History: **International Fluidization Conference Series** by L.-S. Fan and **Dale Keairns** In collaboration with John Grace, Wen-Ching Yang, Xiaotao Bi

Hans Kuipers, Masa Horio, and Ted Knowlton

Fluidization XVI – Guilin, 2019

Background

International Fluidization Conference Series was initiated in 1975, under the auspices of the U.S. Engineering Foundation, with Dale Keairns as the Conference Convener. It was later transitioned to Engineering Conference International (ECI) and AIChE as the hosting organizations. The concurrent conferences on or prior to 1975 on this same subject took place at:

- International Symposium on Fluidization, Eindhoven, 1967
- Symposium on Fluidization (IChemE, Tripartite Chemical Engineering Conference), Montreal, 1968
- Fluidization and Its Applications (Ste Chimie Industrielle), Toulouse, 1973
- Fluidized Combustion (Institute of Fuel) London 1975
- International Conferences on Fluidized Bed Combustion, USA, 1968, 1970, 1972, 1975 (primary sponsors including DOE, EPA, Energy Research & Development Administration)



1st conference site: Pacific Grove/Asilomar , California

Background (cont.)

Two Major Conference Series Branched Out:

- International Conference on Circulating Fluidized Beds 1st Conference organized by Prabir Basu in Halifax, Canada, in 1985, 13th Conference to be held in Vancouver, Canada in 2020,
- International Conference on Gas-Liquid and Gas-Liquid-Solid Recator Engineering – 1st Conference organized by L.-S. Fan in Columbus Ohio in 1992, 14th Conference to be held in Guilin, China in 2019

Fluidization Conference Series

Conference	Year	Location	Chair/co-chairs
I	1975	Asilomar/Pacific Grove, CA, USA	D. L. Keairns
II	1978	Cambridge, England	J. F. Davidson, D. L. Keairns
Ш	1980	Henniker, NH, USA	John R. Grace, John M. Matsen
IV	1983	Kashikojima, Japan	Daizo Kunii, Ryozo Toei
V	1986	Elsinor, Denmark	Knud Østergaard, Ansgar Sørensen
VI	1989	Banff, Alberta, Canada	John R. Grace, Leslie W. Shemilt, Maurice A. Bergougnou
VII	1992	Gold Coast/Brisbane, Australia	O.E. Potter, D.J. Nicklin
VIII	1995	Tours, France	Jean-François Large, Claude Laguérie
IX	1998	Durango, Colorado	Liang-Shih Fan, Ted M. Knowlton
Х	2001	Beijing, China	Moonson Kwauk, Jinghai Li, Wen-Ching Yang
XI	2004	Ischia, Naples, Italy	Umberto Arena, Riccardo Chirone, Michele Miccio, Piero Salatino
XII	2007	Harrison Hot Springs/Vancouver, British Columbia, Canada	Xiaotao Bi, Franco Berruti, Todd Pugsley
XIII	2010	Gyeong-ju, Korea	Sang Done Kim, Yong Kang, Jea Keun Lee, Yong Chil Seo
XIV	2013	Noordwijkerhout, Netherlands	J.A.M. Kuipers, R.F. Mudde, J.R. van Ommen, N.G. Deen
XV	2016	Montebello, Quebec, Canada	Jamal Chaouki, Franco Berruti, Xiaotao (Tony) Bi, Ray Cocco
XVI	2019	Guilin, China	Chi-Hwa Wang, Wei Ge

Presentation Format

- One all-attended session with one rapporteur reporting, discussing and criticizing each paper in the session
- One all-attended session with 5-7 minute oral presentation by lead authors of each paper followed by posters and general question session
- Parallel sessions in usual large conference style

Fluidization Conference Proceedings I & II

Conference	Year	Location	Chair/co-chairs
I	1975	Pacific Grove, CA, USA	D. L. Keairns
	1978	Cambridge, England	J. F. Davidson, D. L. Keairns
FI	uidization		Fluidization II

Fluidization I



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Technology

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Fluidization

Proceedings of the Second **Engineering Foundation** Conference, 1978

Edited by J.F. Davidson and D.L.Keairns

PREFACE

Fluidization is a subject that has proved uniquely attractive during the last 30 years. uniquely attractive during the last 30 years. On the one hand academics have been enthral-led by the wealth of basic problems suggested by the upward flow of fluid through a bed of particles. On the other hand practical engineers have devised an ever greater warlety of applications for fluidized systems. Variety or applications for riudized systems. The primary objective of the meeting based on the papers in this volume was to bring together these two groups of workers. The wealth of knowledge generated by basic studies is not fully applied in industry and for this reason there are many industrial processes that have had only the most cursory processes that have had only the most cursory scientific investigation. The confluence of differing persons at the conference was planmed to promote the application of basic science to industrial processes and, conver-sely, to suggest new basic problems which deserve study.

With these considerations in mind, the With these considerations in mind, the Second Engineering Foundation Conference on Fluidization was held in April 1978: it followed from the first of its kind held at Asilomar, California in 1975. Other notable conferences held on the same subject during the last ten years have been stimulus from the need to burn and gasify coal International Symposium on Fluidization,

Eindhoven 1967 Eindhoven 1967 Symposium on Fluidization (IChemE, Tripartite Chemical Engineering Conference), Montreal 1968 Fluidization and its applications (Stő Chimie Industrielle), Toulouse 1973 Fluidised Combustion (Institute of Fuel) London 1951

London 1975 International Conferences on Fluidized Bed Termational conferences on fluidized Bed Combustion USA, 1968, 1970, 1972, 1975, 1977 (primary sponsors include Department of Energy, Energy Research & Development Administration, Environmental Protection

Agency).

It was decided not to report the discus-It was decided not to report the discus-sion, to allow a frank and uninhibited exchange of views at the meeting. It was hoped that the absence of written discussion would allow industrialists to be a little freer. A further reason for omitting printed discussion was to allow speedy publiprinted discussion was to allow speedy publi-cation. Although we feel sure that the papers herein will be of lasting value, the benefit of having the volume available immediately after the meeting seemed to us to outweigh the doubtful advantage of including printed discussion with the delay caused by that inclusion.

Likewise we decided against the use of rapporteurs. Authors, being human, like to

Fluidization, Cambridge University Press, 1978

present their own work and the same is true of rapporteurs who inevitably give a persona slant to what they report. The coverage of subjects reflects current interests. Among the basic topics, bubbles, distributors, particle circulation, elutridistributors, particle circulation, elutri-ation and mixing are still deservedly popular. Centrifugal fluidized beds are a new topic on which several papers present basic informat-ion but a practical application has yet to

Ion but a practical application has yet to everyar. There are fever papers than algor buy not fully understood in spite of the variety of theories that have been pullished; it may be that the difficulty of finding matifafc-uoyhers. Consultion of coal is rightly a topic of great current interest: the com-bution and gasification of coal provides to the coal provides to the combustion and gasification or coal promises to be one of the most important applications of fluidization. The related topics of sulphur absorption, emission of nitrogen oxides, and heat transfer have also attracted interest. The experimentally difficult question of high pressure operation may have received a starbust for the most how much easify

We believe that the coal interest alone will stimulate even greater activity in fluidization in the not-too-distant future and we commend this book as a likely indica-tor of future trends. Another trend in the

tor of future trends. Another trend in the West is to have more women scientists and engineers. One of the few women to have contributed to our subject remarked 'I fell in love with fluidisation as a student and I've been working on it ever since'. Those of us who found the subject attractive as a masculine preserve will welcome this new acquisition of charm and brainpower. Acknowledgements are the most important

Acknowledgements are the most important part of the preface to a multi-author work. We are very grateful to the authors for their ready acceptance of our complex res-traints as to length, format, and time of production. Referees deserve a special mention: their work is usually anonymous but crucial in maintaining standards. We but crucial in maintaining standards. We give below a complete list of those who agreed to act; a few were not called upon, but most of those listed refereed one, two or three papers in a short time and we are grateful.

We are also grateful to the Syndics of the Cambridge University Press for agreeing to publish this unusual book.

Workers in the Cambridge University Chemical Engineering Department who helped

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Fluidization Conference I & II Topics

	Conference	Year	Location	n	Ch	air/co	o-chairs
	I	1975	Pacific Grove, C	CA, USA	I	D. L. Ke	eairns
		1978	Cambridge, Er	ngland	J. F. Dav	idson,	D. L. Keairns
	FI	uidization	I		Fluid	dizati	on II
Ses	sion Topics:			Sess	ion Topics:		
•	Bubble Pheno	mena		• 8	Bubbles	•	Reactors and Mass Transfer
• (Gas Exchange	and Fluid	Bed Modeling	• 0	Distributors	•	Three-Phase Fluidization
•	Liquid Phase I	luidizatio	n	• +	ligh Pressure	•	Gasification
• •	Fhree-Phase F	luidizatio	n	• 8	Basic Measurements	•	Combustion
•	Fluidized Bed	Performa	nce with	• S	pouted Beds	•	Desulfurization and NOx Remova
I	nternals			• P	Particle Circulation and Flow	v •	Heat Transfer
•	Solids Mixing	and Trans	port	• E	Intrainment, Segregation a	nd M	ixing
•	Fossil Fuel Pro	ocessing					

Applications •

Fluidization Conference Proceedings III & IV

Conference	Year	Location	Chair/co-chairs
III	1980	Henniker, NH, USA	John R. Grace, John M. Matsen
IV	1983	Kashikojima, Japan	Daizo Kunii, Ryozo Toei

Fluidization III



PREFACE

Fluidized beds have gained prominence in many process industries (including chemicals, petroleum, metallurgy, food and pharmaceuticals) as a means of bringing particulate solids into contact with gases and/or liquids. Many fluidized bed operations are physical in nature (e.g. drying, coating, classification, granulation, and rapid heat transfer as in quenching or annealing). Other operations involve chemical reactions including the catalytic cracking of bydrocarbons, the manufacture of acrylonitrite and phthalic anhydride, the roasting of metallurgical ores, and the regeneration of spent catalysts. In recent years fluidized beds have been of special interest because of their potential as the central component in new processes for utilizing coal as a source of energy, notably in coal combustion and gasification

The fluidized bed offers a number of advantages over most other methods of contacting, in particular high rates of heat transfer, temperature uniformity and solids mobility. Among the disadvantages are particle losses by entrainment, attrition of solids, limited reactor efficiency due to gas bypassing and gas and solids backmixing, and difficulties in design and scale-up due to the complexity of fluidized beds.

The International Fluidization Conference held in Henniker, New Hampshire, U.S.A. from 3-8 August 1980 was the fifth international congress devoted to the entire field of fluidization. Preceding meetings have been held in Eindhoven, Holland (1967), Toulouse, France (1973), Asilomar, California (1975) and Cambridge. England (1978). In addition, conferences on fluid bed combustion have been sponsored by the U.S. Department of Energy in 1968, 1970, 1972, 1975 and 1980. Like its two immediate predecessors in Asilomar and Cambridge, this conference was sponsored by the Engineering Foundation.

Fluidization IV



Fluidization Conference III & IV Topics

Conference	Year	Location	Chair/co-chairs
III	1980	Henniker, NH, USA	John R. Grace, John M. Matsen
IV	1983	Kashikojima, Japan	Daizo Kunii, Ryozo Toei

Fluidization III

C. E. Jahnig, D. L. Campbell, H. Z. Martin, **History of fluidized solids development at Exxon**

L. S. Leung. The ups and downs of gas-solid flow: a review

J. J. van Deemter. Mixing patterns in large-scale fluidized beds

Fluidization IV

R. Collins, Gas flow patterns associated with a growing spherical bubble

J.G. Yates, D.J. Cheesman, T.A. Mashingaidze, C. Howe, and G. Jefferis, **The effect of vertical rods on bubbles in gas fluidized beds**

K. Viswanathan, and D.S. Rao, **Gross solid circulation in fluidized beds**

Y. Matsuno, H. Kage, H. Yamaguchi, Y. Ideue, and T. Hirose, A consideration on the determination of the elutriation rate constant by a batch gas-solid fluidized bed experiment

Fluidization Conference Proceedings V & VI

Conference	Year	Location	Chair/co-chairs
V	1986	Elsinor, Denmark	Knud Østergaard, Ansgar Sørensen
VI	1989	Banff, Alberta, Canada	John R. Grace, Leslie W. Shemilt, Maurice A. Bergougnou

Fluidization V



PREFACE

This volume contains the papers to be presented in formal sessions at the Fifth Engineering

Foundation Conference on Fluidization in Elsinore, Denmark, on May 18-23, 1986. Fluidization is an important industrial technology for the handling of solids in the form of powders and particles. It is, furthermore, a complex process of intrinsic academic interest. It has, for these reasons, been the subject of much academic and industrial research and development, and many conferences have been held in the past to present and discuss advances in this field. Outstanding in the history of fluidization research are six previous international conferences: 1967 in Eindhoven (Holland), 1973 in Toulouse (France), 1975 in Asilomar (California), 1978 in Cambridge (England), 1980 in Henniker (New Hampshire), and 1983 in Kashikojima (Japan). The last four were organized and sponsored by the Engineering Foundation, New York.

The International Conference in Elsinore will thus be the fifth in the series of Engineering Foundation Conferences on fluidization. Its purpose will be to discuss the latest advances and applications in fluidization. A particular objective will be to bring together industrial and academic workers in order to promote the application of fundamental work to industrial problems and to stimulate fundamental work in fields of practical importance. This purpose is wellreflected in the 84 papers contained in this volume.

During preparations for the conference we have received valuable assistance from members of the Executive Committee, and in particular from Harold A. Comerer, Director of the Engineering Foundation. This is acknowledged with gratitude.

We are also grateful to the many referees who agreed to evaluate papers submitted for the Conference. Their assistance in the selection and editing of papers has been invaluable and has very markedly contributed to the high quality of the papers accepted for presentation. The referees are listed on pages 679-683 of this volume.

Our special thanks are due to Mrs. H. Wolff who most efficiently carried out all the secretarial work connected with the conference and who thus, for example, took care of the quite voluminous correspondence with authors and referees.

Finally, we wish to acknowledge the generous financial support received from the Engineering Foundation and from the many Danish sources listed on page iii. This support has decisively influenced the quality of the Conference.

> Knud Østergaard Ansgar Sørensen Lyngby, Denmark February 1986



EDITORS JOHN R. GRACE LESLIE W. SHEMILT MAURICE A. BERGOUGNOU

Fluidization VI

Although fluidized beds have been used widely in industry since the 1940's, there continue to be many unsolved questions associated with their behaviour and applicaion. Most of these questions are addressed to one degree or another in this volume. The papers published here have survived an extensive reviewing and revision process, and are drawn from 200 abstracts submitted in response to a call for papers for the International Fluidization Conference held in Banff, Canada from May 7-12, 1989. This is the sixth in a series of such conferences held under the auspices of the Engineering Foundation. Previous conferences in the series have been held in Pacific Grove, U.S. (1975), Cambridge, England (1978), Henniker, U.S. (1980), Kashikojima, Japan (1983) and Elsinore, Denmark (1986). Earlier International Fluidization Conferences were also held in Eindhoven, Netherlands (1967) and Toulouse, France (1973). Each of these conferences has led to a volume like this one. Collectively, these olumes constitute one of the primary sources of information on fluidization and fluid-particle systems.

PREFACE

In selecting papers for the present volume, we have attempted to include papers which emphasize new applications or current major concerns in the field of fluidization. This is reflected in papers which treat advanced materials processing, biochemical fluidized bed reactors, erosion of in-bed tubes, circulating fluidized beds, and attrition and agglomeration of particles. At the same time, we have endeavored to include papers presenting new information in a wide variety of topics which have been covered at previous conferences. We are indebted to Dr. Amos Avidan of Mobil Oil Research who has helped to assemble a number of papers on catalytic cracking, an area which has been under-represented at previous conferences despite its historical and practical importance in the field of fluidization. We have also striven to include papers from most of the major fluidization research groups and from a wide geographical distribution of countries. The fluidization community is truly an international one, and the Engineering Foundation conferences have emerged as the foremost medium for assembling experts from industry, universities and government laboratories to consider the complete range of applications and fundamental problems related to fluidized beds.

The papers in this volume correspond to the material presented in the formal sessions of the conference. Each paper has been limited to eight pages, except that permission was given in a small number of cases to use ten pages where the quality of the paper would have suffered unduly by being limited further. Two invited papers given at the conference and one review paper are being published separately in journals. In order to ensure that the volume is available at the conference itself, we have had to adopt a strict schedule, and this has helped us to assure that the volume, when published, is as current as possible. Unfortunately, postal problems in France caused several papers to arrive so late that they had to be put at the end, out of their preferred sequence.

Fluidization Conference V & VI Topics

Conference	Year	Location	Chair/co-chairs
V	1986	Elsinor, Denmark	Knud Østergaard, Ansgar Sørensen
VI	1989	Banff, Alberta, Canada	John R. Grace, Leslie W. Shemilt, Maurice A. Bergougnou

Fluidization V

D. Gidaspow, M. Syamlal, Y. Seo, Hydrodynamics of Fluidization of a single and binary size particles: Supercomputer modeling

P. U. Foscolo, L. G. Gibilaro, S. P. Waldram, R. Di Felice, **The** application of a particulate model to fluidization dynamics

M. H. Peters, Statistics mechanics of fluidized particles.

A. Padhye, T. J. O'Brien, A numerical study of the effect of operating conditions on the minimum fluidization velocity

R. A. Newby, D. L. Keairns, **Test of the scaling relationships for fluid-bed dynamics**

Fluidization VI

Y. Tung, Z. Yang, Y. Xia, W. Zheng, Y. Yi and M. Kwauk, Assessing fluidizing characteristics of powders

I.H. Farag, H.M. Ettouney and C.B.C. Raj, **Threephase fluidized bioreactors: experimental and simulation analysis**

K. V. Thambimuthu and R. Clift, Ash filtration and agglomeration in fluidized beds

D.F. King, Estimation of dense bed voidage in fast and slow fluidized beds of FCC catalyst

Fluidization Conference Proceedings VII & VIII

Conference	Year	Location	Chair/co-chairs
VII	1992	Brisbane, Australia	O.E. Potter, D.J. Nicklin
VIII	1995	Tours, France	Jean-François Large, Claude Laguérie

Fluidization VII



PREFACE

Fluidteed beds continue to demand closer understanding and improved practice. The emphasis may shift from decade to decade but wherever large-scale processing is under consideration then also fluidized beds are being proposed as a means of meeting modern regularements - not as the only means but as a most important one with many successes to its credit, albeit some tailures. Examples are: gasilication particularly for combined cycle power generation, steam dying rhigh molisture brown coals, circulating fluid bed combustors, inon-ore reduction, new catalytic processes - the list could be made very extensive. From around 250 abstracts submitted about 100 papers appear in these Proceedings, covering a wide range of current problems, developments and opportunities.

This is the seventh in a series of international Fluidization Conferences held under the auspices of the Engineering Foundation. Previous conferences have been held in Pacific Grove, USA (1975), Cambridge, England (1978), Henniker, USA (1980), Kashikojima, Japan (1983), Elsinore, Denmark (1986), and Banti, Canada (1969).

Reducing the number of potential papers to a manageable number has been quite a task which has required much cooperation from authors and reviewers, and to both groups graftude is extended for their forbearance. A perfect balance of papers has not been achieved, but there is broad coverage of work in progress of mibilities where were were processes. Because of the importance of fluidized beds in the energy field, close ateration has been paid to heat transfer and drying. New methods of contacting are expired together with an increasing emphasis on fast beds in circulating fluidized beds. Liquid and three-phase fluidization get coverage while much attention is pad to unsolved problems in conventional fluidized beds. In order to ensure that the volume is available at the Conference, we have had to adopt a strict schedule but problems have asten – from the worsening of communications with some countries, to the disappearance in the post of some reviews of papers.

We wish to acknowledge the support of Charles Freiman, Barbara Hickernell, Donna McArdle and Joanne Storza of the Engineering Foundation in organizing the Conference and publishing the Proceedings. Members of the international working party, Dale Keatims, John Matsen, John Grace, Maurice Bergougnou and also L.S. Fan have assisted in various ways, not least as a sounding board. We are also grateful to fellow members of the Australian organizing committee: P.K. Agarwal, M. Burridge, T. Fane, C. Fryer, C.J. Hamilton, I. Jeffcoat, R.D. La Nauze, V.Rudojah and J. Stubington.

We also called on many referees: R. Abed (USA), P.K. Agarwal (Australia), H. Arastoopour (USA), A.A. Avidan (USA), S.P. Basu (Canada), W. Bauer (Germany), J.M. Beeckmans (Canada), L.A. Behie (Canada), M.A. Bergoygnou (Canada), F. Berrul (Canada), J.S.M. Botterill (UK), C. Brereton (Canada), C. Briens (Canada), D.B. Bukur (USA), M. Burridge (Australia), H.S. Caram (USA), J. Chaouki (Canada), C. Chavarie (Canada), J.C. Chere (USA), S. Chiba (Japan), R. Citti (UK), J.F. Davidson (UK), C.E. Davies (NZ), H.I. deLasa (Canada), R.J. Dry (Australia), M. Dudokovic (USA), S.E. H. Einashaie (Saudi Arabia), N. Epstein

nel FLUIDIZATION VIII Jean-François Large and Claude Laguérie

Fluidization VIII



Approximately 200 participants from many countries (including about 60% from universities and 40% from industry) were in Tours from May 14 to 19, 1995. In these four days they discussed advanced experimental research or theories and their applications to reactors, combustion and solid processing. The city of Tours and its Convention Center offered appropriate facilities and a pleasant environment which greatly enhanced relations among the participants.

technical exchanges in fluidized bed technologies.

All the subjects discussed in the conference were published in paperback form and distributed prior to the meeting. This provided a good background knowledge which improved discussions during the sessions. However, an important aim was to make Fluidization VIII internationally recognized and to provide easy access to the conference results.

In order to do this, the International Advisory Board decided to publish a state of the art book containing selected material. This volume is an updated reference on Fluidization Technologies which includes varied papers and gives a survey of worldwide research in this area. Close attention has been given to its content and to the balance between the different aspects of fluidization. We do hope that this book will provide and overview of fluidized bed technologies and thus encourage more people to join our community and to discover new fields of application.

Organizing this conference has been a pleasure for me and I have good memories of its preparation. I am certain that Claude, whose death was greatly felt by all his colleagues, would have shared this sentiment with me. In his absence, I would like to take this opportunity to thank the European Committee Members who contributed to the conference preparation. Their efficiency and dedication was greatly appreciated. Among them I particularly acknowledge the support of P. Guigon, M. Hemati and D. Steinmetz for their

Fluidization Conference VII & VIII Topics

Conference	Year	Location	Chair/co-chairs
VII	1992	Brisbane, Australia	O.E. Potter, D.J. Nicklin
VIII	1995	Tours, France	Jean-François Large, Claude Laguérie

Fluidization VII

J. F. Davidson, Fluidized combustion of solids, gases and mixtures thereof

Desmond King, Fluidized Catalytic crackers: an engineering review.

T. M. Knowlton, **Pressure and temperature effects in fluid particle systems**

Daizo Kunli, Octave Levenspiel, Heat transfer between fluidized beds and wall surface

Keith Masters, Industrial fluid bed drying: trend and development

Fluidization VIII

B. Kozanoglu, E.K.Levy, T. Ulge, R. Sahan, T. Schmitt, **Particle setting rates in bubbling fluidized beds**

C.H.Soong, K. Tuzla, J.C. Chen, Experimental determinations of cluster size and velocity in circulating fluidized bed

B. Caussat, M. Hemati, J.P. Couderc, A local analysis of hydrodynamics and mass transfer inside and around a single bubble

U. Arena, A. Cammarota, R. Chirone, Fragmentation and attrition during the fluidized bed combustion of the two waste-derived fuels

Fluidization Conference Proceedings IX & X

Conference	Year	Location	Chair/co-chairs
IX	1998	Durango, Colorado	Liang-Shih Fan, Ted M. Knowlton
Х	2001	Beijing, China	Moonson Kwauk, Jinghai Li, Wen-Ching Yang

Fluidization IX



Schouten J. C. (THE NETHERLANDS) Wei F. (P. R. CHINA) Weimer A. (USA) Senior R. C. (USA) Weinstein H. (USA) Seville J. (UK) Wells J. (USA) Sinclair J. L. (USA) Werther J. (GERMANY) Skouby D. (USA) White R. B. (AUSTRALIA) Wirth K.-E. (GERMANY) Soo S. L. (USA) Sundaresan S. (USA) Syamial M. (USA) Yang S.-T. (USA) Takeuchi H. (JAPAN) Yang W.-C. (USA) Tailon S. (NEW ZEALAND) Yates J. G. (UK) Tardos G. I. (USA) Yu A. B. (AUSTRALIA) Tsuchiya K. (JAPAN) Zhang J.-Y. (P. R. CHINA) Turton R. (USA) Zheng Q.-Y. (P. R. CHINA) Tuzla K. (USA) Zhu J.-X. (CANADA) van den Bleek, C. M. (THE NETHERLANDS) MEMBERS OF THE U.S. ORGANIZING COMMITTEE

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PREFACE

Fluidization is an important technology employed in a variety of industrial processes. It plays a major role not only in traditional industries such as coal combustion and gasification, oil refining and metallurgical processes, but also in the development of emerging technologies such as materials processing and biotechnology. With increasing impetus for sustainable development, its applications in energy, resource recovery and environment are being further explored. It has been estimated that over 5% of all published papers in chemical engineering literature deal with fluidization and its related subjects, making it one of the most active subjects in chemical engineering research.

On the other hand, fluidization is one of the most complicated unit operations in practice. Its typical particle-fluid two-phase flow patterns exhibit complex structures through self-organization of solids and fluid. Because of the non-linear and nonequilibrium features of most fluidization systems, their quantitative understanding and practical application constitute a challenge in science and engineering.

Although application of fluidization has been extended to a variety of fields and its research has been carried out for more than half a century, fundamental understanding of its complexity is still very limited. Further efforts are needed to unravel the underlying mechanisms for quantitative design, control and scale-up of fluid-bed reactors. In addition, increasing attention to sustainable development has given rise to more and more opportunities in the field. The advance of interdisciplinary sciences also has further stimulated fundamental research on fluidization to provide generic tools and sound theories for applications.

Previous Engineering Foundation Conferences on Fluidization were held in Asilomar, California in 1975; Cambridge, England in 1978; Henniker, New Hampshire in 1980; Kashikojima, Japan in 1983; Elsinore, Denmark in 1986; Banff, Canada in 1989; Broadbeach, Australia in 1992; Tours, France in 1995 and Durango, Colorado in 1998. This international conference series is now firmly established as the reeminent forum for experts in the field. To face the challenge in the new nillennium, this conference, the tenth in the series, focuses on the central theme - Fluidization for Sustainable Development. Such a theme implies not only the emphasis on its role in various industries to satisfy the requirements of resource utilization, ecology and economy, but also the determination on the development of a quantitative understanding. Therefore, the following aspects have been emphasized and encouraged from the very beginning of organizing the conference:

- Exploitation of fluidization applications for sustainable development
- New methodologies to simulate and scale up fluidized systems
- New memocologies to simulate and scale up huldized systems Exploring the complexity in fluidization, particularly in regard to flow structure integration of existing understanding into user-friendly software Enhancement of interaction between academics and industrialists

Fluidization Conference IX & X Topics

Conference	Year	Location	Chair/co-chairs
IX	1998	Durango, Colorado	Liang-Shih Fan, Ted M. Knowlton
Х	2001	Beijing, China	Moonson Kwauk, Jinghai Li, Wen-Ching Yang

Fluidization IX

R. Jackson, The nature and role of effective stress in fluidized system

J. A. M. Kuipers, B. P. B. Hoomans, W. P. M. van Swaaij, Hydrodynamic models of gas-fluidized beds with their roles for design and operation of fluidized bed and chemical reactors

W. –C. Yang, **30-years of industrial research on fluidization- Bridging the gap between theory and practice**

S. Mori, Development of new fluidization technologies for energy conversion and environmental processes

Fluidization X

L. Plass, Future R&D directions required in fluidization and fluid-particle systems for sustainable development in chemical industries

A. M. Squires, Microreactors simulating present(and future?) fluid beds

J. Chen, Developments of fluidization technology in China's oil refinery industry

I. D. Burdett, R. S. Eisinger, P. Cai, K. H. Lee, Gas-phase fluidization technology for production of polyolefins

Fluidization Conference Proceedings XI & XII

Conference	Year	Location	Chair/co-chairs
XI	2004	Ischia, Naples, Italy	Umberto Arena, Riccardo Chirone, Michele Miccio, Piero Salatino
XII	2007	Vancouver, British Columbia, Canada	Xiaotao Bi, Franco Berruti, Todd Pugsley
Eluidization VI			Eluidization VII

Fluidization XI



Edited by: Umberto Arena, Riccardo Chirone, Michele Miccio and Piero Salatino

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Fluidization is an important field of both fundamental research and broad industrial applications. Current: understanding of the complex fluid-particle two- and threephase flow patterns, coupled with heat and mass transfer and understanding the still insufficient for practitioners to reliably design and scale up dominical reactions, is bed reactors. The past eleven Engineering Foundation Fluidamenterial fulluized from 1975 to 2004, have put the emphasis on fundamental research to simulate schange of ideas from researchers all over the world in order to develop generic tools and theories for fluidization and its applications.

PREFACE

The present Fluidization XII conference continues the distinguished tradition of this conference series, with its focus on fundamental research of fluidization, but it significantly expands into emerging applications of fluidization and novel fluidization technologies. The four invited plenary papers cover four challenging and industrially important areas of fluidization: design and scale-up, instrumentation and diagnosis, multiscale modeling and simulation, and applications in clean and renewable energy. Circulating fluidized beds (CFBs) and bubbling fluidized beds remain the focal areas of fundamental research. As in other recent fluidization conferences, CFBs (both risers and downers) continue to receive greater attention than bubbling fluidization, with 23 contributions on CFBs and 10 contributions on bubbling in this conference. Noticeably, there are four papers dealing with high-density and high-flux risers, while feed configuration, reactor modeling and reactor performance are the subject of downers. Papers on bubbling fluidization deals with bubble flow pattern distribution, manipulation and gas flow field, and particle movement near the wall. Twenty papers deal with modeling and simulation of fluidized beds using computational fluid dynamics (CFD), with subjects ranging from simulation of flow structures, heat transfer and inversion in liquid-solids binary particle systems to reactor performances, capturing the recent interests and advances in this area. Jetting and spouting received a revised interest in this conference, with 15 papers dealing with hydrodynamics, mixing, scale-up and applications for coal gasification, chemical vapour deposition of silicon, powder granulation, and hydrogen production. Flow structure and layer inversion of binary particle mixtures, bed contraction, gas hydrate formation are the subjects of eight papers on gas-liquid-solids systems.

Fluidization of ultrafine and nano particles is the subject of 10 contributions, dealing with assisted fluidization, coating, grinding and production of nano particles. More than 20 aparse explored the application of fluidized beds for biomass combustion, gasification, pyrolysis and hydrogen production, chemical looping combustion cracking of used etible oil, air and water pollutant abatements, demonstrating the commitment and contribution of the fluidization community to the global efforts on greenhouse gas emission reduction and environmental protection.

Measurement and monitoring of multiphase systems remain a challenge to fluidization researchers. Recent advances in this area is well represented by the 10 papers in this conference, exploring the application of positron emission particle tracking, multi-particle tracking, magnetic resonance, confocal microparticle tracking, x-ray fluoroscopy, electrostatic and capacitance tomography for fluidized beds, and the development of advanced signal analysis techniques. Heat transfer in bubbling, turbulent tand fast fluidized beds are contributed by 5 papers in this conference.

Fluidization Conference XI & XII Topics

Conference	Year	Location	Chair/co-chairs					
XI	2004	Ischia, Naples, Italy	Umberto Arena, Riccardo Chirone, Michele Miccio, Pie Salatino					
XII 2007 Vancouver, British Columbia, C		Vancouver, British Columbia, Canada	Xiaotao Bi, Franco Berruti, Todd Pugsley					
FI	uidizatio	on XI	Fluidization XII					

Fan L. S, Advance in gas-liquid-solid fluidization

Campbell C. S. , Granular flow and gas-fluidization

Seville J. P. K, Cohesion in fluidization

T. M. Knowlton, S. B. K. Reddy Karri, J. S. Smith, Hydrodynamic scale-up of circulating fluidized bed

Jinghai Li, Wei Ge, Jiayuan Zhang, Shiqiu Gao, Wei Wang, Ning Yang, Qichang Sun and Jian Gao, **Analytical Multi**scale Methodology for fluidization systems– retrospect and prospect

J. Ruud van Ommen, Robert F. Muddle, Measuring the gas- solids distribution in fluidized beds– a review

Filip Johnsson, Fluidized bed combustion for clean energy

Fluidization Conference Proceedings XIII & XIV

Conference	Year	Location Chair/co-chairs					
XIII	2010	Gyeong-ju, Korea	Sang Done Kim, Yong Kang, Jea Keun Lee, Yong Chil Seo				
XIV	2013	Noordwijkerhout, Netherlands	J.A.M. Kuipers, R.F. Mudde, J.R. van Ommen, N.G. Deen				

Fluidization XIII



PREFACE

The Thirteenth International Conference on Fluidization, Fluidization XIII will be held The Thirdean in Revea, from 16th to 21st of May, 2010. The theme of this conference in Gyeong d, total in Fluidization Engineering. Fluidization XIII is following the success of the twelve previous Fluidization Conferences, which have been held every three years since 1975.

It is our great pleasure and honor to organize the prestigious Fluidization XIII conference and edit its proceedings. The venue of the Fluidization XIII has been alternated amongst the continents to provide opportunities for all the world class researchers in the field to participate in this conference series. This is the first time for Korea to host this conference series and we believe that this event will provide great synergetic energy to the Korean fluidization community as well as showcase the recent advancements made by Korean researchers.

The Fluidization XIII conference continues the tradition of this conference series by focusing on the fundamental research on fluidization but it also expands its scope into emerging applications of fluidization and novel fluidization technologies. Specific topics to be covered by the conference include dense fluidization; bubbling and slugging; measurement and instrumentation; liquid and three-phase fluidization; novel fluidized-bed reactors; circulating and fast fluidization; reactor performance; heat and mass transfer; spouted beds and rotating fluidization; reactor modeling and simulation; and non-conventional fluidized beds. 123 peer reviewed papers have been accepted from 186 submitted papers for the publication in this proceedings.

We are also much honored to dedicate this proceedings to Professor Sang Done Kim on the occasion of his retirement from the Korea Advanced Institute of Science and Technology (KAIST) in the recognition of his extraordinary contribution to the Korean academic community as a pioneer in the field of fluidization engineering. His innovative research and endless teaching have been the main force of the modern development of fluidization engineering in Korea.

We would like to express special thanks to POSCO, SK Energy and other Korean companies for their financial support and interests, which are imperative for the success of this conference. We would also like to extend our sincere appreciation to all members of the Local and International Organizing Committees and the International Scientific Committee, and to all authors, reviewers and participants for their enthusiastic efforts, which have made the Fluidization XIII another success. The organizing committee would also like to thank to the Engineering Conference International (ECI) for their valuable organizational efforts.

FLUIDIZATION XIV



Edited by J.A.M. Kuipers, R.F. Mudde, J.R. van Ommen and N.G. Deen



Fluidization XIV

ference Co-chairs: Hans Kuipers, Multiphase Reactors Group Dept. Chemistry and Chemical Engineering, Eindhoven University of Technology Robert Mudde, Multiscale Physics Group Faculty of Applied Sciences, Delft University of Technology Ruud van Ommen, Product and Process Engineering Group Faculty of Applied Sciences, Delft University of Technology Niels Deen, Multiphase Reactors Group Dept. Chemistry and Chemical Engineering, Eindhoven University of Technology

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International Scientific Committee Harry van den Akker, Delft University of Technology Franco Berruti, University of Western Ontario Ray Cocco, PSRI L.S. Fan, Ohio State University Bruno Formisani, University of Calabria ney Fox, Iowa State University Gauthier, IFP Energies Nouvelle hn Grace, University of British Columbia n Heinrich, Hamburg University of Technology Hounslow, University of Sheffield tine Hrenya, University of Colorado Ted Knowlton, PSRI Jinghai Li, Chinese Academy of Sciences, Beijing Stefan Palzer, Nestle R&D fgang Peukert, University of Erlanger a Salman, University of Sheffield aap Schouten, Eindhoven University of Technology han Seville, University of Surrey Olivier Simonin, IMFT, Toulouse Sankaran Sundaresan, Princeton Jose Manuel Valverde, University of Seville Joachim Werther, Hamburg University of Technology Karl-Ernst Wirth, University of Erlangen Peter Witt, CSIRO Aibing Yu, University of New South Wales

Fluidization Conference XIII & XIV Topics

Conference	Year	Location Chair/co-chairs				
XIII	2010	Gyeong-ju, Korea	Sang Done Kim, Yong Kang, Jea Keun Lee, Yong Chil Seo			
XIV	2013	Noordwijkerhout, Netherlands	J.A.M. Kuipers, R.F. Mudde, J.R. van Ommen, N.G. Deen			

Fluidization XIII

John R. Grace, A perspective on development of novel fluidized bed process for a more sustainable global future

Jonathan Seville, A single particle view of fluidization

J. Ruud van Ommen, Robber Pfeffer, Fluidization of nanopowders: experiments modelling and applications

Masayuki Horio, Fluidization: past & future

Sankaran Sundaresan, Coarse-grained models for momentum, energy and species transport in gas-particle flows.

Fluidization XIV

Prof. Heinrich (TU Hamburg) and Prof. Palzer, Fluidization of amorphous granules - Practical challenges, product structures and progress in modeling

Prof. Yi Cheng, Integrating Plasma Physics & Chemistry with Mulitiphase Flows in Fluidization Engineering

Jose Manuel Valverde (Universidad de Sevilla), Fluidization of fine powders: Cohesive versus dynamic aggregation

Fluidization Conference Proceedings XV

Conference	Year	Location	Chair/co-chairs					
XV	2016	Montebello, Quebec, Canada	Jamal Chaouki, Franco Berruti, Xiaotao (Tony) Bi, Ray Cocco					
XVI	2019	Guilin, China	Chi-Hwa Wang, Wei Ge					
		Fluidization	XV					
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Fluidization Conference XV & XVI Topics

Conference	Year	Location	Chair/co-chairs						
XV	2016	Montebello, Quebec, Canada	Jamal Chaouki, Franco Berruti, Xiaotao (Tony) Bi, Ray Cocco						
XVI	2019	Guilin, China	Chi-Hwa Wang, Wei Ge						

Fluidization XV

Guangwen Xu, A few recent developments in fluidized bed technology applications for fuel conversion

Olivier Simonin, CFD in fluidized beds: The state of the art Piero Salatino, Mixing and segregation in fluidized bed thermochemical conversion of biomass

Leslaw Mleczko, Fluidized bed chemical reactors – Old and new applications

Thierry Gauthier, CLC, a promising concept with challenging development issues

Liang-Shih Fan, Chemical looping gasification and reforming – A perspective and prospects of novel circulating fluidized bed systems Ludvik Martinu, Surface engineering and vapor phase technologies for coating and functionalizing complex objects and small particles Guangxi Yue, CFB reactor to CFB combustor - The R&D of CFB combustion in China

Fluidization XVI

J.A.M. Kuipers, **Recent Advances in the Multi-Scale Simulation of** Mass, Momentum and Heat Transfer in Dense Gas-Particle Flows Qingshan Zhu, Fluidized Bed Mineral Roasting: From **Fundamental to Application** Stefan Heinrich, Title: TBA Hamid Arastoopour, Fluidization and Fluid Particle Systems **Research Contribution in Creating a Pathway to Sustainable** Society Marc-Olivier Coppens, Innovations in Fluidization, Inspired by Nature Fei Wei, A Multistage Fluidized Bed Reactor: Stability Analysis, Suppression of Back-mixing and its Application in **Heterogeneous Catalysis** Jamal Chaouki, Hydrodynamics of High Temperature Gas-Solid Fluidized Beds Benjamin Glasser, Scale-up of Fluidized Bed Drying: Hydrodynamics, Mixing and Heat and Mass Transfer

Sample Topics in Heated Discussion

- Bubble or Jets
- Density to be used for the buoyancy force of suspended particles
- Cluster definition, shape, formation mechanism
- Naming of fast fluidization
- Scale-up criteria
- Modeling and computation: restitution coefficient, solids stress and pressure and kinetics theory, granular temperature, and drag force
- Etc.



International Fluidization Award of Achievement

- Selected by an International Covert Committee, convened by Dale Keairns on behalf of the Engineering Foundation
- The initial Awards Team agreed with using the wood cut from Agricolae's 1556 book, viewed by many as an initial reference to fluidization, as the background for the Award Certificate, along with the Steuben Glass as the Gift





Awardees International Fluidization Award of Achievement

- John Davidson (1989)
- Moonson Kwauk (1989)
- Peter Rowe (1989)
- Daizo Kunii (1989)
- John Grace (1998)
- Fred Zenz (2007)
- Ted Knowlton (2007)
- Joachim Werther (2007)
- L-S Fan (2007)
- Octave Levenspiel (2011, awarded at 10th CFB Conference, in cooperation with this conference series)

Awardee International Fluidization Technology Leadership Award



 Dale Keairns (2011, awarded at 10th CFB Conference, in cooperation with this conference series)

Awardees Fluidization Conference Organizing Committee Award

- Owen Potter (Gold Coast/Brisbane, 1992)
- Maurice Bergougnou (Tours, 1995)
- J.S.M. Botterill (Tours, 1995)
- Derek Geldart (Tours, 1995)

Fluidization I - Asilomar



Fluidization I - Asilomar



M. Bergougnou, CY Wen, T. Shirai

J. F. Davidson, O. Molerus, P. LeGoff



L. Massimilla, H. Angelino

Fluidization II - Cambridge

Fluidization III - Henniker

Working Party Meeting

Fluidization III - Henniker

Fluidization III - Henniker

John and Sandy Matsen; John and Sherrill Grace

Henniker, CYWen, Keairns

T. Thompson, F. Zenz, D. Well, T. Knowlton

Henniker, Matsens, Botterill, Levenspiel

Fluidization IV - Kashikojima

Working Party Meeting

Fluidization V - Elsinor

Working Party Meeting

Fluidization V - Elsinor

Fluidization VI - Banff

Working Party Meeting

Fluidization VI - Banff

Fluidization VI - Banff

Fluidization VII – Gold Coast

Working Party Meeting

Fluidization VII – Gold Coast

Fluidization VIII - Tours

Another unique conference dinner experience

Fluidization IX - Durango

Working Party Meeting

Fluidization IX - Durango

Fluidization IX - Durango

Working Party Meeting

Fluidization XI - Ischia

Working Party Meeting

Fluidization XI - Ischia

Fluidization XII – Harrison Hot Springs

Fluidization XIII – Gyeong-Ju

Working Party Meeting

FUNDAMENTALS TO PRODUCTS

Fluidization XIV

May 26-31, 2013 NH Conference Center Leeuwenhorst Noordwijkerhout, The Netherlands

Tributes

* Professor Derek Geldart

* Professor Mooson Kwauk

Fluidization XIV – Noordwijkerhout

A Tribute to Professor Derek Geldart (1931-2012)

"He kept six serving men (Who taught him all he knew) Their names were What? And Why? And When? And Where? And How? And Who?" R Kipling

Condolence of Prof. Mooson Kwauk (1920-2012)

科学做事

Working on everything scientifically

悉心育人

Teaching youth elaborately

Fluidization XV – Montebello

Survey at Fluidization X - Beijing

	No. of					Confe	rences				
Name	Attendance	1	2	3	4	5	6	7	8	9	10
M. Bergougnou	8	*	*	4	*	*	4	*	Y		
J. C. Chen	9	Y	*	Х	*	*	4	*	4	*	4
J. F. Davidson	10	*	*	4	*	*	4	*	4	*	4
N. Epstein	8	*	*	4	*	*	Y	*	х		4
L. S. Fan	7				4	4	*	*	4	*	4
D. Geldart	10	4	4	4	4	4	4	4	Y	4	4
L. R. Glicksman	8		*		*	*	*	*	*	*	
J. R. Grace	9	*	*	4	*	*	4	*	х	*	4
R. A. Graff	8	*		Y	*	Х	4	*	4	*	4
M. Horio	9	*			*	*	*	*	*	*	*
K. Kato	9	4		4	4	4	4	4	4	4	4
D. L. Keaims	10	*	*	*	*	*	4	*	4	*	4
T. M. Knowlton	10	*	*	4	*	*	4	*	4	*	4
M. Kwauk	6				*	*	*	х		*	*
E. K. Levy	9	Y	*	4	*	4	*	*	*	*	
J. M. Matsen	10	4	4	4	4	4	4	4	4	4	4
& Wife	10	4	4	4	4	4	4	*	4	4	4
S. Mori	8	*			4	4	*	*	Y	*	4
O. E. Potter	9	*	*	4	Y	*	4	*	Y	*	
H. Weinstein	8			Y	*	*	*	*	*	*	*
J. Werther	9	*	*		*	4	*	*	*	*	4
W. C. Yang	9	*	*	4	*	4	*	*		*	4
J. G. Yates	?		*	4	4	х	Y	*	4	*	?
D. Kunii		Y	Y	Y	Y	Y	Y	Y	Y		
J. S.M. Botterill		Υ	Y	Y	Y	Y	Y	Y	х		
L. Behie		Y	х	х	х	Y	Y	Y	Y		
O. Levenspiel		Y	Х	Y	Y	Х	Y	Y	Y		
P. Rowe		Y	Y	Y	Y	X	Y	X	Y		
A. M. Squires		Y	Y	Y	Y	Y	Y	X	X		
D. J. Cheesman		X	Y	Y	X	Y	Y	Y	Y		
JF. Large		X	Y	Y	Y	Y	X	Y	Y		
H. Littmann		Y	Y	Y	X	Y	Y	X	Y		
T. Chiba		X	X	Y	Ŷ	Ŷ	Ŷ	Ŷ	X		
D. Gidaspow		X	X	Y	X	Y	Y	Y	Y		
A. Avidan		X	X	Y	X	Y	Y	Y	Y		
H. Caram		х	х	Y	Y	Y	Y	Y	Y		

Comments by Ted Knowlton Who Attended the meeting most times,15/16

- Greetings to everyone attending Fluidization XVI especially to all my friends and colleagues.
- I am extremely disappointed that I cannot attend Fluidization XVI. It is due to circumstances beyond my control.
- I have attended all of the Fluidization Conferences except for this one, and in my opinion, they have been exceptional.
- For me, the Conferences have always been 1) the best place to learn of new advances in the Fluidization field, and 2) to see old friends and colleagues working in the field. I looked forward to Every One.
- The Fluidization I Conference in Asilomar, California was different Than the Rest of the Conferences in that it Had a *Rapporteur* format, where one person would report on/discuss/criticize each paper in a session.
- The Rapporteur for my paper in Fluidization I was Professor Peter Rowe from University College London who was known to be very exacting and as a young engineer I was a bit worried. Fortunately, my Paper "Survived" his scrutiny.

Comments by Ted Knowlton Who Attended the meeting most times,15/16 (cont.)

- One other memory that I have from Fluidization I was that there was a Workshop where Fast Fluidization was debated as to whether it was really a separate Fluidization Regime! It was a very spirited debate! The Consensus was that it was a different regime.
- For me, all of the Conferences have been extremely good, but I especially remember Fluidization I, Fluidization II (in Cambridge), Henniker Conference (it was hot with no air conditioning), Banff Conferences, Fluidization IX (that I Co-Chaired With Professor LS Fan) in Durango, and Fluidization X (in China)
- My overall remembrance of the Conferences is that they have always represented quality and opportunity. Above All, However, what is remembered is the sense of shared purpose, collegiality and friendliness.
- I would like to wish all of you a very enjoyable time in China and an extremely successful conference.

Closing Thoughts

- A strong sense of personal gratitude to the field of fluidization—it has been the focus for a research and teaching career characterized by lifelong friendships, supportive colleagues, a harmonious research community, and stimulating intellectual environment. It is imperative on all of us to maintain this tradition and culture
- We are entering a period marked by a new generation of scholars, new problems, new approaches, new excitement, and new leadership, but we should not forget the foundation of the work from those on whose shoulders we stand
- There remains a new 30 years and more of fluidization history to be written