and group leader for process sweep improvement at the Petroleum Recovery Institute and adjunct associate professor of chemistry at the University of Calgary, where he lectures in applied colloid and interface chemistry. Dr. Schramm received his B. Sc. (Hons.) in chemistry from Carleton University in 1976 and Ph.D. in physical and colloid chemistry in 1980 from Dalhousie University, where he studied as a Killam and NRC Scholar. From 1980 to 1988 he held research positions with Syncrude Canada Ltd. in its Edmonton Research Centre.

His research interests have included many aspects of colloid and interface science applied to the petroleum industry, including research into mechanisms of processes for the improved recovery of light, heavy, or bituminous crude oils, such as in situ foam, polymer or surfactant flooding, and surface hot water flotation from oil sands. These mostly experimental investigations have involved the formation and stability of dispersions (foams, emulsions, and suspensions) and their flow properties, electrokinetic properties, interfacial properties, phase attachments, and the reactions and interactions of surfactants in solution.

Dr. Schramm is a Fellow of the Chemical Institute of Canada (including serving on the Local Section Executive) and is a member of the American Chemical Society and the International Association of Colloid and Interface Scientists. He has written more than 60 scientific publications and patents. This is his third ACS book, following *Emulsions: Fundamentals and Applications in the Petroleum Industry* and *The Language of Colloid and Interface Science*.

PREFACE

FOAMS CAN BE FOUND in almost every part of the petroleum production and refining process, from deep in the producing reserviors, through oilwell drilling, stimulation, and production, to downstream vessels in the refining process. In these cases the foams may occur naturally or by design and may be desirable or undesirable. In all cases the presence and nature of the foam can determine both the economic and technical successes of the industrial process concerned.

This book provides an introduction to the nature and occurrence, properties and uses, and formation and breaking of foams in the petroleum industry. It is aimed at scientists and engineers who may encounter foams or apply foams, whether in process design, petroleum production, or research and development. Primarily the focus is on the introduction and subsequent application of foam principles, and includes attention to practical foam problems. Books available up to now are either principally theoretical (such as the colloid chemistry texts) or focus on foams in general (like Bikerman's classic books). A significant gap in this coverage concerns foams in the petroleum industry, a topic that is not only of great practical importance but also presents many problems of fundamental interest.

In this book a wide range of authors' expertise and experiences have been brought together to yield the first book on foams that focuses on the uses and occurrences of foams in the petroleum industry[1]. This broad range has allowed for a variety of foams and applications to be highlighted, foams that are bulk or lamellar, aqueous or nonaqueous, and flowing or static. It also covers the occurrences of foams in a wide variety of situations: in porous media, well-bores, flotation vessels, and process plants.

To provide an introduction to the science and engineering of foams in the petroleum industry, the book does not assume a knowledge of colloid chemistry, the initial emphasis being placed on a review of the basic concepts important to understanding foams. As such, it is hoped that the book will also be of interest to senior undergraduate and graduate stu-

[1]For those interested in foams for mobility control, I also recommend reading *Surfactant-Based Mobility Control*, Smith, D. H., Ed.; ACS Symposium Series No. 373, American Chemical Society: Washington, DC, 1988.

dents in science and engineering, because these topics are not normally part of university curricula.

The focus of the book is practical rather than theoretical. In a systematic progression, beginning with the fundamental principles in bulk foams, the reader is soon introduced to the case of lamellar foams being generated and flowing in porous media, followed by commercial foam applications and treatments. The first four chapters deal with foam fundamentals, including bulk foam stability and antifoaming, foams in porous media, and foam sensitivity to oil in porous media. Armed with the necessary tools, the reader is next introduced to some exemplary petroleum industry applications of foams. Chapters 5–7 cover the application of foams to improving oil recovery from porous media, including the uses of CO_2, steam, and hydrocarbon foams. Chapters 8–10 present some examples of the application of foams to oil well and near-well petroleum production problems. Chapters 11 and 12 give some examples of foams in surface processes: froth flotation in oil sands processing, and antifoaming and defoaming in refineries. Finally, a comprehensive and fully cross-referenced glossary of foam terminology is included.

Overall, the book illustrates how to understand, make, and use desirable foams and how to approach breaking, or preventing, undesirable foams. It also serves as a companion volume to *Emulsions: Fundamentals and Applications in the Petroleum Industry*[2].

Acknowledgments

I thank all the authors who contributed considerable time and effort to their chapters. This book was made possible through the support of my family, Ann Marie, Katherine, and Victoria, who gave me the time needed for the organization, research, and writing. I am also very grateful to Conrad Ayasse for his consistent encouragement and support. Throughout the preparation of this book many valuable suggestions were made by the reviewers of individual chapters and by the staff of ACS Books, particularly Cheryl Shanks, Stephanie Patton, Margaret Brown, and Colleen P. Stamm.

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CONTENTS

Foam Fundamentals

1

Foams: Basic Principles

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This chapter provides an introduction to the occurrence, properties, and importance of foams as they relate to the petroleum industry. The fundamental principles of colloid science may be applied in different ways to stabilize or destabilize foams. This application has practical importance because a desirable foam that must be stabilized at one stage of an oil production process, may be undesirable in another stage and necessitate a defoaming strategy. By emphasizing the definition of important terms, the importance of interfacial properties of foam making and stability is demonstrated.

Importance of Foams

If a gas and a liquid are mixed together in a container, and then shaken, examination will reveal that the gas phase has become a collection of bubbles that are dispersed in the liquid: A foam has been formed (Figure 1). Foams have long been of great practical interest because of their widespread occurrence in everyday life. Some important kinds of familiar foams are listed in Table I. In addition to their wide occurrence, foams have important properties that may be desirable in a formulated product, such as fire-extinguishing foam, or undesirable, such as a foam in an industrial distillation tower.

Petroleum occurrences of foams may not be as familiar but have a similarly widespread, long-standing, and important occurrence in industry. Foams may be applied or encountered at all stages in the petroleum recovery and processing industry (oil well drilling, reservoir injection, oil

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Table I. Some Examples of Foams in Everyday Experience

Group	*Product*
Foods	Champagne, soda heads
	Beer head
	Whipped cream
	Meringue
Detergency	Manual dishwashing suds
	Machine dishwashing suds
	Commercial bottle-cleaning process foam
	Machine clothes-washing suds
Personal Care Products	Shaving cream
	Hair shampoo suds
	Contraceptive foams
	Bubble bath foam
Process Industries	Foam blankets on electroplating baths
	Sewage treatment effluent foams
	Mineral or oil flotation froths
	Foam fractionation
	Pulping black liquor foam
Other	Fire extinguishing foams
	Explosion suppressing foam blankets
	Fumigant, insecticide, and herbicide blankets

well production, and process plant foams). This chapter is intended to provide an introduction to the basic principles involved in the occurrence, "making", and "breaking" of foams in the petroleum industry. Subsequent chapters in this volume will go into specific areas of occurrence in greater detail.

As suggested in Table II, petroleum industry foams may be desirable or undesirable. For example, one kind of oil well drilling-fluid (or "mud") is foam-based. Here, a stable foam is used to lubricate the cutting bit and to carry cuttings up to the surface. Drilling with a foam drilling-fluid also allows lower pressures to be applied to the formation, which is important when drilling into low-pressure reservoirs. This foam is obviously desirable, and great care goes into its proper preparation. Other foams that are desirable near well-bores include fracturing foams and acidizing foams.

It may happen that a foam that is desirable in one part of the oil production process may be undesirable at the next stage. For example, in the oil fields, an in situ foam that is purposely created in a reservoir to increase viscosity (and thereby improve volumetric sweep efficiency as part of an oil recovery process) may present a handling problem when produced.

Table II. Some Examples of Foams in the Petroleum Industry

Type	*Occurrence*
Undesirable foams	Producing oil well and well-head foams
	Oil flotation process froth
	Distillation and fractionation tower foams
	Fuel oil and jet fuel tank (truck) foams
Desirable foams	Foam drilling fluid
	Foam fracturing fluid
	Foam acidizing fluid
	Blocking and diverting foams
	Gas-mobility control foams

Foams may contain not just gas and liquid, such as water, but solid particles, and even oil. In the large Canadian oil–sands mining and processing operations, bitumen is separated from the sand matrix in large tumblers, as an emulsion of oil dispersed in water, and then further separated from the tumbler slurry by a flotation process. The product of the flotation process is bituminous froth, a foam that may be either air and water dispersed in the oil (primary flotation), or air and oil dispersed in water (secondary flotation). In either case, the froths must be "broken" and deaerated before the bitumen can be upgraded to synthetic crude oil.

Finally, many kinds of foams pose difficult problems wherever they may occur. In surface emulsion treaters (e.g., oil–water separators) and in refineries (e.g., distillation towers), the occurrence of foams is generally undesirable, and any such foams will have to be "broken".

The same basic principles of colloid science that govern the nature, stability, and properties of foams apply to all of the previously mentioned petroleum industry foam applications and problems. The widespread importance of foams in general and scientific interest in their formation, stability, and properties have precipitated a wealth of published literature on the subject. The present chapter provides an introduction, and is intended to complement the other chapters dealing with petroleum industry foams in this book. A good starting point for further basic information is the classic text, J. J. Bikerman's *Foams: Theory and Industrial Applications* (*1*) and several other books on foams (*2–4*). Most comprehensive colloid chemistry texts contain introductory chapters on foams (*5–7*), but some of the chapters in specialist monographs (*8–13*) give a much more detailed treatment of advances in specific foam-related areas. With regard to the occurrence of other colloidal systems in the petroleum industry, a recent book describes the principles and occurrences of emulsions in the petroleum industry (*14*).

Foams as Colloidal Systems

Definition and Classification of Foams. Colloidal species of any kind (bubbles, particles, or droplets), as they are usually defined, have at least one dimension between 1 and 1000 nm. Foams are a special kind of colloidal dispersion: one in which a gas is dispersed in a continuous liquid phase. The dispersed phase is sometimes referred to as the internal (disperse) phase, and the continuous phase as the external phase. In practical occurrences of foams, the bubble sizes usually exceed the size limit given, as may the thin liquid-film thicknesses. Table II lists some simple examples of petroleum industry foam types. Solid foams, dispersions of gas in a solid, will not in general be covered in this chapter. A glossary of frequently encountered foam terms in the science and engineering of petroleum industry foams is given at the end of this volume.

A two-dimensional slice of a general foam system is depicted in Figure 1. The general foam structure is contained on the bottom by the bulk liquid and on the upper side by a second bulk phase, in this case, gas. Within the magnified region, the various parts of the foam structure are clarified. The gas phase is separated from the thin liquid-film, by a two-dimensional interface. In reality, a sharp dividing surface does not exist between gas and liquid properties. Dictated by mathematical convenience, the physical behavior of this interfacial region is approximated by a two-dimensional surface phase (the Gibbs surface). For the purposes of this book, a lamella is defined as the region that encompasses the thin film, the two interfaces on either side of the thin film, and part of the junction to other lamellae. The connection of three lamellae, at an angle of 120°,

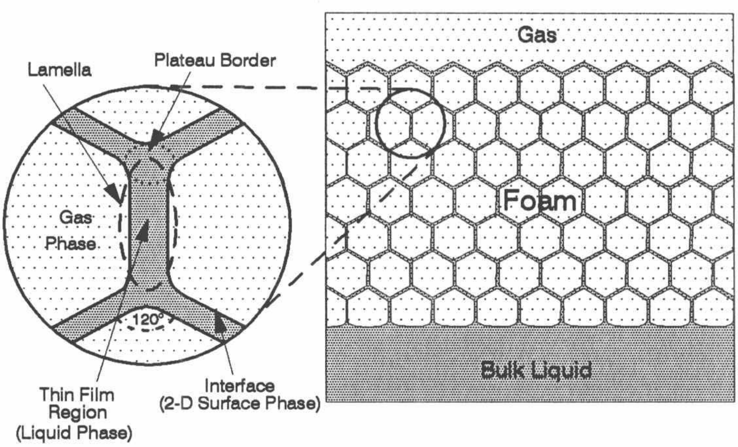

Figure 1. A generalized foam system.

is referred to as the Plateau border. Because Figure 1 represents only a two-dimensional slice, the Plateau border extends perpendicularly, out of the page. The relevance of the definitions, given here, will become clear in the following paragraphs.

"Making" Thin Films and Foams. Much of this chapter is concerned with foam properties and stability, and as a practical matter one frequently has to contend with already formed foams. Nevertheless, a few comments on how foams are made is appropriate. The "breaking" of foams will be discussed later.

A foam structure can always be formed in a liquid if bubbles of gas are injected faster than the liquid between bubbles can drain away. Even though the bubbles coalesce as soon as the liquid between them has drained away, a temporary dispersion is formed. An example would be the foam formed when bubbles are vigorously blown into a viscous oil. Such a foam, comprising spherical, well-separated bubbles, is referred to as a wet foam, or kugelschaum. Wet foams in which the liquid lamellae have thicknesses on the same scale as the bubble sizes are sometimes referred to as "gas emulsions". Here, the distinction of whether this is a foam or not relates to stability. But it is complicated by the fact that, as for other types of colloidal dispersions, no foams are thermodynamically stable. Eventually they all collapse.

In pure liquids, gas bubbles will rise up and separate, more or less according to Stokes' law. When two or more bubbles come together, coalescence occurs very rapidly, without detectable flattening of the interface between them; that is, there is no thin-film persistence. The adsorption of surfactant at the gas–liquid interface promotes thin-film stability between the bubbles and lends a certain persistence to the foam structure. Here, when two bubbles of gas approach, the liquid-film thins down to a persistent lamella instead of rupturing at the point of closest approach. In carefully controlled environments, it has been possible to make surfactant-stabilized, static bubbles and films with lifetimes on the order of months and years (*3*).

Arrangement of the Phases. In a persistent foam, the spherical bubbles become transformed into foam cells, polyhedra separated by almost flat liquid-films. Such foams are referred to as dry foams, or polyederschaum. The polyhedra are almost, but not quite, regular dodecahedra. Figure 1 illustrates the two-dimensional structure of such a foam. These arrangements of films, which come together at equal angles, result from the surface tensions, or contracting forces, along the liquid-films. The bubbles in a foam arrange themselves into polyhedra such that, along the border of a lamella, three lamellae always come together at angles of