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978-0-521-48192-2 - Cryogenic Two-Phase Flow: Applications to Large-Scale Systems
N. N. Filina and J. G. Weisend II
Frontmatter
More information

Cryogenic systems that involve two-phase (vapor–liquid) flows are widely used in industries such as aerospace, metallurgy, power engineering, and food production, as well as in high-energy physics research.

The purpose of this book is to describe characteristic features of cryogenic systems involving two-phase flow, create mathematical models of these systems, and then show how the models may be used to develop optimal designs for practical cryogenic systems. The models are examined using analytical and numerical techniques, and then the predictions are compared to experimental measurements. Since transient phenomena can produce severe and unexpected effects in cryogenic systems, the authors pay particular attention to this important topic.

Examples in the book are drawn from cryogenic fluid transport, gasification, and the stabilization of superconducting magnets. Much of this work is related to the development of large Russian systems in the areas of space technology, energy research, and particle physics.

This book, the first devoted solely to cryogenic two-phase flow, will be a valuable reference for cryogenic engineers and scientists.

CRYOGENIC TWO-PHASE FLOW

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Applications to large-scale systems

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Contents

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Preface

The subject of this book is cryogenic two-phase flow. Because of their very low boiling points, cryogenic fluids frequently exist in the two-phase state. In some cases this is intentional, such as when using the constant temperature of a two-phase flow to stabilize superconducting magnets. In other cases, the two-phase mixture is an undesirable consequence of heat leak or of a sudden change in the cryogenic system. An example of this is the creation of two-phase flow in a long cryogenic transfer line due to intrinsic heat leak.

Planned or not, the presence of two-phase flows in practical cryogenic systems is often a fact of life. The proper design of such systems requires an understanding of such flows and the ability to predict the effect of the two-phase flow on the system. This book describes techniques for modeling two-phase flows so that useful predictions can be made. The models are derived from the basic conservation laws. However, some empirical data is frequently required to complete the model. Once finished, the model is examined using analytical and numerical techniques. The predictions are then compared to experimental measurements.

The examples in this text are drawn from three important areas of cryogenic technology: gasification, fluid transport, and cryostabilization. These topics are all practical large-scale applications of cryogenic engineering. The methods described in this book can be applied to other cryogenic systems provided the underlying assumptions still hold true. Since transient phenomena can produce severe and unexpected effects, a significant portion of the text is spent discussing transient two-phase flow in cryogenic systems.

Chapter 1 gives a very brief introduction to cryogenic two-phase flow as well as discussing the problems associated with gasification, transport, and cryostabilization systems. Chapter 2 develops the conservation laws for cryogenic two-phase flows and uses them to model steady-state two-phase flow in a variety of large-scale systems. Chapter 3 introduces transient two-phase

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flow, stressing the relationship between the transient disturbance and the response time of the system. Chapter 4 models transient two-phase flow in gasification systems, and Chapter 5 looks at the transient behavior in magnet-stabilization systems.

The original manuscript of this book was written in Russian by N. N. Filina, based in large part on research she conducted. This was then translated into English by Valentina V. Savchenko of NPO Cryogenmash. J. G. Weisend II then completely revised the English text, checked the equations, and added additional material and references.

The authors wish to thank Professor William Schiesser of Lehigh University for his support and encouragement of this work. Dr. Philippe Lebrun of CERN and Professor Randall Barron of Louisiana Tech University both read a draft of the book and provided many useful comments. V. I. Datskov, Y. P. Filippov (both of JINR-Dubna), M. Levin (formerly of the SSC Laboratory), and S. Zinchenko (IHEP-Protvino) all helped to maintain contact between the authors. Florence Padgett, Physical Science Editor of Cambridge University Press, and her assistant Adam Tempkin are to be thanked for their assistance and enthusiasm.

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Nomenclature, SI units

English symbols

A = Area, m^2
C = Speed of sound, m/s
D = Channel diameter, m
d = Characteristic dimension, m
Fw = Specific frictional force between wall and two-phase flow, N/m^3
$F_{1,2}$ = Specific frictional force between phases, N/m^3
g = Gravitational acceleration, m/s^2
G = Mass flowrate, kg/s
I_i = Enthalpy of the ith phase, J/kg
$J_{1,2}$ = Liquid evaporation intensity (rate), kg/m (m^3/s)
k = Thermal conductivity, W/m^2 K
L = Channel length, m
P = Pressure, Pa
Q_w = Volumetric wall heat flux, W/m^3
$Q_{1,2}$ = Volumetric heat flux between phases, W/m^3
R = Gas constant, J/kg K
S = Slip
T = Temperature, K
t = Time, s
u_i = Internal energy of the ith phase, J
V = Volume, m^3
v_i = Velocity of the ith phase, m/s
$v_{1,2}$ = Longitudinal velocity component of fluid undergoing phase transition at the liquid–vapor interface, m/s
x = Mass vapor concentration (quality)
z = Spatial coordinate, m

Greek symbols

α_i = Volumetric concentration (void fraction) of the ith phase
ρ_i^0 = Density of the *i*th phase, kg/m^3
ρ_m = Mixture density, kg/m^3
ζ = Heat of vaporization, J/kg
μ_i = Viscosity of the *i*th phase, Pa s
τ = Time, s
τ^* = Time of disturbance propagation, s

Dimensionless parameters

Re_i = Reynolds number for the *i*th phase
Fr = Froude number
Nu = Nusselt number
Pr = Prandtl number
M = Martinelli number
Sh = Strouhal number
Eu = Euler number

Index

g = Gas
l = Liquid
o = Initial conditions
s = Equilibrium state parameters
v = Vapor
w = Wall
1 = Vapor
2 = Liquid
$2ph$ = Two-phase

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