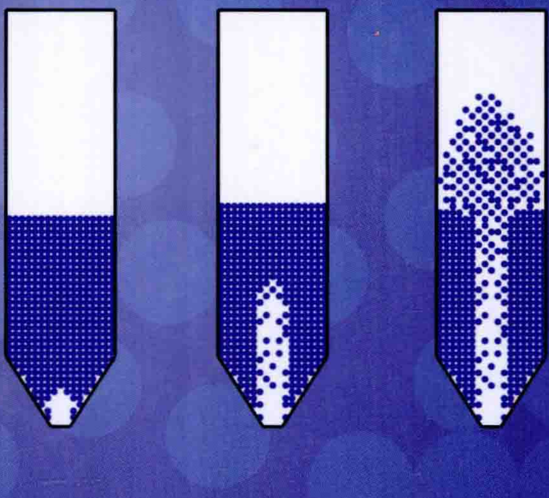
Spouted and Spout-Fluid Beds

Fundamentals and Applications



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Fundamentals and Applications

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Spouted and Spout-Fluid Beds

Fundamentals and Applications

Since the pioneering text by Mathur and Epstein over 35 years ago, much of the work on this subject has been extended or superseded, producing an enormous body of scattered literature. This edited volume unifies the subject, pulling material together and underpinning it with fundamental theory to produce the only complete, up-to-date reference on all major areas of spouted bed research and practice. With contributions from internationally renowned research groups, this book guides the reader through new developments, insights, and models. The hydrodynamic and reactor models of spouted and spout-fluid beds are examined, as well as such topics as particle segregation, heat and mass transfer, mixing, and scale-up. Later chapters focus on drying, particle-coating, and energy-related applications based on spouted and spout-fluid beds. This is a valuable resource for chemical and mechanical engineers in research and industry.

Norman Epstein is Honorary Professor in the Department of Chemical and Biological Engineering at the University of British Columbia. His research areas during the past 60 years have focused on heat, mass, and momentum transfer; on the fluid-particle dynamics of spouted beds and liquid-fluidized beds; and on various aspects of heat exchanger fouling. He is a former Editor of the *Canadian Journal of Chemical Engineering* and has published widely.

John R. Grace is Professor and Canada Research Chair in the Department of Chemical and Biological Engineering at the University of British Columbia. He has more than 40 years' experience working on fluidized and spouted beds, fluid-particle systems, and multiphase flow. His work includes reactor design, hydrodynamics, heat and mass transfer, and applications. Professor Grace has published widely, and has lectured and consulted for industry in these fields.

Both Epstein and Grace are Fellows of the Canadian Academy of Engineering and of the Chemical Institute of Canada, and former Presidents of the Canadian Society for Chemical Engineering.

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Preface

Spouted beds have now been studied and applied for more than 50 years; during this period there has been a continual output of research papers in the engineering literature, considerable efforts to apply spouted beds in agriculture-related and industrial operations, and five international symposia dedicated solely to spouted beds. The book *Spouted Beds* by Kishan Mathur and the first-named editor of this volume summarized the field up to 1974. Since then there have been several reviews,[1–4] but none that have surveyed the entire field comprehensively, including aspects that were barely touched in the earlier book or that were entirely absent. Examples of new areas include mechanically assisted spouting, slot-rectangular spouted beds, spouted and spout-fluid bed gasifiers, spouted bed electrolysis, and application of computational fluid dynamics (CFD) to spouted beds.

Our original intention was to prepare a sequel to the Mathur and Epstein book, but we soon realized that this chore would be too daunting, especially in view of competing time commitments. We therefore adopted the idea of a multiauthored book for which we would provide editing and prepare a subset of the chapters ourselves. Our intent was to choose an international array of authors able to provide a truly comprehensive view of the field, fundamentals as well as applications. Almost all those whom we asked to participate agreed to do so, and they have been remarkably cooperative in submitting material, following instructions, and responding to requests for changes, many of these being editorial in nature.

In addition to acknowledging the authors and the cooperation of Cambridge University Press, we especially acknowledge the secretarial assistance of Helsa Leong, without whom we probably would never have finished. We are also indebted to the Natural Sciences and Engineering Research Council of Canada for continuing financial support.
The book is dedicated to Kishan B. Mathur, co-inventor and a pioneer in spouted beds and an inspiration to us both.

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Common nomenclature

A	cross-sectional area of column, m^2
A_a	cross-sectional area of annulus, m^2
A_i	fluid inlet cross-sectional area, m^2
A_s	cross-sectional area of spout, m^2
Ar	Archimedes number
Bi	Biot number
C_A	concentration of component A in fluid, mol/m^3
C_D	drag coefficient
c_p	heat capacity at constant pressure, $J/(kg \cdot K)$
D	diameter of cylindrical column, m
$\mathcal{D}$	diffusivity or dispersion coefficient, m^2s^{-1}
D_H	diameter of upper surface of bed, m
D_i	diameter of fluid inlet, m
D_o	diameter of cone base, m
D_s	spout diameter, m
d_p	particle diameter or mean diameter, m
d_s	sphere-equivalent diameter of particle based on its surface area, m
d_v	sphere-equivalent diameter of particle based on its volume, m
$F(t)$	output tracer concentration/step input tracer concentration
f	Fanning friction factor
G	superficial mass flux of fluid, kg/m^2s
g	acceleration of gravity, m/s^2
H	bed depth, usually measured as loose-packed static bed depth after spouting, m
H_c	cone height, m
H_f	fountain height, measured from bed surface, m
H_m	maximum spoutable bed depth, m
H_o	static bed depth, m
h	heat transfer coefficient, W/m^2K
i, j	integers
k	chemical reaction rate constant, s^{-1} if first order
L	length, m
M	inventory of particles, kg
m_p	particle mass, kg
Nu	Nusselt number

P	pressure, Pa
Pr	Prandtl number
Q	volumetric flow rate, m^3/s
q	heat transfer rate, W
R	radius of cylindrical column, m
R_g	universal gas constant, 8.315 $J/mol \cdot K$
Re	Reynolds number
r	radial coordinate, m
S	surface area, m^2
Sc	Schmidt number
Sh	Sherwood number
T	temperature, K
t	time, s
U	superficial velocity of spouting fluid based on D, m/s
U_a	upward superficial velocity in annulus, m/s
U_{aH}	value of U_a at $z = H$, m/s
U_M	superficial velocity corresponding to ΔP_M, m/s
U_m	value of U_{ms} at $H = H_m$, m/s
U_{mf}	superficial velocity at minimum fluidization, m/s
U_{ms}	superficial velocity at minimum spouting, m/s
U_t	free settling terminal velocity, m/s
u	local fluid velocity, m/s
u_i	average fluid velocity at fluid inlet, m/s
u_{msi}	minimum spouting velocity based on D_i, m/s
V_p	particle volume, m^3
v	local particle velocity, m/s
x, y	horizontal Cartesian coordinates, m
z	vertical coordinate measured from fluid inlet, m

Greek letters

α	thermal diffusivity, m^2/s
β	mass transfer coefficient, m/s
ΔP	pressure drop, Pa
ΔP_M	maximum pressure drop across bed, Pa
ΔP_S	spouting pressure drop across bed, Pa
ε	fractional void volume
θ	total included angle of cone
λ	thermal conductivity of fluid, $W/(m \cdot K)$
λ_p	thermal conductivity of particles, $W/(m \cdot K)$
μ	absolute viscosity, $Pa \cdot s$
θ	total included angle of cone
ρ	density of fluid, kg/m^3

ρ_p	density of particles, kg/m^3
τ	mean residence time, s

Subscripts

A, B	component A, B
a	annulus, auxiliary
f	fountain
ms	minimum spouting
p	particle
s	spout

Abbreviations

CSB	conventional spouted bed
CCSB	conical-cylindrical spouted bed = CSB
CcSB	conical (Coni-cal) spouted bed

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