

Professor A.S. Mujumdar's Contribution to Transport Phenomena R&D

S. Devahastin, G. Chen, M.L. Passos and L. Huang

International Workshop and Symposium on Industrial Drying
Mumbai, India

December 22, 2004

OUTLINE

- **ASM101: Introduction to A.S. Mujumdar**
- **Research strategies and methodologies**
- **Areas of research and development**
- **Contributions to research community**



Professor Arun S. Mujumdar
FASME, FCIC, FICHe, FIES

EDUCATION

- **B.Chem.Eng. (Distinction), UDCT, University of Mumbai, India (1965)**
- **M.Eng. and Ph.D., Chemical Engineering, McGill University, Montreal, Canada (1968, 1971)**
- **Theses (a) Turbulent flow in packed beds (b) Effects of free stream turbulence on heat transfer from cylinders**

**WORKSHOP ON INDUSTRIAL DRYING
PRINCIPLES AND PRACTICE**

**BY
PROFESSOR ARUN S. MUJUMDAR
UDCT ALUMNI ASSOCIATION AND
CHEMICAL ENGINEERING DIVISION
UDCT, MATUNGA, MUMBAI
10, 11 DECEMBER, 2001**





METALL ENGINE
MEDICAL ENGINE

大 学

INDUSTRIAL EXPERIENCE

- **Research Engineer, Aerodynamics, Carrier Research Centre, Syracuse, New York (1969-71)**
- **Pulp & Paper Research Institute of Canada, Pointe Claire, Quebec (1972-75)**
- **President and Principal Consultant, Exergex Corporation, Brossard, Canada (1989-2000)**
- **Consultant to over 60 companies in four continents (on drying, heat mass transfer)**

PROFESSIONAL SERVICE

(Journals and Books)

- **Editor-in-Chief, Drying Technology, 1988 – present**
- **Editor and Principal Contributor, Handbook of Industrial Drying, Marcel Dekker, USA (now in 3rd Edition)**
- **Editor, Advances in Drying (Hemisphere, USA), 5 volumes**
- **Editor, Advances in Transport Processes (Elsevier, Netherlands), 11 volumes**
- **Editor, Drying of Solids (Science Publishers, USA), 3 volumes**

PROFESSIONAL SERVICE

(Journals and Books)

- **Co-author, Advanced Drying Technologies, Marcel Dekker, USA (2002)**
- **Co-Editor, Handbook of Postharvest Technologies, Marcel Dekker (2003)**
- **Co-Editor, Handbook of Mathematical Modeling in Food Processing (2006)**
- **Editor/Co-editor of about 40 volumes of IDS and other conference proceedings**



Selected books and journals in drying and transport phenomena edited / authored by Professor Arun S. Mujumdar, National University of Singapore and McGill University, Canada (1978-2004)

Visit for details:
www.geocities.com/as_mujumdar

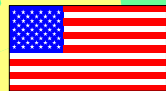
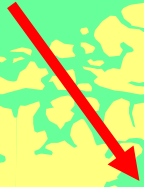
PROFESSIONAL SERVICE

(Others)

- **Founder/Program Chair, International Drying Symposium Series (IDS's) since 1978 (14 IDS's held to date)**
- **Co-Founder/Chair of Drying Conference Series e.g. ADC, IADC, NDC, CDC**
- **Editorial Board Member of 5+ international journals**
- **Reviewer for 30+ international journals**

International Drying Symposium (since 1978)

First IDS starts here



First IDS awards given here



Most recent IDS held here



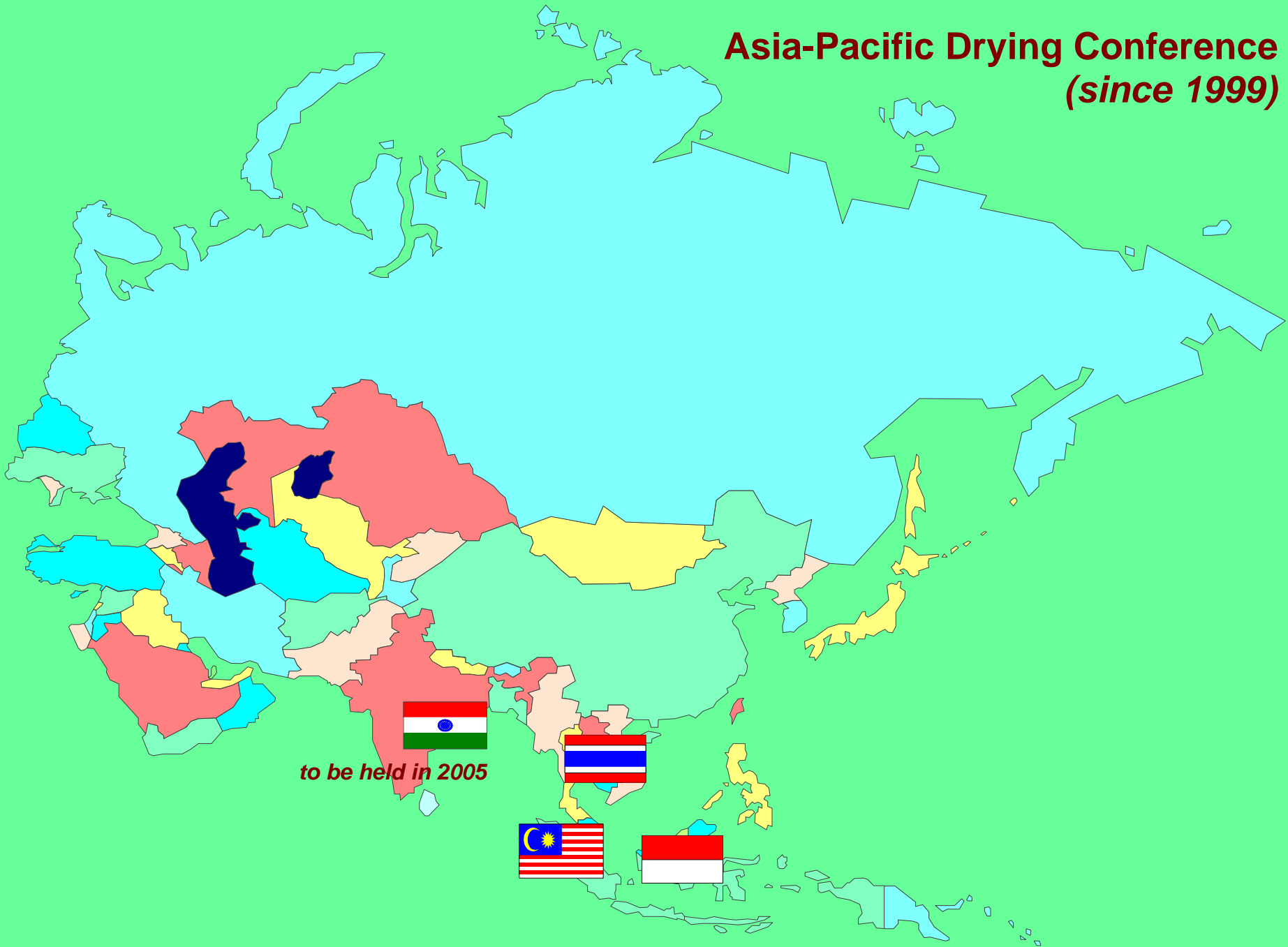
First IDS in Asia here





***Caricature from
IDS2000 held in
the Netherlands -
just to make the
event less “dry”***

Asia-Pacific Drying Conference (since 1999)



to be held in 2005

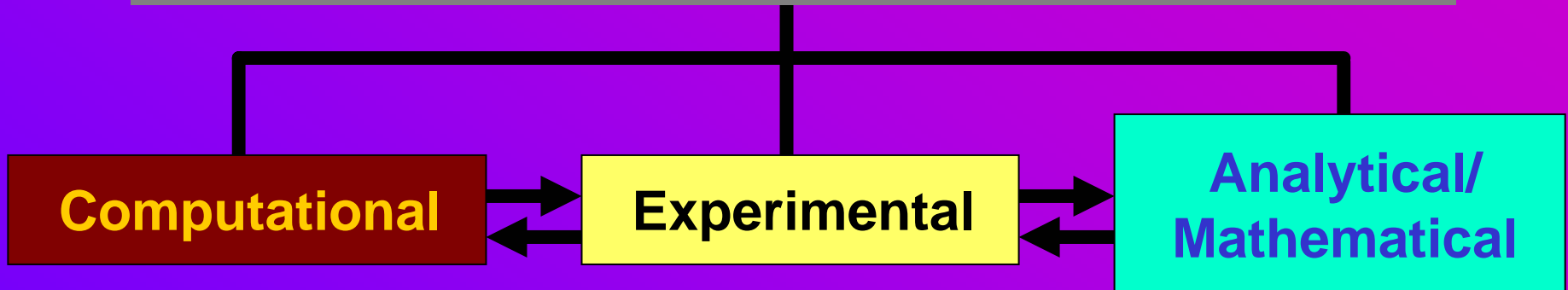
PROFESSIONAL RECOGNITION

- **Elected Fellow of ASME, CIC, IChE, IES**
- **Medals from Czech and Polish Academies of Science**
- **Procter & Gamble Award for Excellence in Drying Research**
- **Hemisphere Award for Innovation in Drying**
- **Jules Stachiewicz Heat Transfer Award (CSCChE)**
- **Honorary Professor at five Chinese universities**

TEACHING INTERESTS

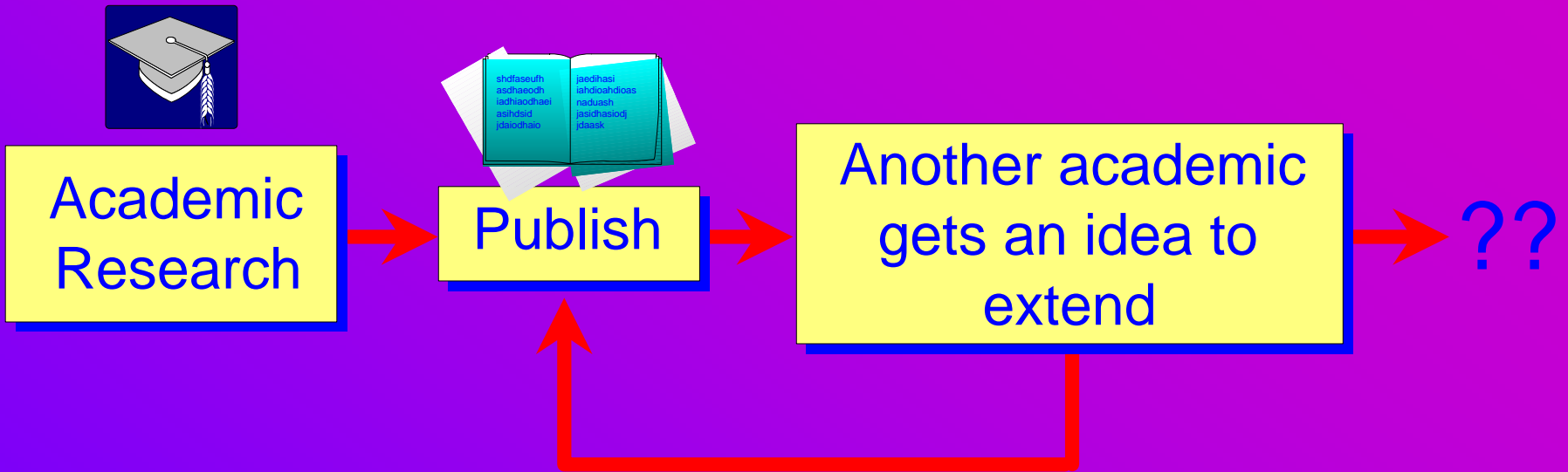
- **Transport Phenomena**
- **Fluid Mechanics**
- **Drying**
- **Thermodynamics**
- **Mass Transfer**
- **Fluidization**

Research Methodology
Outcome: Trained Researchers +
Research Results of Engineering Values



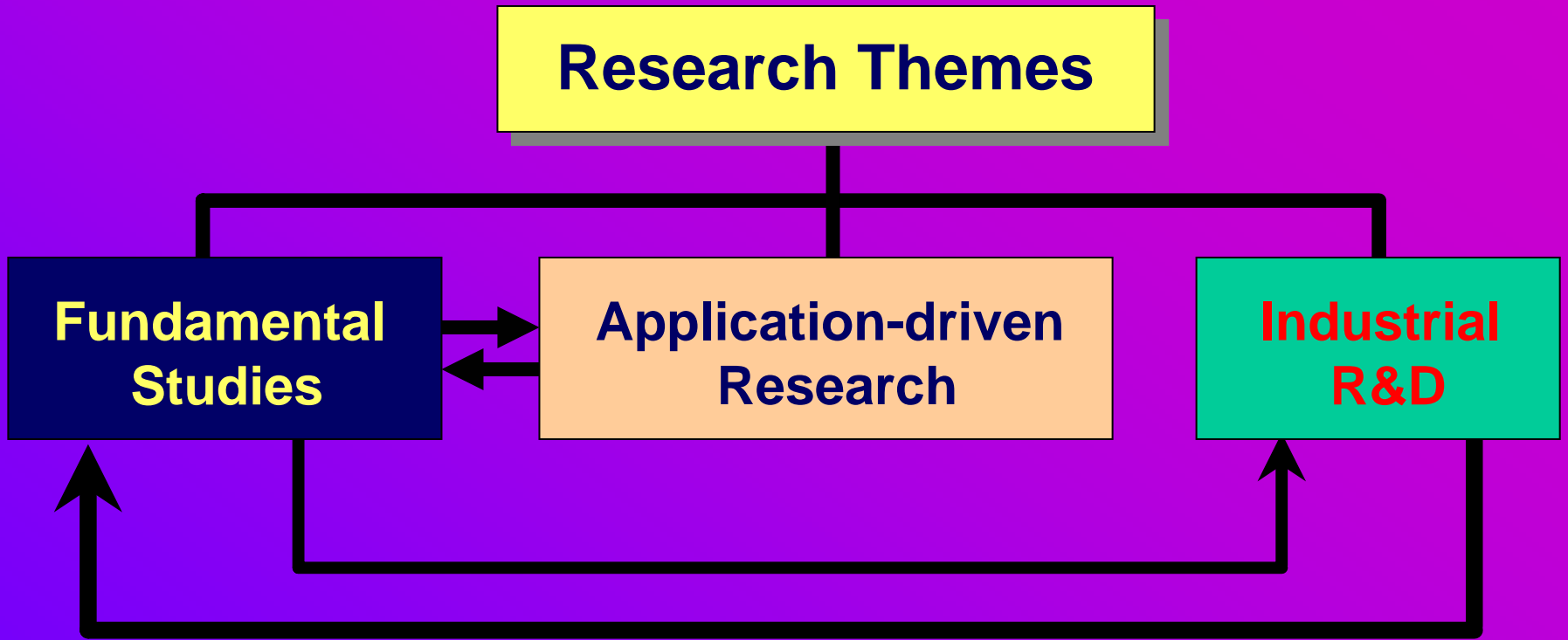
***Coupling between models and experiments
is mutually beneficial***

OLD PARADIGM OF RESEARCH

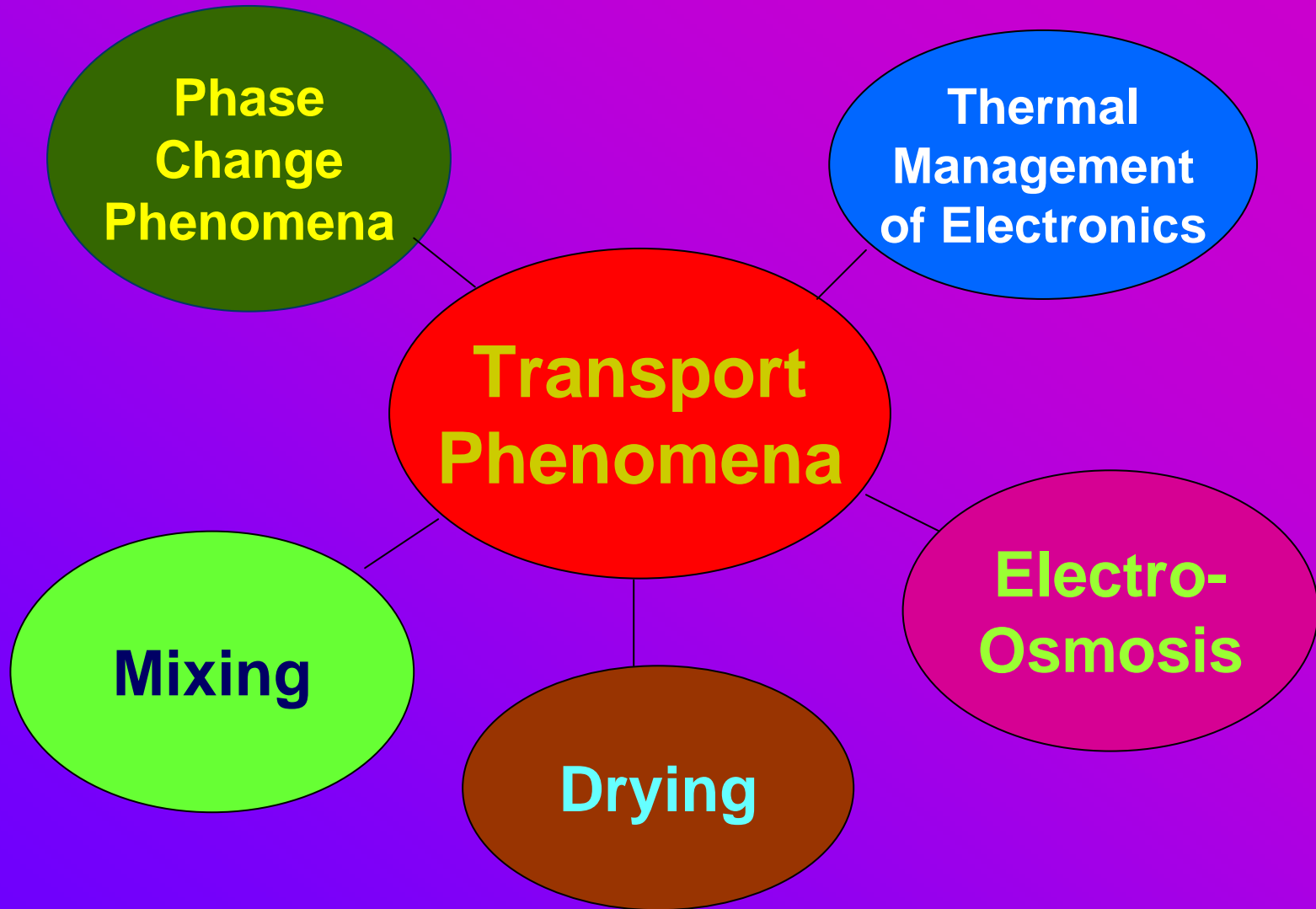


NEW PARADIGM OF RESEARCH





- Fundamental research driven by long-term mission
- Fundamental understanding can intensify innovation
- Test with math model prior to lab tests - cost-effective way to be creative/innovative!



Global Areas of Research of Professor A.S. Mujumdar

DRYING R&D

Continuous sheets e.g. paper, textiles

- Impinging jets
- Through drying
- Simulation of Yankee dryers

Liquids/ solutions

- Spray
- Drum
- Spouted bed of inert particles

Particulates

- Fluid beds
- Vibrated beds
- Agitated FB
- Novel spouted beds

Sludges

- Electro-osmosis

Industrial sectors covered: Agriculture, Ceramics, Foods, Pulp & Paper, Waste Sludges



RESEARCH IN PRE-DRYING STAGE

**Professors M.E. Weber, A.S. Mujumdar,
G.S.V. Raghavan**

Non-Thermal Dewatering

- ➔ Dewatering of colloidal suspensions/pastes using electro-osmosis**
- ➔ Innovative concept - interrupted power supply to enhance dewatering rate and reduce final moisture content of model clays**
- ➔ International cooperation - VTT, Finland; Oyama, Japan**
- ➔ Extended to electro-remediation of contaminated soils**



SUPERHEATED STEAM DRYING (SSD)

- ➔ **Interest in SSD at McGill initiated by W.H. Gauvin (1980)
- simple spray drying model**
- ➔ **Mujumdar (1981) proposed extension of Papridryer
concept using SSD**
- ➔ **Douglas, Mujumdar, Crotogino et al. examined
engineering/physical aspects of SSD for various
paper/pulp grades on lab scale**
- ➔ **Concept being tested on pilot scale at VTT, Finland**
- ➔ **Good potential for commercialization as "booster"
dryers - Jury still out!**

ABACUS CRYSTAL
BALL INC.

Computerized Predictions
Using Neural Nets
and Very Fuzzy Logic

MONEY BACK GUARANTEE



A CRYSTAL BALL THAT COUNTS!

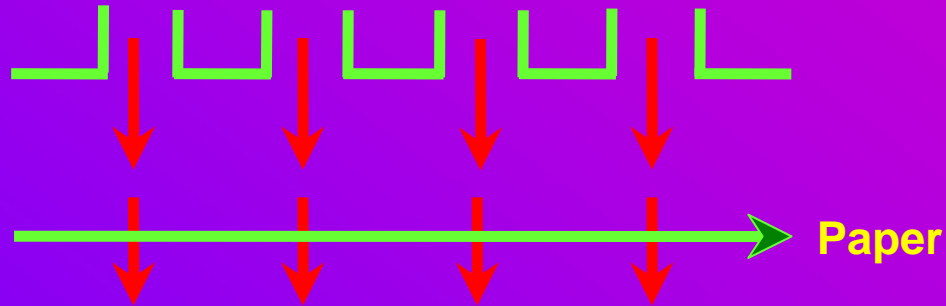
Munday '94

大久年

STEAM DRYING OF PAPER

Novel Solution

Use superheated steam impingement + throughflow:



Advantages: High drying rate
Better strength
Better efficiency

Disadvantages: Air infiltration
Condensation
COST!!!
New technology

*Pilot testing at VTT,
Finland*

At McGill SB research was initiated in 1980

Areas studied are:

- **Two-dimensional SBs with/without draft plates**
- **Two-dimensional spout-fluid beds**
- **Spouting of wet particles**
- **Intermittently SBDs/pulsed beds**
- **Coating in SBs**

MODIFIED SPOUTED BEDS



⇒ Grains

⇒ Coated particles

Basic Studies of Modified SB's

SPOUTED BEDS

Studies at McGill University

Two-dimensional spouted bed with/without draft plates

- ➔ Two-sided
- ➔ One-sided

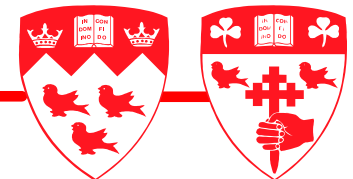
- ➔ Grains
- ➔ Coated particles

Rotating jet spouted bed

- ➔ Intermittent
spouting
- ➔ Intermittent
drying

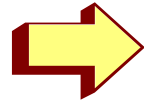
Rotating jet annular spouted bed

- ➔ Variable air mass
flow rate
- ➔ Variable inlet air
temperature
- ➔ Two-dimensional
liquid diffusion model

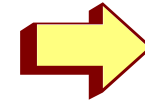


CHRONOLOGICAL DEVELOPMENTS OF SB DESIGNS AT MCGILL

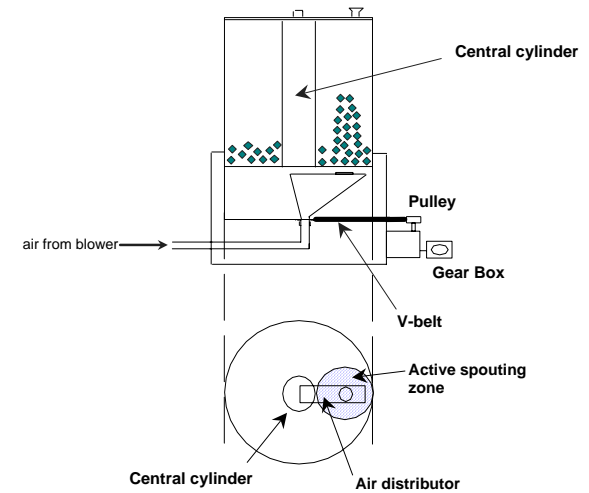
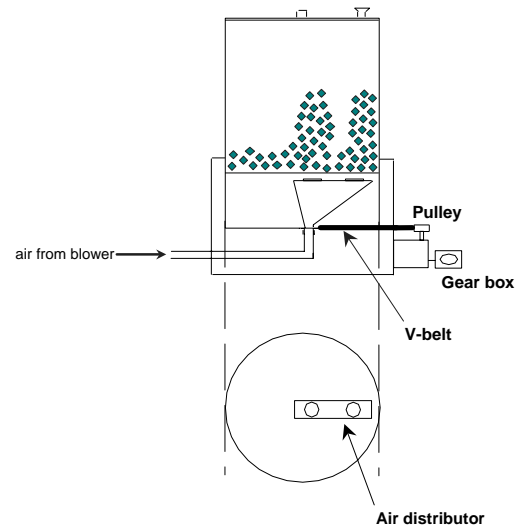
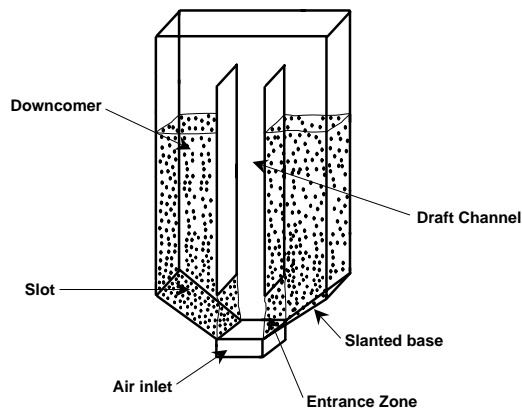
TDSB



RJSB



RJASB



Industrial Significance/Applications

Selected Drying research

RESEARCH SUBJECT

Superheated steam drying
of paper

Two-dimensional spouted beds;
Rotating jet spouted beds for
grain/seed/particulate drying

APPLICATION/STATUS

Pilot tests in Finland
Commercialization under
consideration

Semi-commercial units in
operation in Brazil, India,
Australia, China, etc.

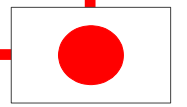
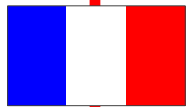
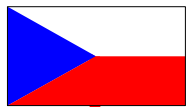
International Impact of McGill on Drying R&D

- ➔ International Drying Symposium (IDS) since 1978
- ➔ 14th IDS in Brazil - 450 attendees from 40 countries
- ➔ Drying Technology-An International Journal (DRT) since 1982; 10 issues per year; 2000+ pages; near exponential growth
- ➔ Handbook of Industrial Drying (2 volumes, 2ed., 1995)
- ➔ Modern Drying Technology (in Chinese, 1998)
- ➔ 45 other edited books

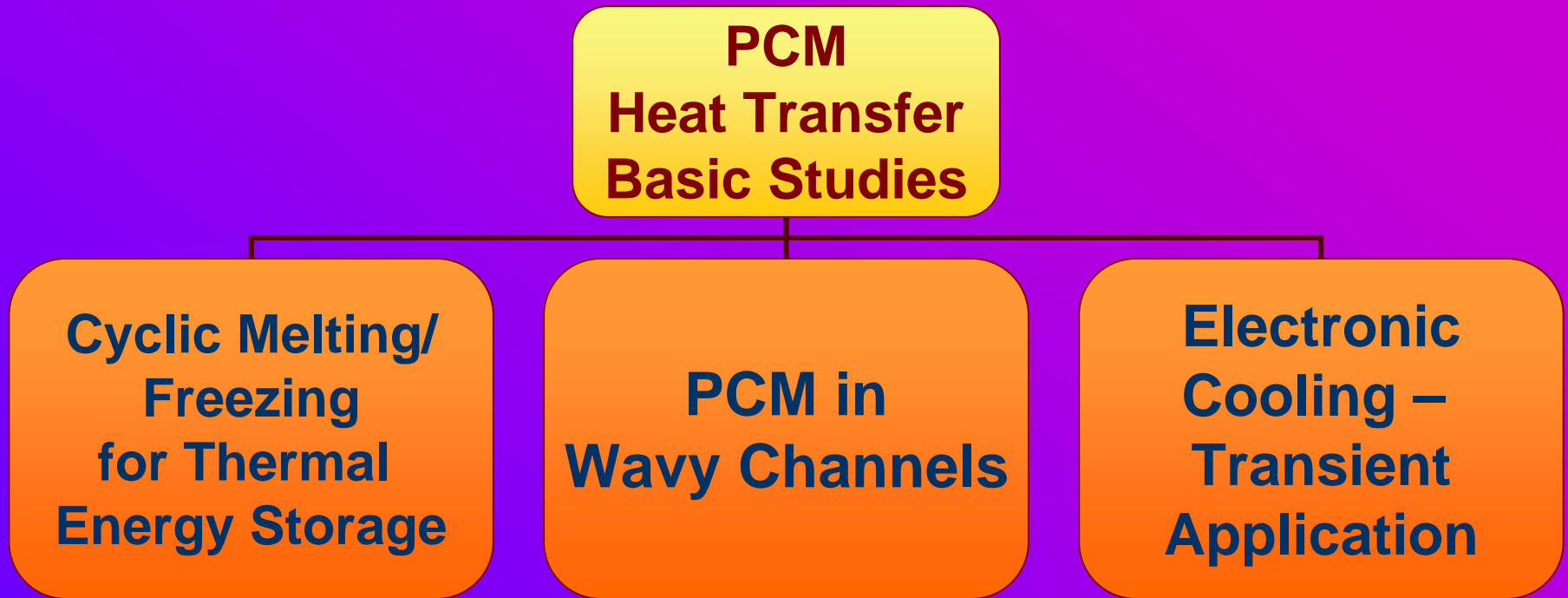
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International Impact of McGill on Drying R&D

- ➔ **Postgraduate/undergraduate research students**
- ➔ **PDFs/Visiting Professors/Visiting Scholars from over 20 countries - now conducting drying R&D in own countries**
- ➔ **Collaborative research**



NON-DRYING R&D



NON-DRYING R&D

**Thermal
Management of
Electronic
Components**

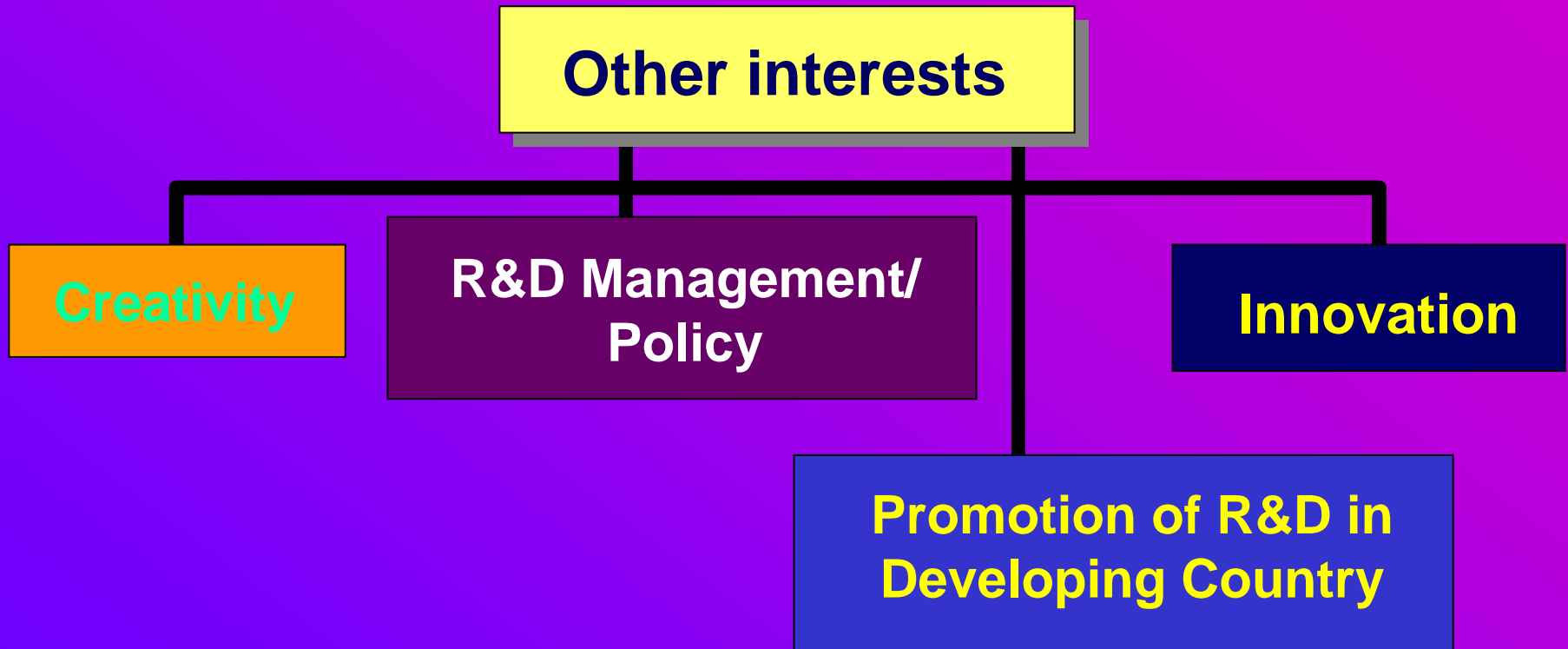
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graph TD; A[Thermal Management of Electronic Components] --- B[Use of Phase Change Materials (PCM)]; A --- C[Impinging Jets – Single/ Two Phase]; A --- D[Nanofluid Heat Transfer];
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**Use of
Phase Change
Materials
(PCM)**

**Impinging
Jets – Single/
Two Phase**

**Nanofluid
Heat
Transfer**

NON-DRYING R&D



CURRENT ACTIVE AREAS

- **Atmospheric freeze drying (NTNU, Norway)**
- **Electro-kinetic dewatering**
- **Chemical heat pump-assisted drying**
- **Transport phenomena in fuel cells**
- **Heat pump-assisted multi-mode drying**
- **Cyclic pressure/vacuum drying**
- **Low-pressure superheated steam drying (KMUTT, Bangkok, Thailand)**
- **Spray drying (Brazil)**

Multi-disciplinary Research

Joint collaboration with colleagues in:

- **Agricultural/Biosystems Engineering**
- **Food Engineering/Food Science**
- **Chemical/Environmental Engineering**
- **Computer/Electrical Engineering**
- **Mechanical Engineering/Energy Engineering**

**Research collaboration
Truly Global Scope**

Joint research / publication with members in:

Brazil	Canada	Finland
Norway	Poland	Greece
Hungary	UK	USA
China	Croatia	Hong Kong
Singapore	Malaysia	India
Japan	Oman	Thailand

CONTRIBUTIONS

- **Over 30 M.Eng., 40 Ph.D., 30 postdoctoral fellows advised to date**
- **Over 300 refereed papers and 250 conference presentations**
- **Over 60 keynote and plenary lectures**
- **Lectured in 40+ countries**
- **Professional Development Courses for industry and academia in 10 countries**

CONTRIBUTIONS

- **Donated books/journals worth over \$250K to developed nations (researchers, students, libraries)**
- **Free professional development courses in developing countries - over 1000 participants in 20+ countries**
- **Free dissemination of information through Web site (maintained by Dr. S. Devahastin and by NUS students)**
- **Free rights given to translation of Guide into various languages to promote easy access**



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