

Christopher M. Boyce

Assistant Professor
Columbia University
Department of Chemical Engineering
Email: cmb2302@columbia.edu

EDUCATION

University of Cambridge, Trinity College, Cambridge UK

Ph.D. Chemical Engineering, 2015

Advisor: Prof. John Dennis

Faculty Collaborators: Profs. John Davidson, Lynn Gladden; Drs. Daniel Holland, Stuart Scott

Honors:

- Danckwerts-Pergamon Prize for the best PhD thesis related to chemical engineering, 2015
- Gates Cambridge Scholar (2011-2014)

Massachusetts Institute of Technology, Cambridge, MA

B.S. 2011

Majors: Chemical Engineering and Physics

Minor: Nuclear Science and Engineering

Honors:

- Phi Beta Kappa Academic Honor Society
- Tau Beta Pi Engineering Honor Society
- Sigma Pi Sigma Physics Honor Society

RESEARCH EXPERIENCE

Columbia University

Assistant Professor, January 2018-Present

Department of Chemical Engineering

Description: My research group aims to uncover and characterize hydrodynamic instabilities and other flow phenomena in multiphase and granular flows. We seek to connect this fundamental physics with heat and mass transport and chemical reactions to generate a deeper understanding of the coupled multi-physics in a variety of complex systems. We look to apply this knowledge gained to problems in geophysics as well as to optimize processes and engineer new technologies in the health, energy and construction sectors, such as in pharmaceutical production, carbon capture, solar thermal energy generation and cement mixing. Our research is enabled by the development and utilization of novel optical and magnetic resonance imaging as well as physics-based, multi-scale computational modeling.

ETH Zürich

Postdoctoral Researcher, January 2017-December 2017

Department of Mechanical and Process Engineering

Advisor: Prof. Christoph Müller

Description: My second postdoctoral work focused on using ultrafast MRI as a means to visualize flow and chemical reactions in opaque multiphase flow systems in a quantitative and spatially resolved manner.

Princeton University

Postdoctoral Associate, January 2015 – December 2016

Department of Chemical and Biological Engineering

Advisor: Prof. Sankaran Sundaresan

Description: My first postdoctoral work focused on the physics of fluid-particle flows influenced by interparticle forces, such as cohesive liquid bridging and electrostatic forces. Non-dimensional characterization of these flows was achieved by developing and utilizing computational models which captured the multiphysics in an efficient manner.

University of Cambridge

Ph.D. Candidate, October 2011 – December 2014

Department of Chemical Engineering and Biotechnology

Advisor: Prof. John Dennis

Dissertation: *Fundamental Studies of the Physics of Gas-Solid Fluidization*

Description: My doctoral research focused on the hydrodynamics of fluidized beds by developing and validating experimental and computational techniques to reveal new insights into the physics of these multiphase flows. Experiments focused on development and use of magnetic resonance imaging to visualize the physics of particle and gas flow under bubbling fluidization conditions. Computational work focused on developing and validating a 3D cylindrical Euler-Lagrange model of fluidized beds and utilizing the model to uncover fundamental aspects of the physics of fluidization, including the origin of pressure oscillations in bubbling fluidized beds.

Stanford University

Research Collaboration as Co-Founder and Engineer for Infinite Corridor Technology, LLC
August, 2008 – March 2013

Department of Mechanical Engineering

Stanford Collaborators: Prof. Beth Pruitt and Dr. Rebecca Taylor

Description: My research designed a stretchable micro-electrode using the patterned substrate technology that I invented and developed for making circuit boards stretchable and applied this technology to a Stanford project on electro-mechanical stimulation of heart cells.

Massachusetts Institute of Technology

Undergraduate Researcher, June 2009 – December 2010

Department of Chemical Engineering

Advisor: Prof. Karen Gleason

Graduate Student: Dr. Miles Barr

Description: My research used chemical vapor deposition to deposit organic electrodes necessary to create solar cells on arbitrary materials. It helped to launch the solar energy company Ubiquitous Energy.

RESEARCH ADVISING EXPERIENCE**Columbia University**

Advisor, PhD Research Projects, October 2017 – Present

- I began supervising PhD students in the Department of Chemical Engineering in October 2017. I am currently supervising a PhD student on the use of MRI and computational modeling to study multiphase flows and spatially heterogeneous chemical reactions.

Advisor, Master's and Undergraduate Research Projects, January 2018 – Present

- I began supervising master's and undergraduate students in the Department of Chemical Engineering in January 2018. I am currently supervising two master's students and one undergraduate in utilization of MRI data and computational modeling to shed light on instabilities in multiphase flows.

ETH Zürich

Advisor, Master's Thesis Project, November 2017 – Present

- Supervised Master's student research project studying the Rayleigh-Taylor instability in dense suspensions using optical imaging and computational modeling

Advisor, Bachelor's Thesis Project, September 2017 – Present

- Supervised undergraduate student research project studying granular fingering

Advisor, Master's Thesis Project, June 2017 – Present

- Supervised Master's student research project building a system for controlled injection of single or multiple gas bubbles into a fluidized bed for study of bubble shape, motion and coalescence using ultrafast MRI

University of Cambridge

Co-Supervisor, MPhil Research Project, March 2014 – August 2014

- Supervised Master's student research project using MRI to measure gas flow patterns in the freeboard of fluidized beds and compare against existing theories and computational models. Assisted student in learning MRI, compressed gas circulation and computational modelling techniques prior to his PhD studies in the field in October 2014

Co-Supervisor, MPhil Research Project, March 2013 – August 2013

- Supervised Master's student research project comparing X-ray, MRI and PEPT imaging techniques of fluidized beds; provided input on how to properly analyze and compare data. Research project led to publication of an article in *Chemical Engineering Science*

TEACHING EXPERIENCE

Columbia University

Assistant Professor, Department of Chemical Engineering, January 2018-Present

- Developed and instructed a graduate elective course in Computational Fluid Dynamics
- Instructor for undergraduate course Transport I focusing on fluid mechanics

University of Cambridge

Supervisor, Heterogeneous Reactors Course, January 2013 – April 2014

- Supervised 3rd year undergraduates in groups of 2 or 3 for one-hour-long sessions going over practice problems and core concepts for advanced chemical reaction engineering course

PROFESSIONAL SERVICE

- Reviewed papers for:
 - Science Advances
 - PLoS ONE
 - AIChE Journal
 - Chemical Engineering Science
 - Chemical Engineering Research and Design

- Physics of Fluids
- International Journal of Multiphase Flow
- Powder Technology
- PhD thesis examiner:
 - ETH Zürich, Chen Yong, “Lattice Boltzmann simulations of fluid-solid momentum and heat transfer in gas solid flows comprising cubic particles”, 2017
 - Columbia University, Jack Davis, “Membraneless Electrolyzers for Solar Fuels Production”, 2019

ENTREPRENEURIAL EXPERIENCE

Infinite Corridor Technology, LLC

Co-Founder and Stretchable Design Engineer, June 2007 – Present

- Invented and prototyped novel substrate designs and first-of-its-kind functioning multi-layered stretchable and flexible electronic circuit boards
- Awarded Defense Advanced Research Projects Agency (DARPA) Small Business Innovation Research (SBIR) contract
- Designed stretchable circuit boards for a wide variety of applications to pursue and/or fulfill contracts for collaborators and for customers in the biomedical, military and consumer electronics industries

HONORS AND AWARDS

- Sabic Young Professional Award from the AIChE for outstanding contributions to particle technology from an individual under 40
- Forbes 30 Under 30 in Science, 2019
- Danckwerts-Pergamon Prize for the best PhD thesis related to chemical engineering, University of Cambridge, 2015
- Gates Cambridge Scholar, 2011-2014
- 2nd Prize, third year presentation, Department of Chemical Engineering and Biotechnology, University of Cambridge, 2014
- 1st Prize, second year poster presentation, Department of Chemical Engineering and Biotechnology, University of Cambridge, 2013
- Phi Beta Kappa Academic Honor Society, MIT, 2011
- Sigma Pi Sigma Physics Honor Society, MIT, 2011
- Tau Beta Pi Engineering Honor Society, MIT, 2010

PUBLICATIONS

- 31) McLaren, C. P.; Kovar, T. M.; Penn, A.; Müller, C. R.; Boyce, C. M. Gravitational Instabilities in Binary Granular Materials. *Proc. Natl. Acad. Sci.* **2019**, 201820820. [Link](#)
- 30) Boyce, C.M.; Penn, A.; Lehnert, M.; Pruessmann, K.P.; Müller, C. R. Characteristics of a Single Jet Injected into an Incipiently Fluidized Bed: A Magnetic Resonance Imaging Study. *Adv. Powder Technol.* **2019** Accepted.
- 29) Boyce, C.M.; Penn, A.; Lehnert, M.; Pruessmann, K.P.; Müller, C. R. Magnetic Resonance Imaging of Interaction and Coalescence of Two Bubbles Injected Consecutively into an Incipiently Fluidized Bed. *Chem. Eng. Sci.* **2019**, 115152. [Link](#)

- 28) Boyce, C. M.; Penn, A.; Padash, A.; Lehnert, M.; Pruessmann, K. P.; Müller, C. R. Anomalous Collapse of Interacting Bubbles in a Fluidized Bed: A Magnetic Resonance Imaging Study. *Phys. Rev. Fluids* **2019**, *4*, 034303. [Link](#)
- 27) Boyce, C. M.; Penn, A.; Lehnert, M.; Pruessmann, K. P.; Müller, C. R. Magnetic Resonance Imaging of Single Bubbles Injected into Incipiently Fluidized Beds. *Chem. Eng. Sci.* **2019**, *200*, 147-166. [Link](#)
- 26) Boyce, C. M.; Penn, A.; Lehnert, M.; Pruessmann, K. P.; Müller, C. R. Wake Volume of Injected Bubbles in Fluidized Beds: A Magnetic Resonance Imaging Velocimetry Study. *Powder Technol.* **2019**, Accepted (Invited). [Link](#)
- 25) Penn, A.; Boyce, C. M.; Conzelmann, N.; Bezing, G.; Pruessmann, K. P.; Müller, C. R. Real-Time Magnetic Resonance Imaging of Fluidized Beds with Internals. *Chem. Eng. Sci.* **2019**, *198*, 117–123 (Cover Article). [Link](#)
- 24) Boyce, C. M.; Penn, A.; Lehnert, M.; Pruessmann, K. P.; Müller, C. R. Effect of Liquid Bridging on Bubbles Injected into a Fluidized Bed: A Magnetic Resonance Imaging Study. *Powder Technol.* **2019**, *343*, 813–820. [Link](#)
- 23) Boyce, C. M. Gas-Solid Fluidization with Liquid Bridging: A Review from a Modeling Perspective. *Powder Technol.* **2018**, *336*, 12–29. [Link](#)
- 22) Penn, A.; Boyce, C. M.; Kovar, T.; Tsuji, T.; Pruessmann, K. P.; Müller, C. R. Real-Time Magnetic Resonance Imaging of Bubble Behavior and Particle Velocity in Fluidized Beds. *Ind. Eng. Chem. Res.* **2018**, *57* (29), 9674–9682 (Invited). [Link](#)
- 21) Boyce, C. M.; Penn, A.; Pruessmann, K. P.; Müller, C. R. Magnetic Resonance Imaging of Gas–Solid Fluidization with Liquid Bridging. *AIChE J.* **2018**, *64* (8), 2958–2971 (Invited). [Link](#)
- 20) Penn, A.; Tsuji, T.; Brunner, D. O.; Boyce, C. M.; Pruessmann, K. P.; Müller, C. R. Real-Time Probing of Granular Dynamics with Magnetic Resonance. *Science Advances* **2017**, *3* (9), e1701879. [Link](#)
- 19) Kolehmainen, J.; Sippola, P.; Raitanen, O.; Ozel, A.; Boyce, C. M.; Saarenrinne, P.; Sundaresan, S. Effect of Humidity on Triboelectric Charging in a Vertically Vibrated Granular Bed: Experiments and Modeling. *Chem. Eng. Sci.* **2017**, *173*, 363–373. [Link](#)
- 18) Boyce, C. M.; Ozel, A.; Kolehmainen, J.; Sundaresan, S.; McKnight, C. A.; Wormsbecker, M. Growth and Breakup of a Wet Agglomerate in a Dry Gas–solid Fluidized Bed. *AIChE J.* **2017**, *63* (7), 2520–2527. [Link](#)
- 17) Boyce, C. M.; Ozel, A.; Kolehmainen, J.; Sundaresan, S. Analysis of the Effect of Small Amounts of Liquid on Gas–Solid Fluidization Using CFD-DEM Simulations. *AIChE J.* **2017**, *63* (12), 5290–5302. [Link](#)
- 16) Boyce, C. M.; Ozel, A.; Rice, N. P.; Rubinstein, G. J.; Holland, D. J.; Sundaresan, S. Effective Particle Diameters for Simulating Fluidization of Non-Spherical Particles: CFD-DEM Models vs. MRI Measurements. *AIChE J.* **2017**, *63* (7), 2555–2568. [Link](#)
- 15) Kolehmainen, J.; Ozel, A.; Boyce, C. M.; Sundaresan, S. Triboelectric Charging of Monodisperse Particles in Fluidized Beds. *AIChE J.* **2017**, *63* (6), 1872–1891. [Link](#)
- 14) Boyce, C. M.; Rice, N. P.; Ozel, A.; Davidson, J. F.; Sederman, A. J.; Gladden, L. F.; Sundaresan, S.; Dennis, J. S.; Holland, D. J. Magnetic Resonance Characterization of

- Coupled Gas and Particle Dynamics in a Bubbling Fluidized Bed. *Phys. Rev. Fluids* **2016**, *1* (7), 74201. [Link](#)
- 13) Boyce, C. M.; Ozel, A.; Sundaresan, S. Intrusion of a Liquid Droplet into a Powder under Gravity. *Langmuir* **2016**, *32* (34), 8631. [Link](#)
 - 12) Kolehmainen, J.; Ozel, A.; Boyce, C. M.; Sundaresan, S. A Hybrid Approach to Computing Electrostatic Forces in Fluidized Beds of Charged Particles. *AIChE J.* **2016**, *62* (7), 2282. [Link](#)
 - 11) Boyce, C. M.; Rice, N. P.; Davidson, J. F.; Sederman, A. J.; Dennis, J. S.; Holland, D. J. Magnetic Resonance Imaging of Gas Dynamics in the Freeboard of Fixed Beds and Bubbling Fluidized Beds. *Chem. Eng. Sci.* **2016**, *147*, 13. [Link](#)
 - 10) Boyce, C. M.; Rice, N. P.; Sederman, A. J.; Dennis, J. S.; Holland, D. J. 11-Interval PFG Pulse Sequence for Improved Measurement of Fast Velocities of Fluids with High Diffusivity in Systems with Short T2*. *J. Magn. Reson.* **2016**, *265*, 67. [Link](#)
 - 9) Lu, X.; Boyce, C. M.; Scott, S. A.; Dennis, J. S.; Holland, D. J. Investigation of Two-Fluid Models of Fluidisation Using Magnetic Resonance and Discrete Element Simulations. *Procedia Eng.* **2015**, *102*, 1436. [Link](#)
 - 8) Boyce, C. M.; Holland, D. J.; Scott, S. A.; Dennis, J. S. Limitations on Fluid Grid Sizing for Using Volume-Averaged Fluid Equations in Discrete Element Models of Fluidized Beds. *Ind. Eng. Chem. Res.* **2015**, *54* (43), 10684. [Link](#)
 - 7) Pore, M.; Ong, G. H.; Boyce, C. M.; Materazzi, M.; Gargiuli, J.; Leadbeater, T.; Sederman, A. J.; Dennis, J. S.; Holland, D. J.; Ingram, A.; et al. A Comparison of Magnetic Resonance, X-Ray and Positron Emission Particle Tracking Measurements of a Single Jet of Gas Entering a Bed of Particles. *Chem. Eng. Sci.* **2015**, *122*, 210. [Link](#)
 - 6) Boyce, C. M.; Davidson, J. F.; Holland, D. J.; Scott, S. A.; Dennis, J. S. The Origin of Pressure Oscillations in Slugging Fluidized Beds: Comparison of Experimental Results from Magnetic Resonance Imaging with a Discrete Element Model. *Chem. Eng. Sci.* **2014**, *116*, 611. [Link](#)
 - 5) Boyce, C. M.; Holland, D. J.; Scott, S. A.; Dennis, J. S. Novel Fluid Grid and Voidage Calculation Techniques for a Discrete Element Model of a 3D Cylindrical Fluidized Bed. *Comput. Chem. Eng.* **2014**, *65*, 18. [Link](#)
 - 4) Harper, R. N.; Boyce, C. M.; Scott, S. A. Oxygen Carrier Dispersion in Inert Packed Beds to Improve Performance in Chemical Looping Combustion. *Chem. Eng. J.* **2013**, *234*, 464. [Link](#)
 - 3) Boyce, C. M.; Holland, D. J.; Scott, S. A.; Dennis, J. S. Adapting Data Processing To Compare Model and Experiment Accurately: A Discrete Element Model and Magnetic Resonance Measurements of a 3D Cylindrical Fluidized Bed. *Ind. Eng. Chem. Res.* **2013**, *52* (50), 18085. [Link](#)
 - 2) Taylor, R. E.; Boyce, C. M.; Boyce, M. C.; Pruitt, B. L. Planar Patterned Stretchable Electrode Arrays Based on Flexible Printed Circuits. *J. Micromechanics Microengineering* **2013**, *23* (10), 105004. [Link](#)
 - 1) Barr, M. C.; Rowehl, J. A.; Lunt, R. R.; Xu, J.; Wang, A.; Boyce, C. M.; Im, S. G.;

Bulović, V.; Gleason, K. K. Direct Monolithic Integration of Organic Photovoltaic Circuits on Unmodified Paper. *Adv. Mater.* **2011**, 23 (31), 3500. [Link](#)

PATENTS

- 3) Taylor, R.E., Pruitt, B.L., Boyce, M.C., **Boyce, C.M.**, “In-plane-strain-actuated out-of-plane actuator”, U.S. Utility Patent 10150665 (Application 2014, Granted 2018).
- 2) **Boyce, C.M.**, Boyce, D.A., Boyce, M.C., Boyce, M.D., “Stretchable, flexible electronic patch for monitoring impacts and other events”, (*U.S. Provisional Patent Application 2013*), *U.S. Utility Patent Application 14158798* **2014**.
- 1) Boyce, M.C., Socrate, S., **Boyce, C.M.** and Greviskes, B., “Structured material substrates for flexible, stretchable electronics”, U.S. Utility Patent 8,883,287 (Application 2010, Granted 2014).

INVITED PRESENTATIONS

- 5) **Boyce, C.M.** (2019) “MRI and Computational Modeling of Multiphase Granular Flows” *Invited Seminar at the U.S. Naval Undersea Warfare Center.*
- 4) **Boyce, C.M.** (2019) “Magnetic Resonance Imaging of Multiphase Granular Flows” *Invited Seminar at TU Hamburg.*
- 3) **Boyce, C.M.** (2019) “Structures and Instabilities in Multiphase Granular Flows” *Invited Seminar at the Chinese Academy of Sciences.*
- 2) **Boyce, C.M.** (2018) “MRI and Computational Modeling of Multiphase Chemical Reactors” *Invited Seminar at ExxonMobil Chemical.*
- 1) **Boyce, C.M.** (2018) “MRI and Computational Modeling of Multiphase Flows” *Invited Seminar at Pall Corporation.*

PRESENTATIONS

- 16) **Boyce, C.M.**, Penn, A., Lehnert, M., Pruessmann, K.P., Müller, C.R. (2018) “Magnetic Resonance Imaging of Injected Bubble and Jet Dynamics in Fluidized Beds” *Presentation at the AIChE Annual Meeting, Pittsburgh, PA.*
- 15) **Boyce, C.M.**, Penn, A., Lehnert, M., Pruessmann, K.P., Müller, C.R. (2018) “MRI of Bubble and Jet Injection into Fluidized Beds”, Presentation at NETL Workshop on Multiphase Flow Science, Houston, TX.
- 14) **Boyce, C.M.**, Penn, A., Lehnert, M., Pruessmann, K.P., Müller, C.R. (2018) “MRI of Anomalous Flow upon Gas Injection into Fluidized Beds” *Poster Presentation at the Granular Matter Gordon Research Conference, North Easton, MA.*
- 13) **Boyce, C.M.**, Penn, A., Pruessmann, K.P., Müller, C.R. (2018) “Magnetic Resonance Imaging and Modeling of Liquid-Solid Fluidization” *Presentation at the 8th World Congress on Particle Technology, Orlando, FL.*

- 12) **Boyce, C.M.**, Penn, A., Pruessmann, K.P., Müller, C.R. (2017) “Magnetic Resonance Imaging of Wet Fluidization” *Presentation at the AIChE Annual Meeting, Minneapolis, MN.*
- 11) **Boyce, C.M.**, Penn, A., Pruessmann, K.P., Müller, C.R. (2017) “Magnetic Resonance Imaging of Gas-Solid Fluidization with Liquid Bridging” *Poster presented at Powders and Grains, Montpellier, France.*
- 10) **Boyce, C.M.**, Ozel, A., Kolehmainen, J., Sundaresan, S. (2016) “CFD-DEM Simulation of Hydrodynamics in Wet Gas-Solid Fluidized Beds” *Presentation at the AIChE Annual Meeting, San Francisco, CA.*
- 9) **Boyce, C.M.**, Ozel, A., Sundaresan, S. (2015) “MRI Measurements and Simulation Predictions of Gas Dynamics in a Fluidized Bed” *Presentation at the AIChE Annual Meeting, Salt Lake City, UT.*
- 8) **Boyce, C.M.**, Ozel, A., Sundaresan, S. (2015) “Agglomerate Growth and Breakup in Wet Fluidized Beds” *Presentation at the AIChE Annual Meeting, Salt Lake City, UT.*
- 7) **Boyce, C.M.**, Rice, N.P., Dennis, J.S., Holland, D.J. (2014) “Magnetic resonance imaging of gas dynamics in a fluidized bed” *Presentation at the AIChE Annual Meeting, Atlanta, GA.*
- 6) **Boyce, C. M.**; Davidson, J. F.; Holland, D. J.; Scott, S. A.; Dennis, J. S. The Origin of Pressure Oscillations in Slugging Fluidized Beds: Comparison of Experimental Results from Magnetic Resonance Imaging with a Discrete Element Model. *Chem. Eng. Sci.* **2014**, *116*, 611.
- 5) **Boyce, C.M.**, Scott, S.A., Holland, D.J, Dennis, J.S. (2014) “Practical limitations of fluid grid sizing in a 3D cylindrical DEM-CFD model” *Presentation at the AIChE Annual Meeting, Atlanta, GA.*
- 4) **Boyce, C.M.**, Holland, D.J., Scott, S.A., Dennis, J.S. (2013) “Understanding the origin of pressure oscillations in slugging fluidized beds using a discrete element model and magnetic resonance measurements.” *Presentation at the AIChE Annual Meeting, San Francisco, CA.*
- 3) **Boyce, C.M.**, Holland, D.J., Scott, S.A., Dennis, J.S. (2013) “Adapting data processing to compare model and experiment accurately: a discrete element model and magnetic resonance measurements of a 3D cylindrical fluidized bed” *Presentation at AIChE Annual Meeting, San Francisco, CA.*
- 2) **Boyce, C.M.**, Holland, D.J., Scott, S.A., Dennis, J.S. (2013) “Novel fluid grid and voidage calculation techniques for a discrete element model of a 3D cylindrical fluidized bed.” *Presentation at the AIChE Annual Meeting, San Francisco, CA.*
- 1) **Boyce, C.M.**, Holland, D.J., Scott, S.A., Dennis, J.S. (2013) “Computational modelling of fluidized beds: A 3-D cylindrical DEM-CFD model.” *Poster presented at The 14th International Conference on Fluidization, Noordwijkerhout, The Netherlands*