TWO-PHASE FLOW and HEAT TRANSFER in the POWER and PROCESS INDUSTRIES

A. E. Bergles
J. G. Collier
J. M. Delhaye
G. F. Hewitt
F. Mayinger

O359
B3

8263568

TWO-PHASE FLOW AND HEAT TRANSFER IN THE POWER AND PROCESS INDUSTRIES

A. E. Bergles
Iowa State University
Ames, Iowa, U.S.A.

J. G. Collier
Atomic Energy Technical Unit
U. K. Atomic Energy Authority
Harwell, England

J.M. Delhaye
Centre d'Etudes Nucléaires
Grenoble, France

G. F. Hewitt
Engineering Sciences Division and HTFS
U. K. Atomic Energy Authority
Harwell Laboratory, England

F. Mayinger
Institut für Verfahrenstechnik
Technische Universität
Hannover, West Germany

E8263568

华南工学院
图书馆藏书

HEMISPHERE PUBLISHING CORPORATION
Washington New York London

TWO-PHASE FLOW AND HEAT TRANSFER IN THE POWER AND PROCESS INDUSTRIES

Copyright © 1981 by Hemisphere Publishing Corporation. All rights reserved. Printed in the United States of America. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of the publisher.

1 2 3 4 5 6 7 8 9 0 BRBR 8 9 8 7 6 5 4 3 2 1 0

Library of Congress Cataloging in Publication Data

Library of Congress Cataloging in Publication Data

Main entry under title:

Two-phase flow and heat transfer in the power and process industries.

Includes bibliographies and index.
1. Two-phase flow. 2. Heat—Transmission.
3. Power-plants—Equipment and supplies. 4. Chemical plants—Equipment and supplies. I. Bergles, A. E., date
TA357.T94 621.402′2 80-22025
ISBN 0-89116-197-X

Preface

This book grew out of discussions held during the NATO Advanced Study Institute on Two-Phase Flows and Heat Transfer held in Istanbul, Turkey in 1976. At that time a short course was proposed which would emphasize not only the fundamentals of two-phase flow and heat transfer but also industrial applications. Under co-sponsorship of Hemisphere Publishing Corporation and Brookhaven National Laboratory, "Two-Phase Flow and Heat Transfer in the Power and Process Industries" was presented by AEB, JGC, JMD, and GFH in October 1978 at BNL in Upton, New York. In March 1980, FM joined forces to present a revised version of the course in Hannover, under co-sponsorship of Hemisphere and Universität Hannover.

An extensive series of lecture notes was developed for these courses. After consultation with Hemisphere Publishing Corporation, it was decided to publish the latest version of these notes as a book. While recognizing that this book is part of the continued "exponential" growth of literature on this subject, it is felt that the material will be of interest and value to students, researchers, and practioners. The collection of material appears to be unique in that a rather complete overview is presented, ranging from fundamental methods of analysis to practical plant design and operational safety.

Since all of us are extensively involved in teaching and writing on two-phase flow and heat transfer, it is inevitable that we have drawn on material which has been presented elsewhere. This includes lectures at several NATO Advanced Study Institutes, Von Karman Institute for Fluid Dynamics Lecture Series, International Heat Transfer Conferences, and Multi-Phase Flow and Heat Transfer Symposium-Workshops - all of which have been Published by Hemisphere. Additionally, some of the material by JGC is based on *Forced Convection Boiling and Condensation*, published by McGraw-Hill (UK). The material by GFH is partially derived from *Annual Two-Phase Flow* (Pergamon Press), *Two-Phase Flow and Heat Transfer* (Oxford University Press), and *Measurement of Two-Phase Flow Parameters* (Academic Press).

AEB wishes to acknowledge the support given for this project by the Alexander von Humboldt Foundation and the Institut für Verfahrenstechnik der Universität Hannover during 1979-80.

The material in this book was typed by Mrs. Barbara Granito, and we would like to record our thanks to her for her careful and patient work. Our thanks are also due to Mr. William Begell, President of Hemisphere Publishing Corporation, and his staff for their support in this endeavor. We must also thank the students in our courses whose intelligent comments and questions have led to the better development of this material.

Finally, we would like to thank our wives (Penny, Ellen, France, Shirley, and Franziska) who bear so nobly their lonely lives as "two-phase flow widows".

A E Bergles

J G Collier

J M Delhaye

G F Hewitt

F Mayinger

试读结束：需要全本请在线购买： www.ertongbook.com

8263568

Contents

华南工学院图书馆藏书

试读结束：需要全本请在线购买： www.ertongbook.com

Chapter 1

Two-Phase Flow Patterns

J. M. DELHAYE

1.1 Introduction

A two-phase mixture flowing in a pipe can exhibit several interfacial geometries (bubbles, slugs, film,...). But this geometry is not always clearly defined, which prevents the flow patterns from being precisely and objectively described.

In single-phase flow, laminar and turbulent flows are differently modelled. Laminar flows can be described by instantaneous quantities, the solutions of the Navier-Stokes equations, whereas turbulent flows are described by time- or statistical-averaged quantities which are the solutions of a system involving the Reynolds equations and some closure equations.

Likewise, in two-phase flows, the flow patterns must be known in order to model the physical phenomenon as closely as possible. It is obviously impossible to describe bubbly flows and annular flows with a good accuracy by means of the same model. It is far better to adopt two different models, each one fitting the individual flow description. Nevertheless, this approach is still difficult because of the transition zone between two flow patterns and the lack of physical knowledge to describe these buffer zones.

In addition to the random character of each flow configuration, two-phase flows are never fully-developed. In fact the gas phase expands due to the pressure drop along the pipe. This may lead to a modification of the flow structure such as an evolution from bubbly flow to slug flow. The flow pattern depends also upon the singularities occurring along the pipes such as bends, junctions, air-injection devices, etc...

The parameters which govern the occurrence of a given flow configuration are numerous and it seems hopeless to try to represent all the transitions on a two-dimensional flow chart. Among these various parameters, one can select, (1) the volumetric flow-rates of each phase, (2) the pressure, (3) the heat flux at the wall, (4) the densities and viscosities of each phase, (5) the surface tension, (6) the pipe geometry, (7) the pipe characteristic dimension, (8) the angle of the pipe with respect to the horizontal plane, (9) the flow direction (upward, downward, cocurrent, countercurrent), (10) the inlet length, (11) the phase-injection devices. The last two points are of the utmost importance and one always has to keep in mind that a flow map is proposed for given conditions and that it must be used for the same conditions.

The purpose of this chapter is to describe the different configurations of gas-liquid pipe flows, to examine the transition phenomena between the flow patterns and to propose a set of flow maps allowing the determination of the flow pattern, given the system parameters. This chapter starts with the definitions of the basic quantities describing two-phase pipe flows and with a survey of the experimental techniques which can be used to recognize the flow structure.

1.2 **Describing Parameters of Two-Phase Pipe Flows**

Given the fluctuating character of two-phase flows, averaging operators have to be introduced. These operators which act on space or time domains are studied in detail in Chapter 2 of this book. Only definitions and fundamental properties of these operators are given hereunder.

1.2.1 *Phase Density Function*

The presence or absence of phase k(k=1,2) at a given point **x** and a given time t is characterized by the unit value (or zero value) of a phase density function $X_k(\mathbf{x},t)$ defined as follows:

$$X_k(\mathbf{x},t) \triangleq \begin{cases} 1 \text{ if point } \mathbf{x} \text{ pertains to phase k} \\ 0 \text{ if point } \mathbf{x} \text{ does not pertain to phase k} \end{cases} \qquad (1.1)$$

The phase density function is a binary function analogous to the intermittency function used in single-phase flow.

1.2.2 *Instantaneous Space-Averaging Operators*

Instantaneous field variables may be averaged over a line, an area or a volume, i.e. over a n-dimension domain (n=1,2,3 for a segment, an area or a volume). For instance, in a pipe flow, the field variables can be averaged over a diameter, a chord, a plane cross section or a finite control volume. At a given time, this n-dimension domain $\mathcal{D}_n$ can be divided into two sub-domains $\mathcal{D}_{kn}$ pertaining to each phase (k=1,2),

$$\mathcal{D}_1 = \mathcal{D}_{11} + \mathcal{D}_{21}$$

Consequently two different *instantaneous space-averaging operators* are introduced,

$$\langle\ \rangle_n \triangleq \frac{1}{\mathcal{D}_n}\int_{\mathcal{D}_n} d\mathcal{D}_n \qquad (1.2)$$

and

$$\langle\ \rangle_n \triangleq \frac{1}{\mathcal{D}_{kn}} \int_{\mathcal{D}_{kn}} d\mathcal{D}_n \tag{1.3}$$

The *instantaneous space-fraction* R_{kn} is defined as the average over $\mathcal{D}_n$ of the phase density function $X_k(\mathbf{x},t)$,

$$R_{kn} \triangleq \{X_k\}_n = \frac{\mathcal{D}_{kn}}{\mathcal{D}_n} \tag{1.4}$$

This definition leads directly to the usual instantaneous space-fraction,
(i) over a segment

$$R_{k1} = L_k \Big/ \sum_{k=1,2} L_k \tag{1.5}$$

where L_k is the cumulated length of the segments occupied by phase k
(ii) over a surface,

$$R_{k2} = A_k \Big/ \sum_{k=1,2} A_k \tag{1.6}$$

where A_k is the cumulated area occupied by phase k
(iii) over a volume,

$$R_{k3} = V_k \Big/ \sum_{k=1,2} V_k \tag{1.7}$$

where V_k is the volume occupied by phase k.

The *instantaneous volumetric flowrate* Q_k through a pipe cross section of area A is defined by,

$$Q_k \triangleq \int_{A_k} w_k \, dA = A \, R_{k2} \langle w_k \rangle_2 \tag{1.8}$$

where w_k is the axial component of the velocity of phase k.

The *instantaneous mass flowrate* M_k is given by,

$$M_k \triangleq \int_{A_k} \rho_k w_k dA = A \, R_{k2} \langle \rho_k w_k \rangle_2 \tag{1.9}$$

where ρ_k is the density of phase k.

1.2.3 *Local Time-Averaging Operator*

Local field variables can be averaged over a time interval [t-T/2; t+T/2]. As for single-phase turbulent flow, this time interval of magnitude T must be chosen large enough compared with the time scale of the turbulence fluctuations, and small enough compared with the time scale of the overall flow fluctuations. This is not always possible and a thorough discussion of this delicate question can be found in papers by Delhaye and Achard (1977, 1978).

If we consider a given point **x** in a two-phase flow, phase k passes this point intermittently, and a field variable $f_k(\mathbf{x},t)$ associated with phase k is a piecewise continuous function. Denoting by $T_k(\mathbf{x},t)$ the cumulated residence time of phase k within the interval T, we can define two different *local time-averaging operators*,

$$\overline{\quad} \triangleq \frac{1}{T}\int_{[T]} dT \qquad (1.10)$$

and

$$\overline{\quad}^{X} \triangleq \frac{1}{T_k}\int_{[T_k]} dT \qquad (1.11)$$

The *local time-fraction* α_k is defined as the average over T of the phase density function X_k,

$$\alpha_k(\mathbf{x},t) = \overline{X_k(\mathbf{x},t)} = \frac{T_k(\mathbf{x},t)}{T} \qquad (1.12)$$

1.2.4 *Commutativity of Averaging Operators*

Considering all the definitions given previously, one can easily derive the following identity,

$$\overline{R_{kn}\ \langle f_k\rangle_n} \equiv \{\alpha_k \overline{f_k}^{X}\}_n \qquad (1.13)$$

A particular case for equation (1.13) is obtained by taking $f_k \equiv 1$, which leads to

$$\overline{R_{kn}} \equiv \{\alpha_k\}_n \qquad (1.14)$$

Note that identities (1.13) and (1.14) are valid for segments (n=1), areas (n=2) or volumes (n=3).

As a consequence, the time-averaged volumetric and mass flow-rates can be expressed in the following ways,

$$\overline{Q_k} = A\,\overline{R_{k2}\langle w_k\rangle_2} \equiv A\,\langle \alpha_k \overline{w_k}^{x} \rangle_2 \qquad (1.14$$

$$\overline{M_k} = A\,\overline{R_{ke}\,\langle \rho_k w_k\rangle_2} \equiv A\,\langle \alpha_k \overline{\rho_k w_k}^{x} \rangle_2 \qquad (1.16)$$

1.2.5 *Qualities*

The *mass-velocity* $\overline{G}$ is defined by,

$$\overline{G} \overset{\Delta}{=} \frac{\overline{M}}{A} \qquad (1.17)$$

where $\overline{M}$ is the time-averaged total mass flowrate.

The *(true) quality* x is defined as the ratio of the gas mass-flowrate to the total mass-flowrate,

$$x \overset{\Delta}{=} \frac{\overline{M_G}}{\overline{M_G} + \overline{M_L}} = \frac{\overline{M_G}}{\overline{M}} \qquad (1.18)$$

It is currently impossible to measure or to calculate with a high precision the quality of a liquid-vapor mixture flowing in a heated channel and withstanding a phase change. Nevertheless, a fictitious quality, the so-called *equilibrium* or *thermodynamic quality*, can be calculated by assuming that both phases are flowing under saturation conditions, i.e. that their temperatures are equal to the saturation temperature corresponding to their common pressure.

1.2.6 *Volumetric Quantities*

The *volumetric quality* β is defined as the ratio of the gas volumetric flowrate to the total volumetric flowrate,

$$\beta \overset{\Delta}{=} \frac{\overline{Q_G}}{\overline{Q_G} + \overline{Q_L}} \qquad (1.19)$$

The *local volumetric flux* j_k is a local time-averaged quantity defined by,

$$j_k \overset{\Delta}{=} \overline{X_k w_k} = \alpha_k\,\overline{w_k}^{x} \qquad (1.20)$$

Its area-average J_k over the total cross section area A is a space/time-averaged quantity called the *superficial velocity*. This quantity is defined by,

$$j_k \overset{\Delta}{=} \langle \overline{X_k w_k} \rangle_2 = \langle j_k \rangle_2 \qquad (1.21)$$

试读结束：需要全本请在线购买： www.ertongbook.com