NETL Workshop on Multiphase Flow Research

Track 3: Liquid-Solids/Gas-Liquid Flows

--- Models, Current Status, and Future Needs

June 6-7, 2006

Track 3 contents

Track 3	Liquid-solids/Gas-liquid flows				
Chair	P. Ma (Air Products)	CoChair	R. Fox (Iowa State U.)	NETL	Isaac Gamwo
Members					
Technology and Barrier Issues	**Energy:** Fischer-Tropsch reactor, coal-slurry feeder, slurry bubble column reactors, hydrocyclones, trickle bed reactors, Absorbers, scrubber, CO_2 capture and sequestration, fuel cell, bubble column reactors, air-lift reactor				
	Others:				
Discussion Topics	• What are the modeling approaches? What can be modeled with confidence? How well are the models validated? What well defined experiments exist? What other experiments are needed? What information does the design engineers need? What short and long term advances are needed in the models? • Research Topics ○ Absorption/Desorption ○ Rate of droplets entrainment to walls ○ Effect of wall heat flux on deposition of droplets ○ slug formation and flow transition from disperse to slugging ○ Phase distribution in bubbly flows ○ topological changes at relatively sharp spatial regions ○ Interface drag and other forces such as lift force, added mass… ○ Prediction of regime transition: discrete bubble flow, dispersed bubble flow, coalesced bubble flow, slug flow, churn flow, bridging flow and annular flow. ○ Chemical reactions				

Multiphase Flows Models, Current Status, and Future Needs

Type of multiphase flow and physics	Description	Applications	Current Modeling approaches	What can be modeled with confidence	Level of validation	Further development needs
Gas-liquid flow	General gas-liquid contact reactors or equipment, usually with packing material to increase contact surface area.	Absorbers, scrubbers, acid gas removal (AGR) equipment in CO2 capture, Trickle bed reactors, Taylor flow in micro reactor channels, bubble columns, spray towers, liquid fuel combustors	VOF, dispersed phase model, Eulerian multiphase, population density model, mixture model	Packing element level small scale models to understand physics; dilute liquid phase with DPM; dilute gas phase with DPM		Bubble breakup and coalescence, slug formation and breakup; scaling
Liquid-solid flow	Slurries Bubble columns Stirred tank reactors	Coal slurry feeder, gravity assisted filtration system with fixed bed,	Single phase approximation with non-Newtonian properties, Eulerian multiphase, DPM	Mean flow patterns		Sedimentation and agglomeration; scaling
Gas-liquid-solid flows	Three phase flow reactors	Slurry bubble column reactors, bio digesters, hydrogenators, Fisher Tropsch reactors, oil sand processors	Eulerian multiphase, Two-phase approximation (gas liquid, or liquid solid)	Mean flow patterns		Experimental validation under application operation conditions (high T& P)
Gas-solid flow	Fixed bed flows and granular flows	Adsorbers, air-lift reactors, pneumatic transporters, Cyclone separators, fluidized beds, solid fuel combustors	Porous medium model, dispersed phase model if applicable, Eulerian multiphase, detailed element level model	Fixed bed reactors and adsorbers, dilute solid phase with DPM		Agglomeration,
Liquid-liquid flows	Immiscible liquids	Oil-water flows,	VOF, mixture model, Eulerian model			

Fundamental Questions
--- Laminar transport equations

- **Academic research in Eulerian multi-fluid models has focused on the laminar transport equations**
  - **Model requirement: fine grids and time-dependent flow solvers, e.g. DNS**
  - **Problems: industrial application solutions are rarely achieved in reported studies in the literature**
  - **Solution: under-resolved DNS or "uncontrolled" large-eddy simulations (LES)**

Fundamental Questions
--- Consequences of laminar flow models

- **<u>Laminar</u> state of affairs raises significant questions**
  - **Are the constitutive models used to close laminar transport equations valid over a wide range of hold up and flow regimes?**
  - **What is the "minimal" model needed to predict flow transitions?**
  - **How to reconcile the fact that laminar transport equations for G-L flows are unstable with experimental observation that homogeneous flow is statistically stationary? Missing physics?**
  - **With increasing Re, the laminar two-fluid model will generate large-scale turbulent flow. Do the flow statistics of the "numerical" turbulence agree with experimental measurements? How to validate the models?**
  - **Once the flow becomes turbulent, can it be described by statistical quantities (mean holdup, velocities, Reynolds stresses?) Is there sufficient experimental data to validate?**
  - **Is high-Re multiphase turbulent flow independent of the "molecular-scale" transport coefficients?**

Fundamental Questions
--- Industrial applications Vs. Eulerian multi-fluid models

- **Industrial applications are almost always in turbulent regime**
  - **CFD vendors offer multiphase turbulence models based on simple extensions of models for single-phase flows with additional terms for turbulence generation by momentum transfer between phases**
  - **The Eulerian multi-fluid models (even with terms added for turbulent transport) can be unstable under many flow conditions**
  - **Industrial users rely on steady-state, coarse-grid solutions for design of industrial equipment. It is very likely that results from a finer grid with a time-dependent solver would be very different**

Fundamental Questions
--- Time dependent Vs. steady state

- **Modeling time dependent flows using steady state solutions raises important questions**
  - **Is MP turbulence "universal" so that quantities such as turbulent viscosity, diffusivity, etc. can be defined in a consistent manner?**
  - **What is the "min" MP turbulence model that yields grid-independent, steady-state solutions with correct flow statistics at high Re?**
  - **Can we trust steady-state solutions found from current MP turbulence models on coarse grids?**
  - **Do we have the experimental data for high Re MP flow statistics that are needed to validate MP turbulence models? What are the technical limitations?**
  - **Do the inter-phase momentum transfer terms in Eulerian multi-fluid models have a significant effect on turbulence statistics?**
  - **Should academic research be refocused on the development of MP turbulence models instead of testing various formulations of laminar models?**

Fundamental Questions

--- "Complicating" factors of turbulent G-L flows

- **Turbulent gas-liquid flows have a number of "complicating" factors which are important for industrial applications**
  - **Bubble coalescence and breakage --- existing multi-fluid models can be used to model coalescence and breakage by adding more fluid phases. Phenomenological models are then required to describe the coalescence and breakage dynamics in terms of local turbulence quantities which cannot currently be measured experimentally**
  - **Because the effective "bubble diameter" enters the drag law, there is a strong coupling between mass and momentum balances. Experimental validation of model predictions is complicated by the fact that we currently do not have data for local bubble size distributions and turbulence statistics. Instead, a model is assumed to be "accurate" if it does a reasonable job of predicting the average local hold up**
  - **Existing literature studies rely on unvalidated multiphase turbulence models, often solved on coarse grids with steady-state solvers**

Fundamental Questions

--- Proposed modeling procedures for turbulent G-L flows

- **Suggested modeling steps**
  - **Develop and validate models with a uniform “bubble” size (buoyant particles?) over a wide range of sizes and hold up**
  - **study bubble size distributions with no coalescence or breakage**
  - **Investigate systems with coalescence and breakage**
- **Such a comprehensive research project would require long-term funding (and would not address industrial cases in the short term), but is probably the only way to proceed towards addressing these important questions**

Future Plans

- **In the short and medium term, the following numerical and computational issues can be addressed**
  - **When using the steady-state solver in a widely used CFD code to find the hold up in G-L (or F-S) flows, the mass balance for each phase is not conserved during iterations from the starting guess**
  - **Other issues such as grid dependence and the adequacy of the governing equations for predicting steady-state solutions have already been mentioned**
  - **Convergence to the steady-state solutions is often extremely slow (compared to single-phase flow) with current iterative solvers in commercial CFD codes. This situation limits the usefulness of CFD in the industrial setting for equipment design and scale up**

Industrial Perspectives

- **Solid and liquid fuel combustions are unique multiphase flows where the dispersed phase model has been successful due to the dilute nature of the dense phase**
- **Industries do few other complicated multiphase flow simulations due to**
  - **Such processes involve complicated physics, modeling requires a lot of time and effort which most of our internal customers can not afford.**
  - **Most commercially available models/codes have very limited physics that require significant simplification. Such solutions have limited usage for industrial processes. People lost faith.**

Industrial Perspectives

- **Historically, most MP modeling work was done for G-L flows started with nuclear industry. Less development for G-S flows**
  - **For all cases, underlying physical models lag industry needs**
  - **Industrial processes involve many physical laws. It is unclear which forces must be included; and if so which model can be used for what class of problems.**
- **Gas-liquid systems are simply represented by bubbly flows**
  - **How important is the modeling of other flow regimes?**
  - **How to predicate flow regime changes?**
  - **Which drag law should be used?**
- **Different numerical approaches are available for G-S flows**
  - **Are there universal approaches to move from a dilute phase to dense phase, e.g. in a recirculating fluidized bed?**
  - **How to account for particle size distribution, particle-to-particle interaction, and non-spherical particles?**

General Challenges

- **Solution speed up with code optimization and algorithm improvement to bring turn-around time to practical level for the inherently time dependent problems in multiphase flows**
- **Fundamental understanding on interface mass and momentum transfer and its impact on turbulence and flow**
- **Industry has solutions for most problems with a combination of experimental and theoretical approaches. But there is a general reluctance of sharing the knowledge**