Fall 2021, graduate course

Multiphase Flow

Hyungmin Park

Multiphase Flow and Flow Visualization Lab.

Course Introduction

- Multiphase Flow (M2794.012400)
- Prof. Hyungmin Park
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  - Office hour: by appointment

- Major goals
  - to provide graduate students with a introductory background on the multiphase flow to assist the research in their area of interest
  - particularly emphasizing (1) the dynamics of fluid particles (solid, gas and liquid) in other medium such as the solid-gas, gas-liquid, and liquid-gas two-phase flows, and (2) the modification of the carrier phase.

Course Introduction

- ❑ Lecture note (partially contributed by Dr. Hyunseok Kim and Ms. Jungjin Lee)
- ❑ Textbooks
  - "Multiphase Flows with Droplets and Particles" by Crowe et al.
  - "Bubbles, Drops and Particles" by Clift et al.
  - "Fundamentals of Multiphase Flows" by Brennen
  - "Thermo-Fluid Dynamics of Two-Phase Flow" by Ishii & Hibiki
  - "An Introduction to Fluid Dynamics" by Batchelor
  - "Fundamentals of the Heat and Mass Transfer" by Incropera
  - Journal papers
  - Supplementary materials – **please check "eTL" frequently**

- ❑ Evaluation (tentative)
  - Attendance (10%), Homework (20%), Midterm (30%), Final (40%)

Course Introduction

- Topics to be covered (to be operated flexibly)
  - Two-phase flow formulation: conservation laws
  - Phase coupling
  - Equation of particle motion: interfacial forces
  - Conservation equation: two-fluid model
  - Bubble dynamics
  - Cavitation
  - Particle-laden flow
  - Droplet dynamics
  - Turbulence in two-phase flow

INTRODUCTION to Multiphase Flow

- What is a multiphase flow?
  - In the broadest sense, it is a flow in which two or more phases of matter are dynamically interacting
    - Distinguish multiphase and/or multicomponent
      - liquid/gas or gas/liquid or gas/solid
      - liquid/liquid
    - Technically, two immiscible liquids are "multi-fluid", but are often referred to as a "multiphase" flow due to their similarity in behavior
      - oil-water mixture flow

INTRODUCTION to Multiphase Flow

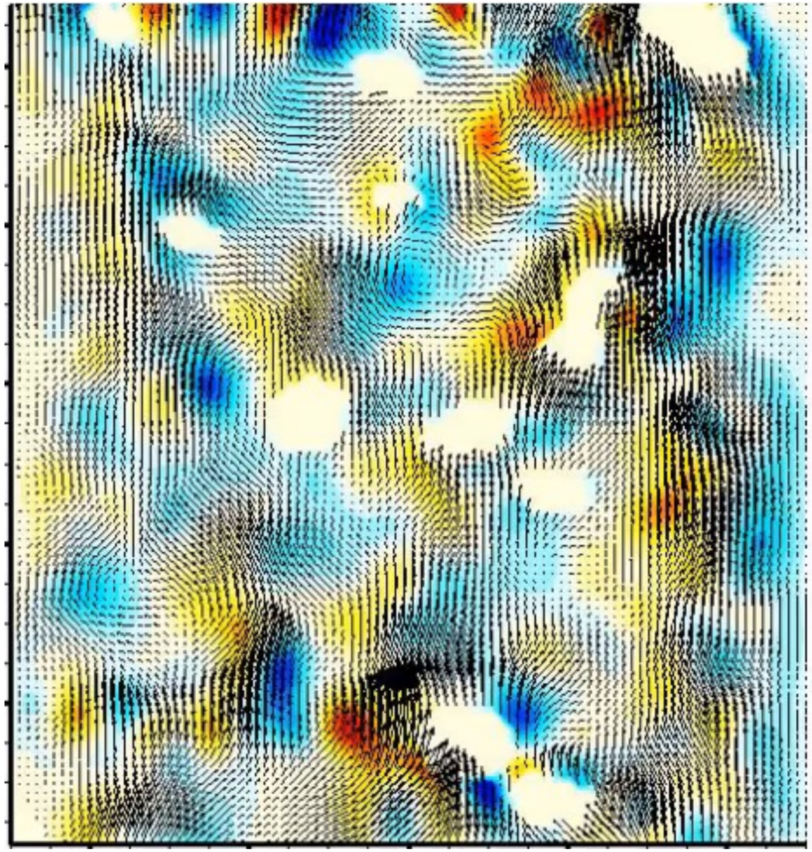
❑ Examples of multiphase flows

Multiphase Flows	Engineering Applications
Solid particles in a gas	solid rockets, fluidized beds, particle separators, clean rooms, fine dust
Liquid droplets in a gas	liquid fuel sprays, plasma sprays, atmospheric analysis
Solid particles in a liquid	sedimentation, solidification, slurries, liquid filters
Gas bubbles in a liquid	bubble columns, molten metal baths, boilers, reactors in chemical process, nuclear plant, cavitation, gas-lift system, naval vessels (ship wake), manufacturing (fabrication) process

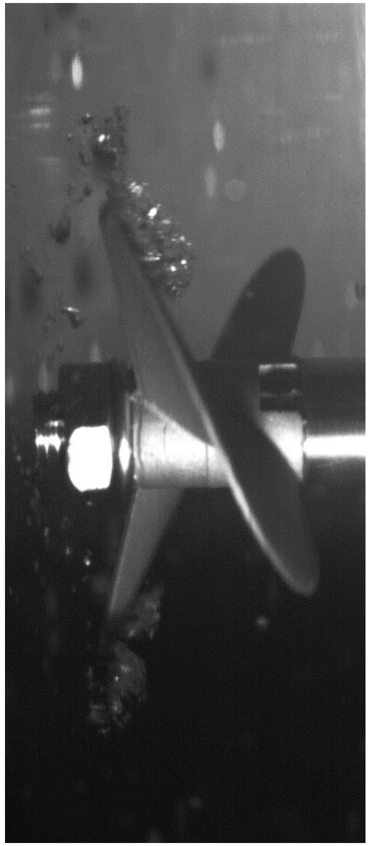
INTRODUCTION to Multiphase Flow

- Examples of multiphase flows: gas-liquid flows

Bubble-swarm flow
(Lee & Park 2020)



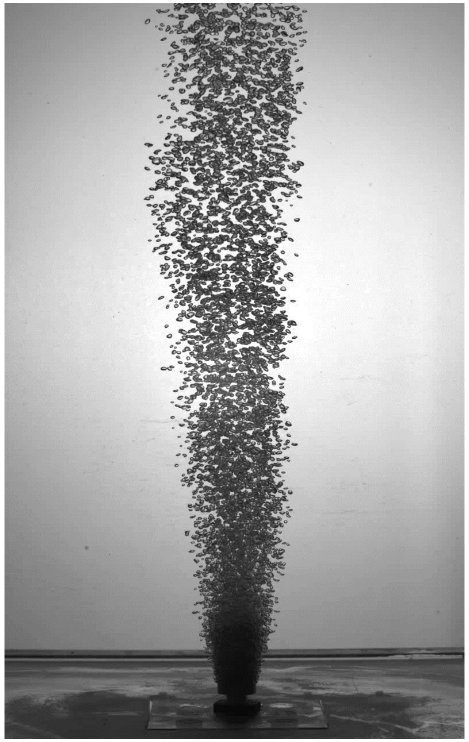
Upward bubbly pipe flow
(Kim et al. 2016)

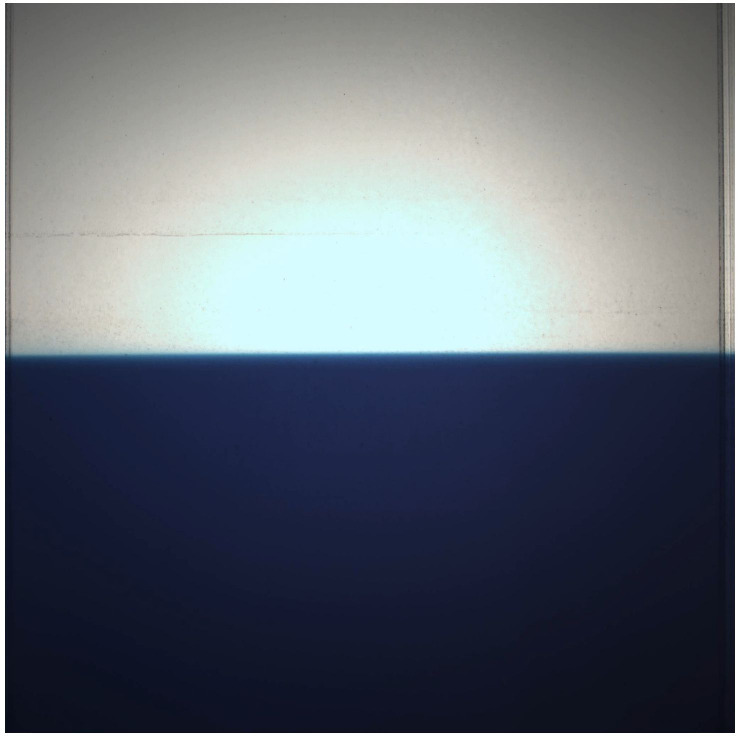


Cavitation
(Unpublished)

INTRODUCTION to Multiplase Flow

- Examples of multiphase flows: gas-liquid flows



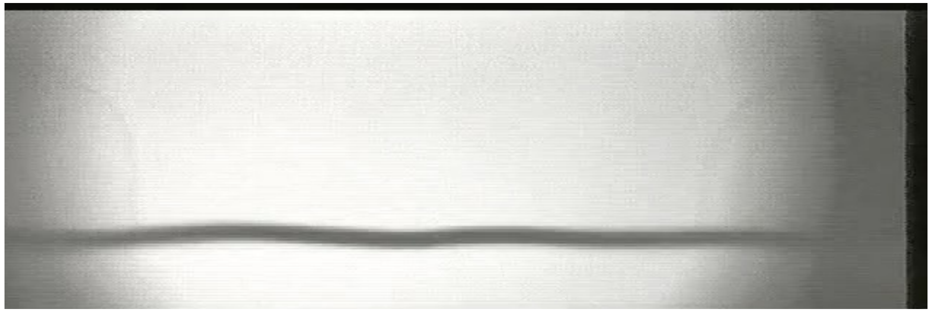


Bubble plume - mixing
(Kim, 2021)

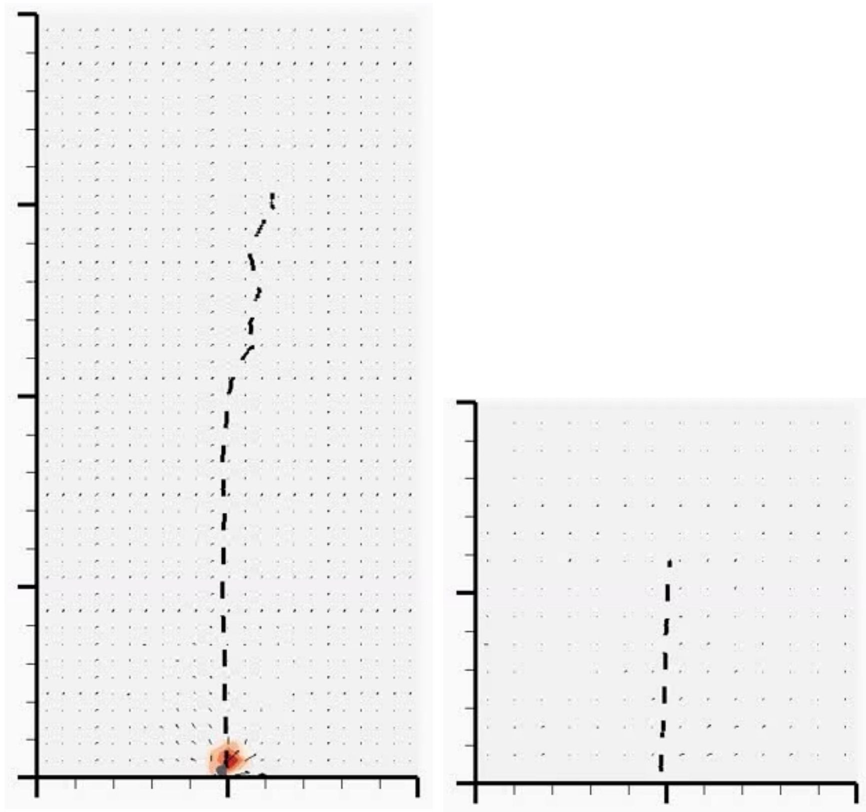
INTRODUCTION to Multiphase Flow

❑ Examples of multiphase flows: gas-liquid flows

Flow patterns in film boiling
in the rod bundle of a reactor core



Pool boiling

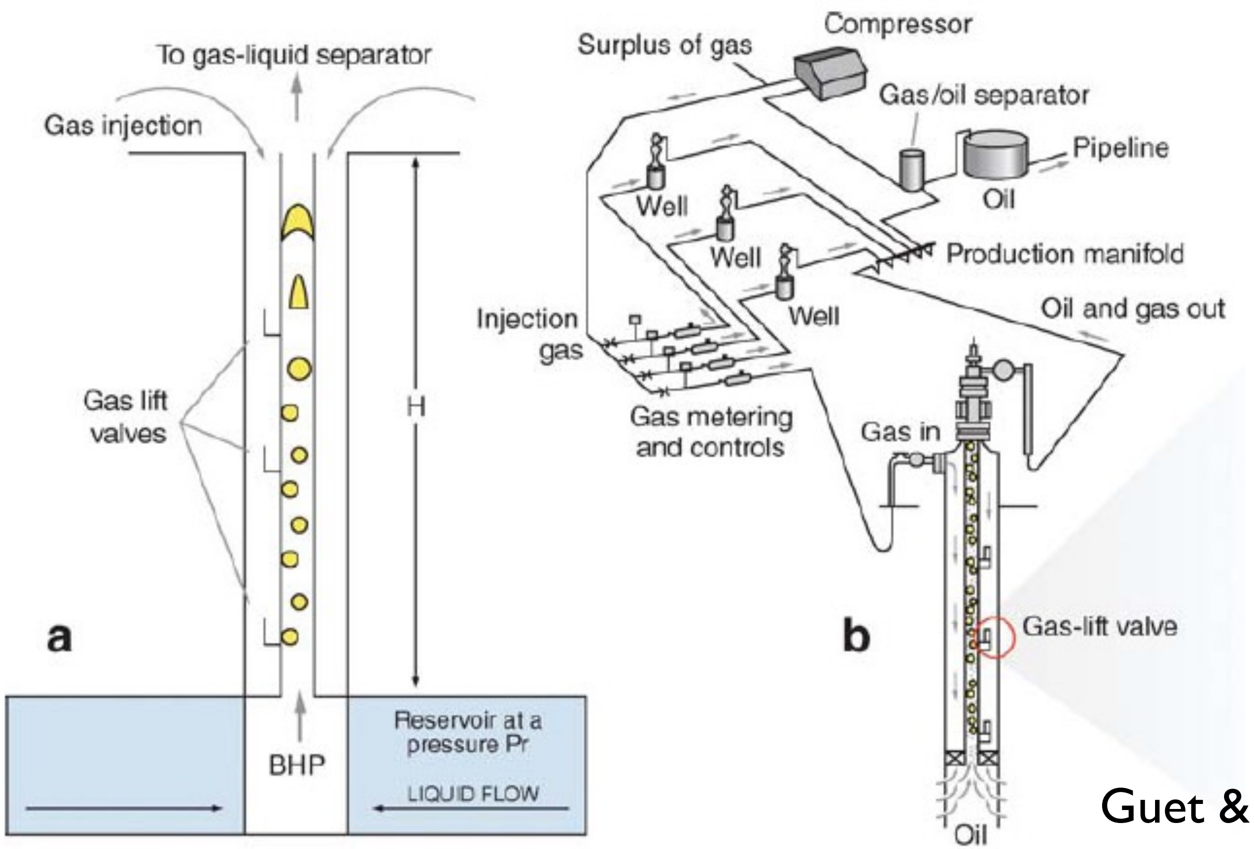


Subcooled pool boiling

INTRODUCTION to Multiphase Flow

- Examples of multiphase flows: gas-liquid flows

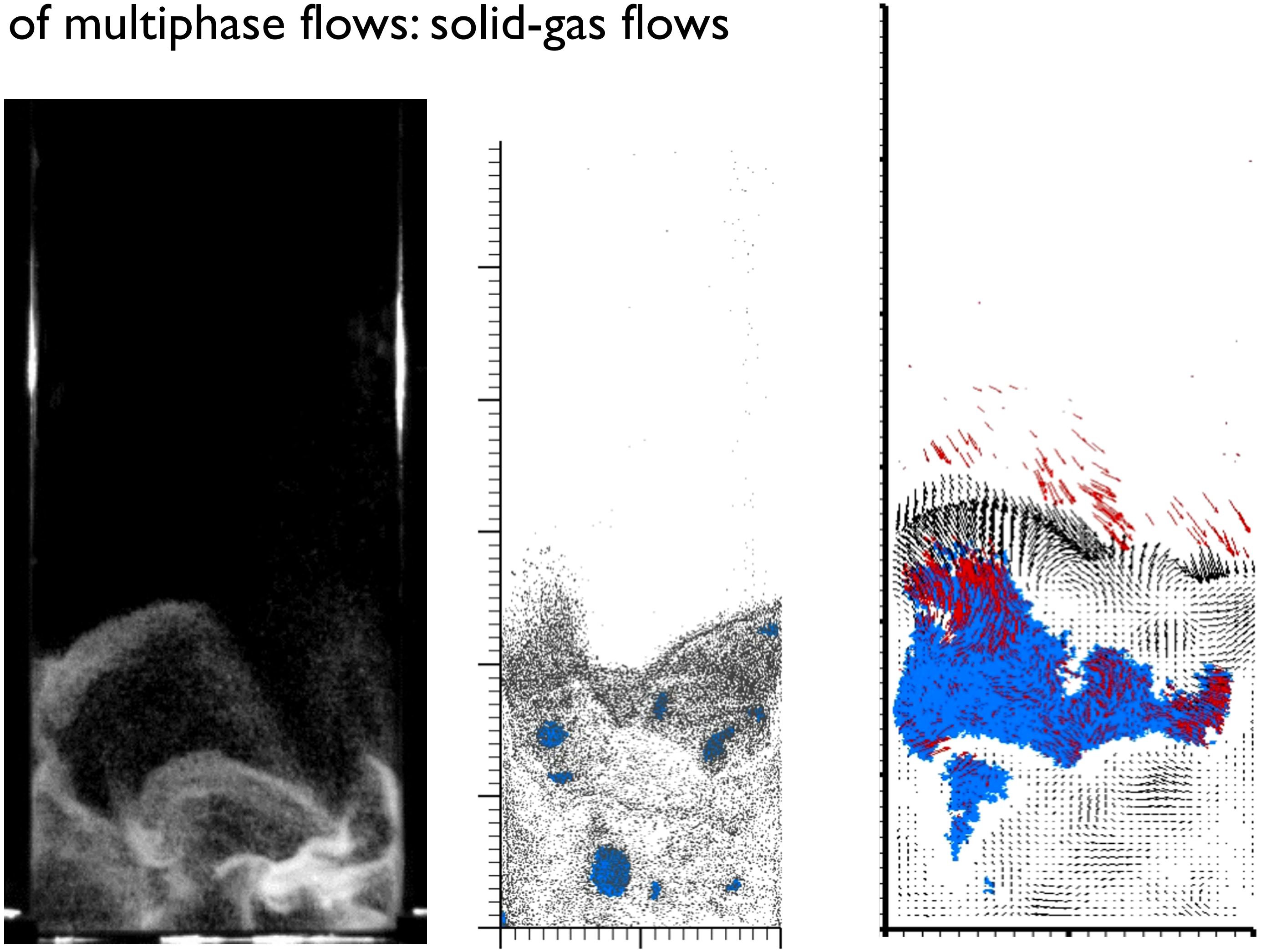
  gas-lift system: injection of gas bubbles in vertical oil wells to increase production



Guet & Ooms (2006)

INTRODUCTION to Multiphase Flow

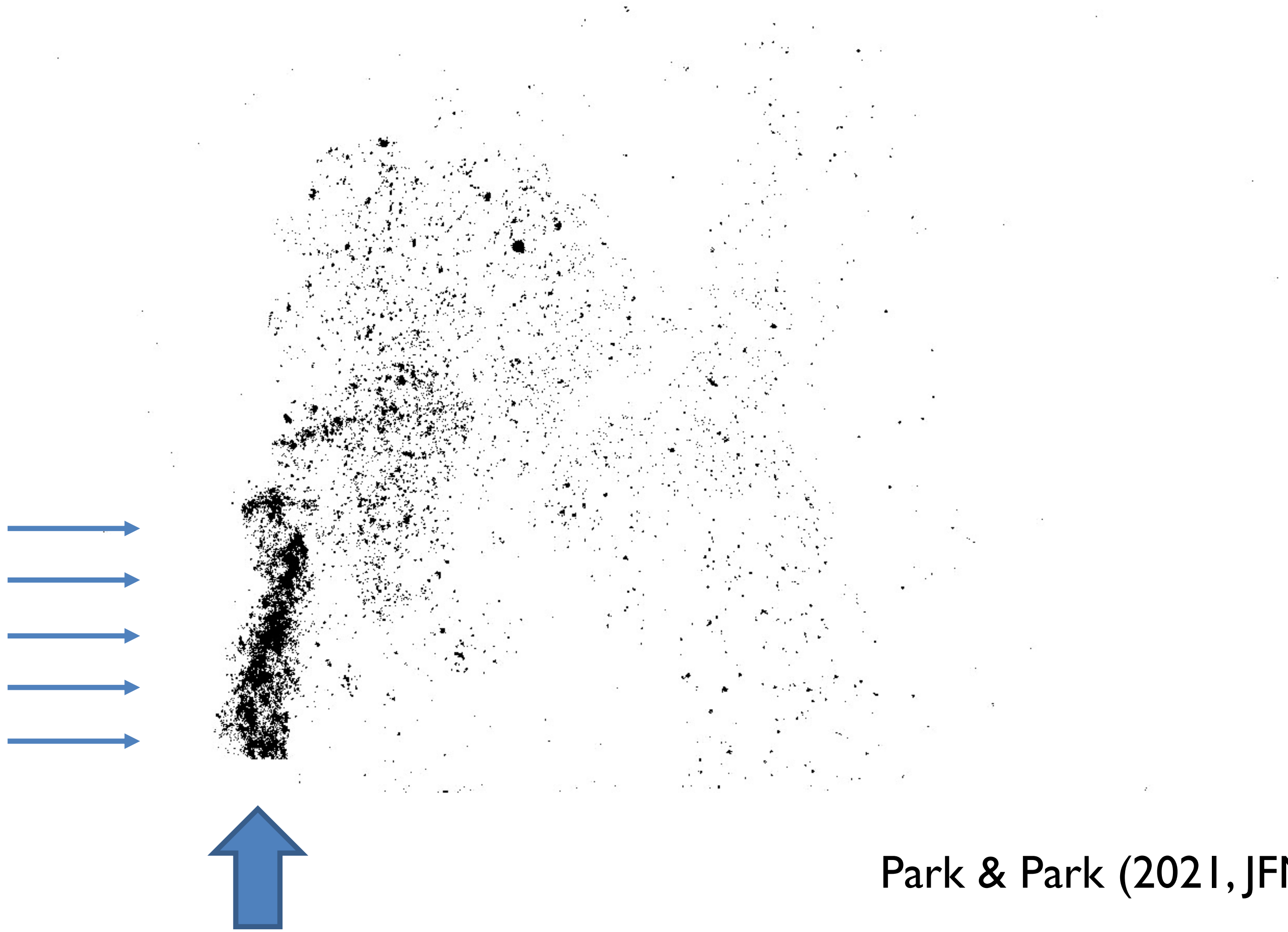
- Examples of multiphase flows: solid-gas flows



Fluidization (unpublished)

INTRODUCTION to Multiphase Flow

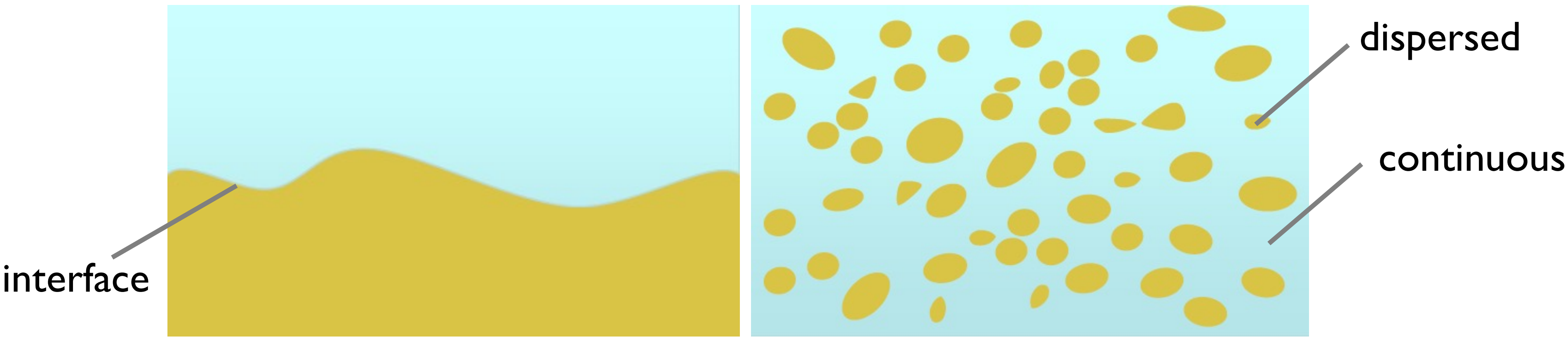
❑ Examples of multiphase flows: particle-laden jet flow



Park & Park (2021, JFM)

INTRODUCTION to Multiphase Flow

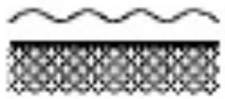
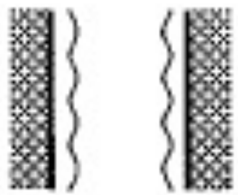
- Categorization by distribution of the components
  - separated or interfacial: both fluids are more or less contiguous throughout the domain
  - dispersed: one of the fluids is dispersed as noncontiguous isolated regions within the other (continuous, carrier) phase
    - The former is the "dispersed" phase, while the latter is the "carrier" phase.
    - geometry of the dispersion: size, morphology, volume fraction,…



INTRODUCTION to Multiphase Flow

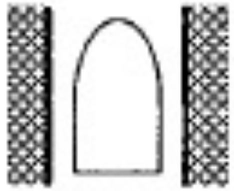
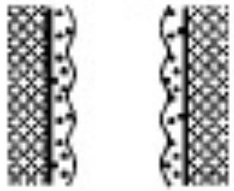
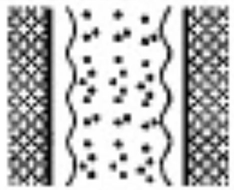
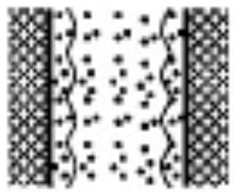
- Classification by interaction level
  - One-way coupling: sufficiently dilute such that fluid feels no effect from presence of particles. Particles move in dynamic response to fluid motion.
  - Two-way coupling: enough particles are present such that momentum exchange between dispersed and carrier phase interfaces alters dynamics of the carrier phase.
  - Four-way coupling: flow is dense enough that dispersed phase collisions are significant momentum exchange mechanism → depends on particle size, relative velocity, volume fraction

INTRODUCTION to Multiphase Flow

Class	Typical regimes	Geometry	Configuration	Examples
Separated flows	Film flow		Liquid film in gas Gas film in liquid	Film condensation Film boiling
	Annular flow		Liquid core and gas film Gas core and liquid film	Film boiling Boilers
	Jet flow		Liquid jet in gas Gas jet in liquid	Atomization Jet condenser

(Ishii & Hibiki, 2006)

INTRODUCTION to Multiphase Flow

Class	Typical regimes	Geometry	Configuration	Examples
Mixed or Transitional flows	Cap, Slug or Churn-turbulent flow		Gas pocket in liquid	Sodium boiling in forced convection
	Bubbly annular flow		Gas bubbles in liquid film with gas core	Evaporators with wall nucleation
	Droplet annular flow		Gas core with droplets and liquid film	Steam generator
	Bubbly droplet annular flow		Gas core with droplets and liquid film with gas bubbles	Boiling nuclear reactor channel

(Ishii & Hibiki, 2006)

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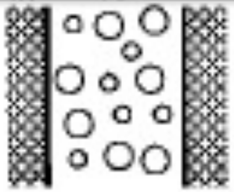
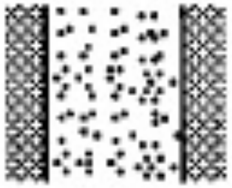
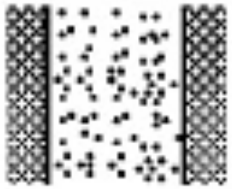
INTRODUCTION to Multiphase Flow

Class	Typical regimes	Geometry	Configuration	Examples
Dispersed flows	Bubbly flow		Gas bubbles in liquid	Chemical reactors
	Droplet flow		Liquid droplets in gas	Spray cooling
	Particulate flow		Solid particles in gas or liquid	Transportation of powder

(Ishii & Hibiki, 2006)

INTRODUCTION to Multiphase Flow

- Characteristics of multiphase flows (differences from the single-phase flows)
  - the relative concentration (spatial distribution) of different phases is usually a dependent parameter of great importance → strongly affects the flow behavior.
  - due to the density of various phases (differing by orders of magnitude, sometimes), the influence of gravitational body force is important, as well.
  - various phases possibly to have different velocities, leading to the phenomena of slip between phases and consequent interfacial momentum transfer.

INTRODUCTION to Multiphase Flow

- Characteristics of multiphase flows (differences from the single-phase flows)
  - of course, the complexity of laminar/turbulent characteristics occurs in multiphase flows as well, with the added complexity of interactions between phases altering the intrinsic laminar/turbulent flow structures.

→ a broad understanding of the thermo-fluid dynamics of two-phase flow has been only slowly developed and predictive capability has not attained the level available for single-phase flow analyses

→ It is essential that the various characteristics and physics of two-phase flow should be modeled and formulated on a rational basis and supported by detailed scientific experiments.