Leading an Effective Unit Operations Laboratory

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Overview and Goals

- Highlight key aspects of the Unit Operations Laboratory course at OSU
- Summarize best practices used to effectively manage the laboratory course
- Relate how course learning objectives are realized in the execution of the course
- Provide an example of resources for students and teaching assistants for one selected experiment

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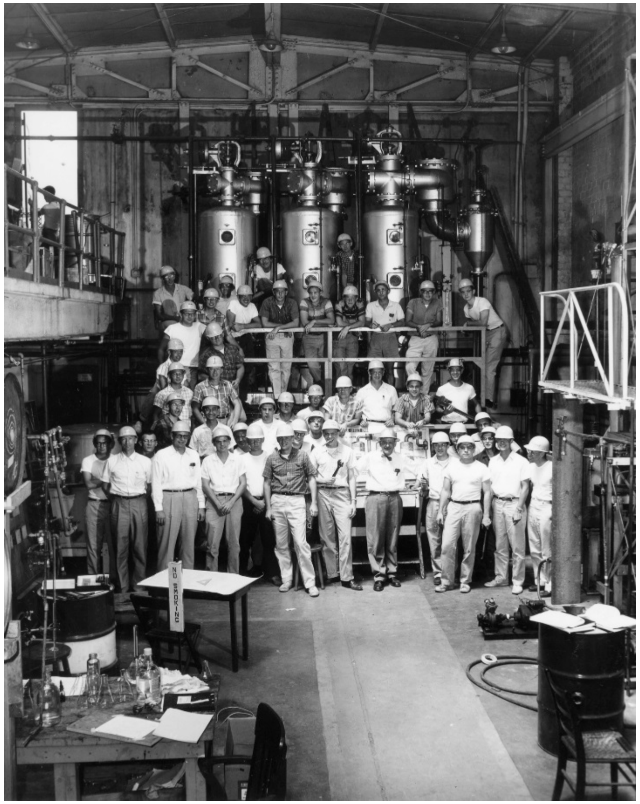
Unit Ops at Ohio State

- Two semester-hour course
- Two sessions required for graduation
- Fourteen (14) experiments
- Three (3) thrusts (Classical, Environmental, and Biological)



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Unit Ops Experiments

Classical

Distillation

Liquid/Liquid Extraction

Plug Flow Reactor

Gas-Solid Fluidization

Shell and Tube HX

Biological

Plate Heat Exchanger

Gas-Solid-Liquid Fluidization

Adsorption

Multiphase Mixing Dynamics

Environmental

Continuous Stirred Tank Reactor

Absorption

Reverse Osmosis

Hydrogen Fuel Cell

Circulating Fluidized Bed

Unit Operations Lab Safety

- Safety is paramount in the lab
- When experiments are active, appropriate personal protective equipment (PPE) is required for entry to the lab
- Students, Teaching Assistants, and Professors must complete seven Environmental Health and Safety (EHS) modules prior to participation in the first lab
- Two lectures per semester are devoted to safety topics, including demonstration of a fire extinguisher
- Students are evaluated on safety performance throughout the semester, with part of the grade devoted to safety
- A safety audit is performed by groups one week in the semester, with submission of a written report

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Unit Ops Course Components

- Laboratory reports
- Group presentation
- Group safety audit
- Individual safety performance
- EH&S training modules
- Lectures and quizzes
- Comprehensive final exam

Unit Ops Group Assignments

- Students groups of 4 or 5
- New students get an overview of the experiments on the first Friday of the semester
- New students fill out a focus selection form
  - Primary and secondary experimental thrusts
  - Conflicts (dates and people)
- Data gets compiled and groups are formed based on a complex algorithm
- Groups divided into one of 4 rotations
- Comprehensive schedule with group assignments published the second week of the semester

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Laboratory Assignments

- Preliminary Assignment
- Pre-Lab Quiz
- Experimental Summary Report
- Laboratory Report
- Post-Lab Quiz
- Group Assessments
- TA Assessment

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Laboratory Report Sections

- Abstract
- Purpose
- Introduction
- Experimental Description
- Discussion of Results
- Error Analysis
- Conclusions
- Recommendations
- Design Extension

1. Title Page, Contents, Notation, References, Appendices	/5
2. Abstract	/5
3. Purpose	/5
3. Introduction (Theory)	/15
4. Experimental Description	/10
5. Discussion of Results	/20
6. Error Analysis	/15
7. Conclusions	/5
8. Recommendations and Future Work	/5
9. Design Extension	/10
10. Experimental Summary Report	/5
CONTENT SUBTOTAL	/100
FORMAT DEDUCTIONS	- /14
TOTAL	/100

Course Learning Objectives

1. Plan efficient laboratory experiments to collect relevant data while minimizing error
   - Achieved by the preliminary assignment submission
2. Design and conduct experiments in the laboratory
   - Achieved by time spent in the lab on assigned Fridays
3. Compare experimentally measured results with literature data and quantify the sources of error that contribute to differences between measured data and literature data
   - Achieved by work on the laboratory report
   - Error analysis and error propagation details summarized in lecture and applied in lab reports

Course Learning Objectives

4. Prepare high quality written reports and oral presentations to summarize a project in a professional manner
   - Achieved by submission of laboratory reports
   - Achieved by oral presentation at the end of the semester
5. Practice effective group dynamics
   - Achieved throughout the semester as students navigate the challenges associated with diverse groups
6. Apply safe laboratory practices important in the chemical industry, including laboratory safety protocols, interpretation of material safety data sheets (MSDS), and proper handling, storage, and disposal of chemicals
   - Achieved by participation in the laboratory sessions and supplemented with safety lectures

Teaching Assistant Resources

- Teaching Assistant Manual
- Old laboratory reports (good and bad)
- Instrumentation manuals and background
- List of key topics, pre- and post-lab questions, and concepts on which to quiz students
- Group training session
  - Expectations
  - Code of conduct with respect to students
- Individual training sessions
  - Experimental protocols and procedures
  - Safety procedures

Student Resources

- Operating Procedure (OP)
- Laboratory report rubric
- Lecture on teamwork skills
- Example reports

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Example Experimental Details

- Gas-Solid Fluidization (GSF) experiment
  - 8 reference documents posted on course portal
  - Detailed operating procedure
  - MOV file with equipment in operation

E-6 GS Fluidization: Objective

The objective of Gas-Solid Fluidization experiment is to determine the basic properties which control the flow regimes of a gas-solid fluidized bed and develop an understanding of the principles of fluidization.

The main goal of this lab is to study fluidization of solids having different particle sizes and densities. The various aspects to be studied include, but are not limited to, pressure drop in a packed bed and fluidized bed, fluidized bed height, minimum fluidization velocity, minimum bubbling velocity, and terminal velocity. The porosity of a packed bed, the solid density, and weight of the solid will be experimentally determined.

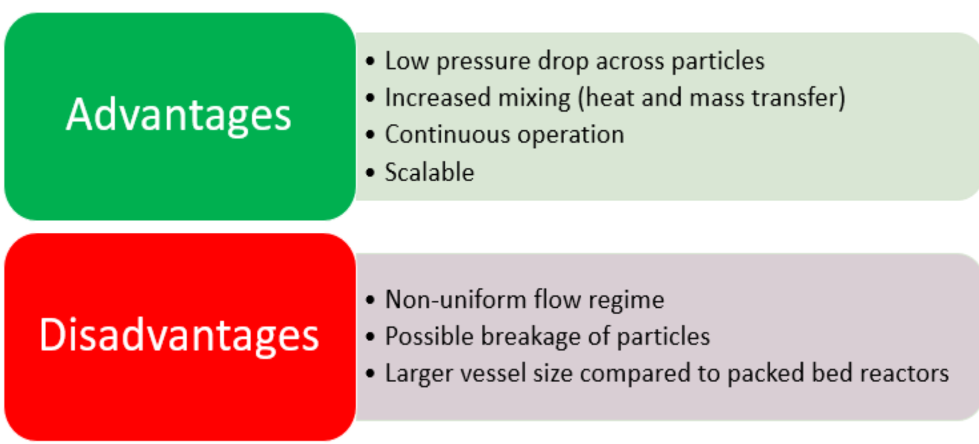
E-6 GSF: Industrial Relevance

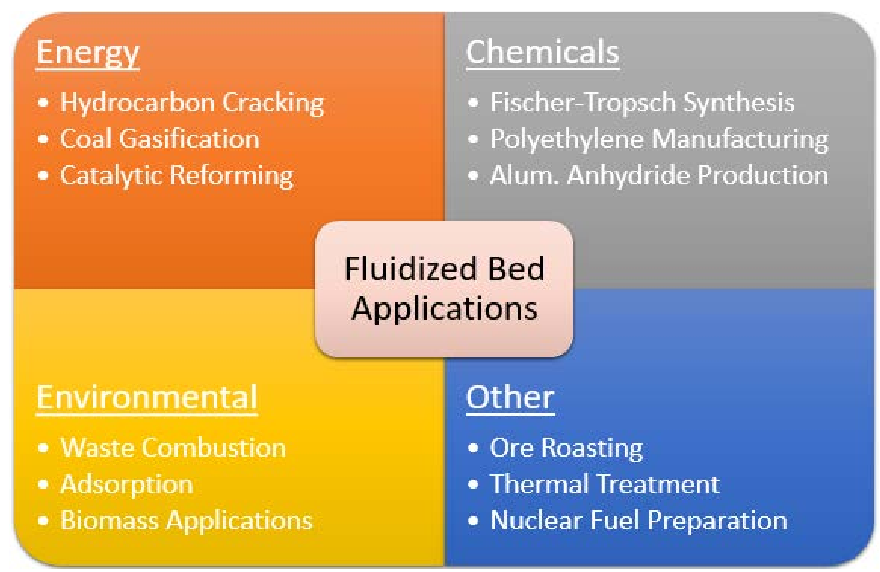
Fluidized beds offer enhanced heat and mass transfer relative to other reactor types

This can be critical to successful conversion of a reactant with catalyst particles (heterogeneous catalysis)

Fluidized beds are often used in the oil industry for catalytic cracking of hydrocarbons (gasoline production)

Fluidized beds are also used in freeze drying of food products





Figures courtesy of Lab Group 6, Spring, 2016 (Kimmel)

E-6 GS Fluidization: Theory

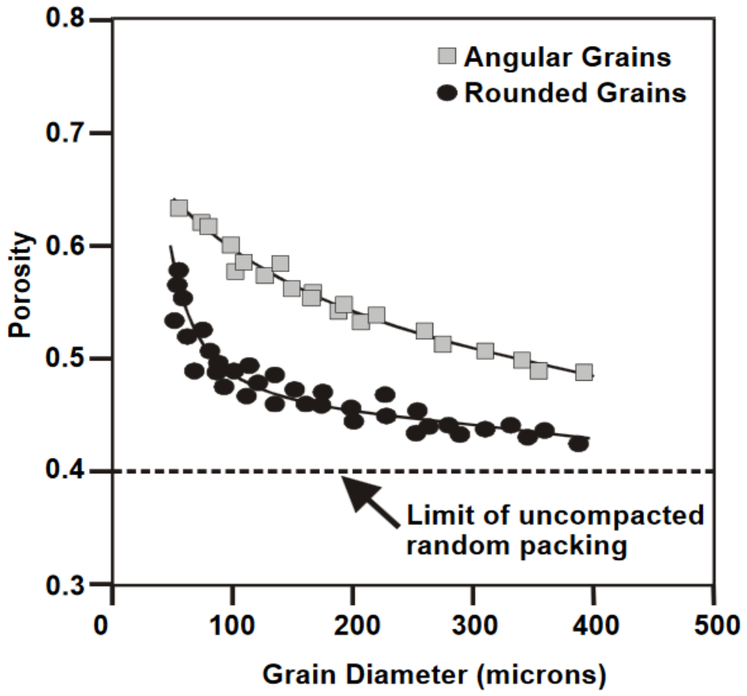
Pressure drop through a packed bed can be predicted from the Ergun Equation

$$f_P = \frac{150}{Re_P} + 1.75$$

$$\epsilon = void\ fraction = \frac{voids\ volume}{total\ volume}$$

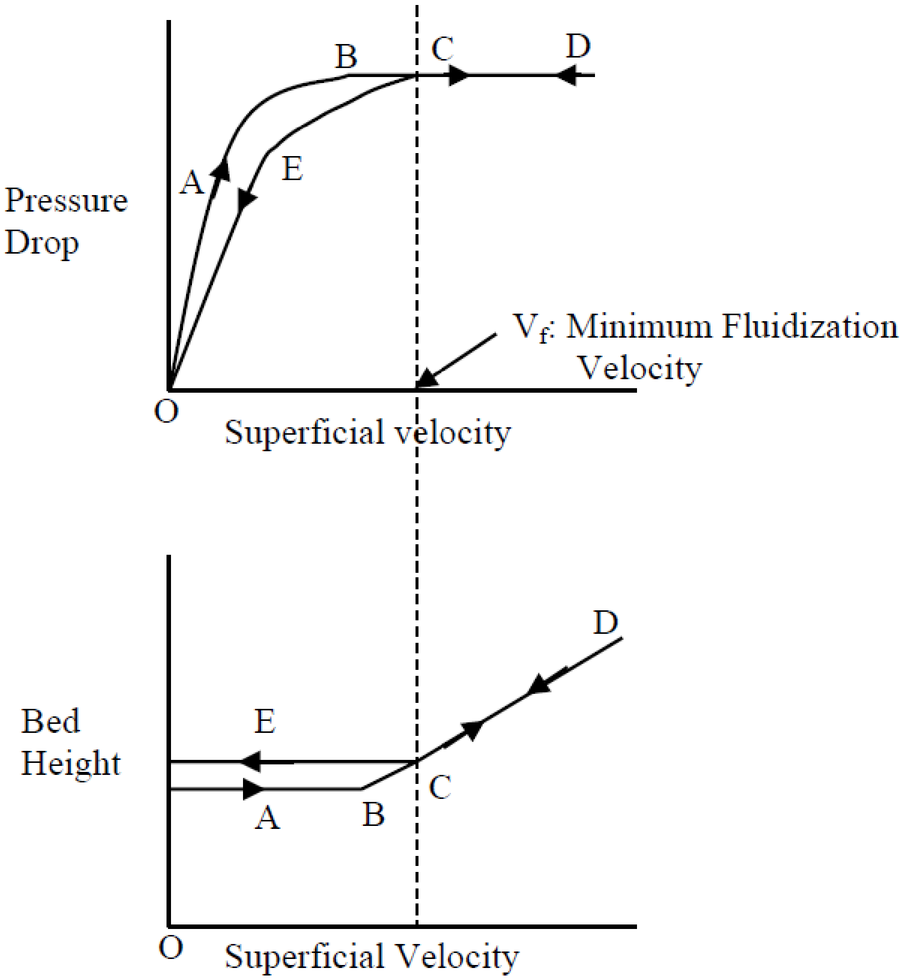
$$\frac{\Delta P * D_P {\varepsilon_g}^3}{L\rho_g v_S^2 (1-\varepsilon_g)} = \frac{150}{\frac{D_P v_s \rho_g}{\mu(1-\varepsilon_g)}}$$

Porosity and shape of the particles play a role in bed performance



E-6 GS Fluidization: Theory

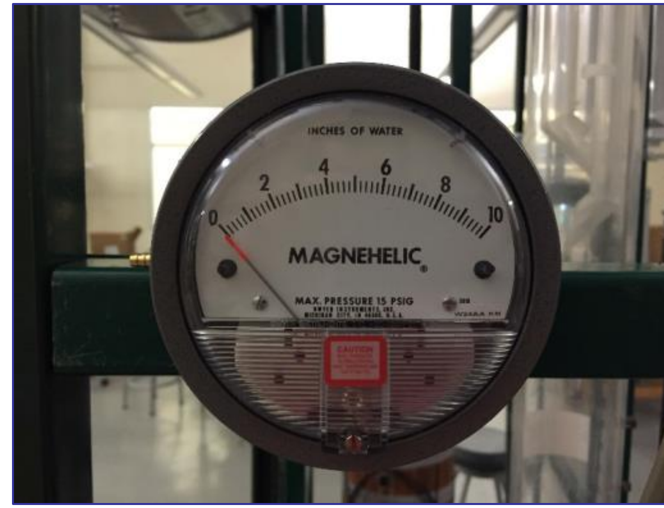
- Ideal behavior for a packed bed is shown as a function of the superficial velocity
- Columns are sized based on the superficial velocity and the terminal velocity



$$V_{om} \approx \frac{g(\rho_p - \rho)}{150\,\mu} \frac{\epsilon_m{}^3}{1 - \varepsilon_m} \Phi_s{}^2 D_p{}^2$$

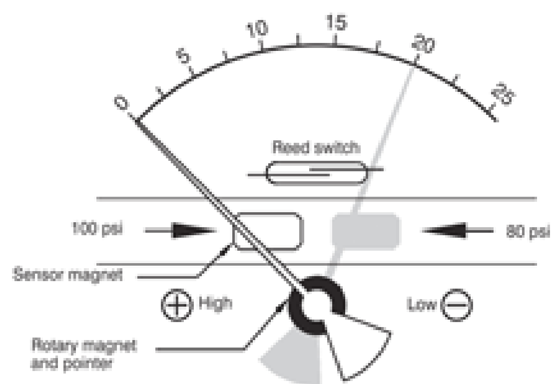
$$V_t = \sqrt{\frac{2g(\rho_p - \rho)m}{A_p \rho_p C_D \rho}}$$

E-6 GS Fluidization: Instrumentation



- Magnehelic differential pressure gauge
- Differential pressure gauge that measures the static pressure
- Differential pressure can be positive, negative, or zero
- Commonly used in HVAC applications (fan and blower pressures, can get linear velocity in conjunction with a Pitot tube)

Magnehelic principle is patented by Dwyer (air pressure transmitted to indicator using magnetic linkage only) and results in less wear on the internal components of the gauge



Summary

- Identifying and implementing best practices is an ongoing challenge for the Unit Operations Lab at OSU
- Learning objectives for the course are achieved using a combination of lectures, lab sessions, overview sessions, and other supplemental assignments
- Highlights of the approach used by OSU have been summarized, with advantages and disadvantages highlighted
- OSU staff welcome feedback on what works and does not work at other universities
- More details on the rubrics, evaluation forms, and other resources are available in the proceedings and will be willingly shared

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