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Work-in-Progress: Expanding Use of Affordable Transport Equipment — Fluidized Bed with Applications for Bio- and Chemical Catalysis

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Abstract

This paper reports on the development of a new fluidized-bed desktop learning module for chemical engineering students. This new module will supplement a set of existing modules developed by our group in the fluid mechanics and heat transfer domains. Packed bed/fluidized bed instruction appears in most chemical engineering curricula, but hands-on exposure is usually relegated to senior-level unit operations laboratories if the equipment is available at all. We have developed a simple system with manometer ports for understanding pressure losses in particle beds; our system can eventually be used for safe low-low temperature catalytic processes that can be visualized with a color change. Classroom implementation strategies, accompanying conceptual-reinforcement materials, and motivational strategies will be presented.

Introduction

Students learn in many ways. Over the past two decades, many studies have shown a connection between student learning and being actively engaged with the topic with the help of learning material [1]–[3]. Freeman's analysis of student performance in undergraduate STEM disciplines showed that students are 1.5 times more likely to fail when they are only exposed to verbal lecturing [3]. The focus of learning is slowly shifting towards more student-centered learning and away from instructor-centered learning as pedagogies broaden.

Several important unit operations covered in the chemical engineering curriculum involve packed or fluidized beds where surface interactions of solids and fluids are very important. Fluidized beds are commonly used in industrial applications such as surface coating, catalytic cracking, heat transfer, adsorption, and combustion [4]. Packed bed and fluidized bed principles can be reinforced by classroom activities such as experiments to help students better understand these processes [5]. Depending on the curriculum, students initially learn about packed/fluidized bed phenomena in the sophomore or junior year. If they ever have a chance, they experience hands-on learning with a fluidized bed in their senior year unit operations laboratory course. Unfortunately, some institutions are not able to afford this costly laboratory equipment and install it in a space where students can benefit from hands-on learning.

Over the past years, our team has worked on learning tools that can fit onto a classroom desk and operate efficiently to demonstrate important concepts in fluid mechanics and heat transfer. These learning tools are called Low-Cost Desktop Learning Modules (LCDLMs). Four of our previously developed LCDLMs, including a shell & tube exchanger [6], a double pipe heat exchanger [7], a venturi [8], and a hydraulic loss unit [9] have been successfully implemented in many classrooms at a variety of institutions in the US. Our previously developed LCDLMs provide valuable insights on improved student learning as well as to grasp misconceptions in related topics for continuous improvement of these tools [10]. Figure 1a & b showing students using a previously developed LCDLM, a shell & tube heat exchanger. LCDLMs, are useful tools to promote hands-on learning in a classroom because they are small and easy to carry, install, and use as they do not require larger laboratory spaces and can be acquired at low cost [10].

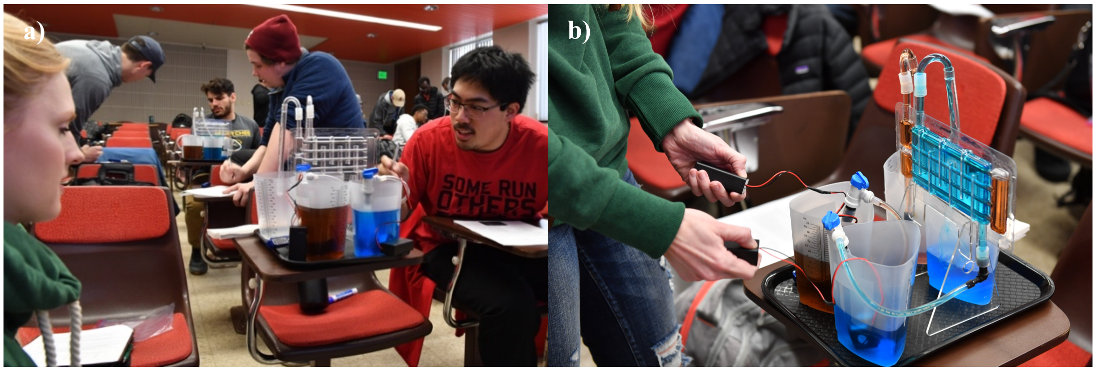

Figure 1. (a &b) *Students at Washington State University (WSU) using the shell & tube LCDLM.*

To expand this active learning pedagogy, we continue to develop new tools. Starting from January 2022, our group has worked to develop a new LCDLM to demonstrate packed/fluidized bed concepts. The new fluidized bed (FB) DLM is designed for visualization of pressure drop and bed height changes as the fluid passes upwards through the column.

In this paper, we present the construction protocol and the testing of this learning tool, the preparation of accompanying learning materials developed to date, classroom implementation plans, assessment strategy, a preliminary analysis of student learning gains and which will be further analyzed by the time of the ASEE Work-In-Progress presentation, and future directions for continuous improvement.

Fluidized Bed LCDLM

Design, Development and Testing of the Fluidized Bed LCDLM

The FB DLM is designed to help student conceptual learning as well as promote active learning of packed bed and fluidized bed theory in a normal classroom. This new module has been constructed from mostly off-the-shelf hardware. Construction of the FB DLM requires minimum additional modifications to the purchased hardware such as drilling holes in the PVC piping, cutting and inserting a mesh, filling the column with beads, connecting the manometer tubes, mounting the setup onto a vertical white Plexiglas panel, and assembling a pump. A schematic of FB DLM is shown in Fig. 2 with its dimensions defined.

We will work on preparing instructional videos on how to construct and assemble this FB DLM on our group's YouTube channel to help people who would like to construct this FB DLM for their classroom use or their learning purposes. Construction of the complete module costs approximately $100, which makes this tool more likely to be adapted by instructors/institutions because of its affordability. The low-cost approach eliminates costly laboratory equipment handling and installation by providing an excellent opportunity for those students who lack hands-on learning.

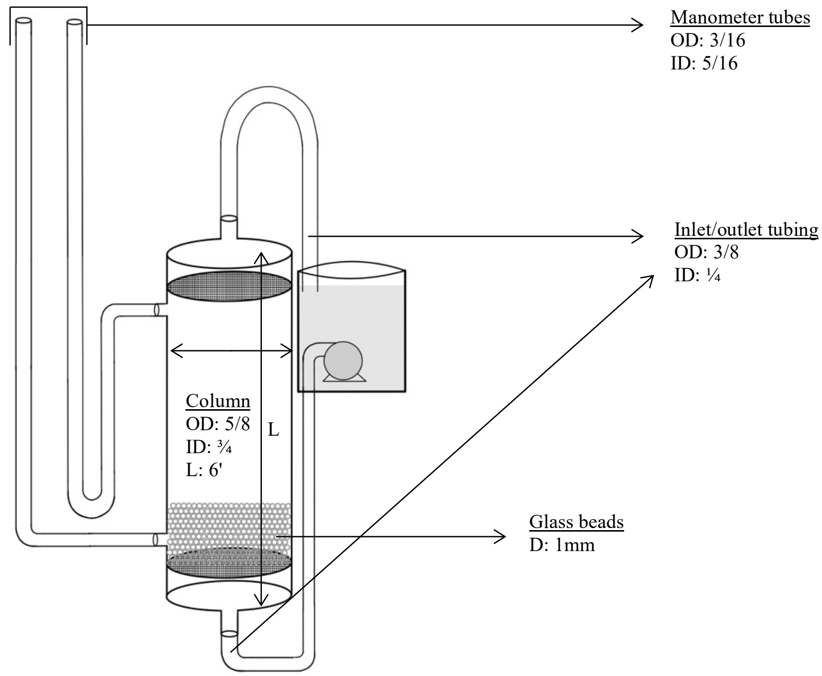

Figure 2. *FB DLM scheme and its dimensions.*

Laboratory testing of the FB DLM used a transducer for pressure measurements and a pump connected to a variable electrical power supply for adjusting the water flow through the column. In the laboratory testing, a calibrated differential pressure transducer was connected between pressure taps at the bottom and top of the column to measure the pressure drop across the column. For accurate testing of the FB module in the laboratory, voltage values from the transducer were recorded for different flow rates. This laboratory testing is different from the classroom setup. The classroom setup uses manometer tubes instead of a transducer to measure pressure drop across the column. In addition, the pump is powered by a 9V battery instead of an adjustable electrical power supply, requiring flow rate adjustment with a valve. Figure 3 shows the FB DLM setup for classroom use including manometer tubes and battery-operated pump installed.

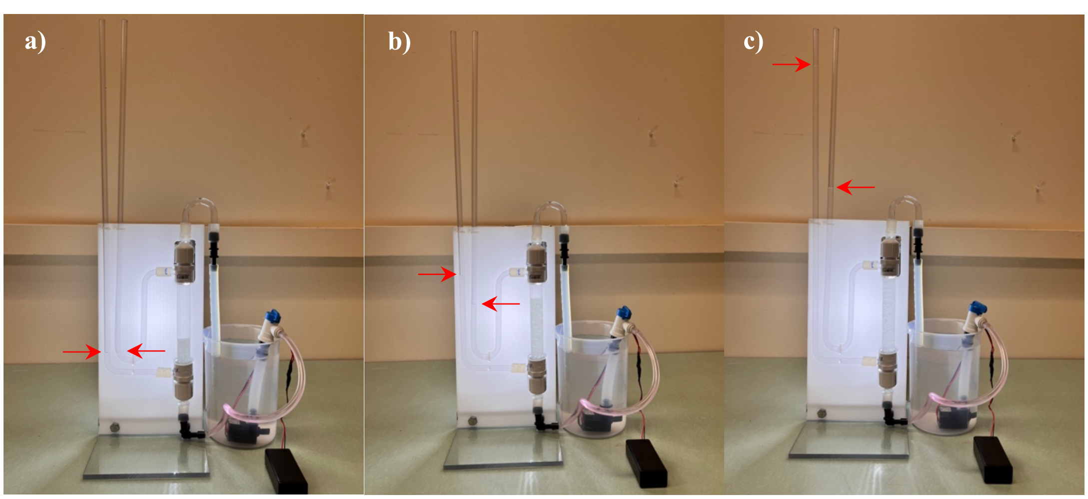

Figure 3. *Fluidized bed LCDLM showing different pressure drops (a) Packed bed (b) Fluidized bed (c) Re-packing.*

The Ergun equation explains the relationship between the pressure drop across the bed as a function of particle properties, bed properties, fluid properties, and column properties. The same dimensions of the column and properties of the fluid were used with the Ergun equation (see Equation 1 below) to find the theoretical values of pressure drop for the same range of flow rates as the experimental setup. Theoretical and experimental results will be compared in the result section.

Ergun Equation:

$$\frac{\Delta P}{L} = \frac{150 V_0 \mu}{{\Phi_s}^2 {D_p}^2} \frac{(1-\varepsilon)^2}{\varepsilon^3} + \frac{1.75 \rho {V_0}^2}{\Phi_s D_p} \frac{(1-\varepsilon)}{\varepsilon^3}$$

Where ΔP is the pressure drop; L is the length of the column; V_0 is the superficial velocity; μ is the viscosity of the fluid; ε is the bed porosity; D_p is the particle diameter; ρ is the density of the fluid.

Results of Fluidized Bed LCDLM

Pilot experimentation with the FB DLM showed that this miniaturized tool can demonstrate the pressure drop when the bed is packed. As minimum fluidization velocity is reached, the module is able to show a constant pressure drop for the fluidized bed. Above a certain flow rate, the module is able to repack some particles at the top of the column to bring about a high-pressure drop. The miniaturized FB DLM experimental results and theoretical calculations are compared in Figure 4. The fluidization concept, explained by the Ergun equation, renders theoretical results (see the black line in Figure 4). In the laboratory setting with the benefit of an electrically operated pump, a transducer generated the experimental values indicated by the red line in Figure 4. Figure 4 shows the theoretical and experimental values are quite close.

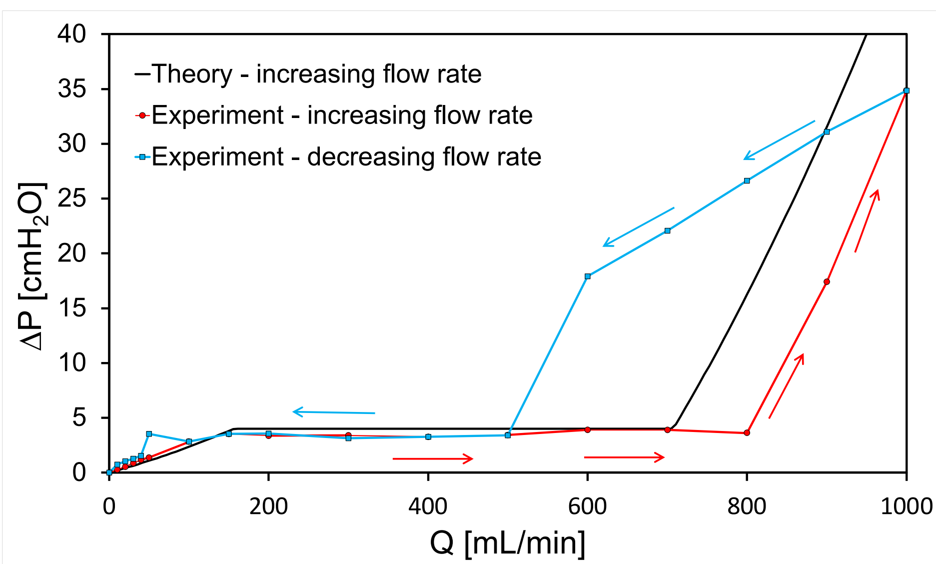

Figure 4. *Pressure drop data from increasing and decreasing flow rates in a bed filled with particles and theoretical pressure drop values from increasing the flow rate.*

As the pump reaches its maximum power at approximately 800 mL/min, some, but not all, of the particles are repacked at the top of the column. As shown by the exponential trend reflected as the red line in the last third of the plot, this repacking of some of the particles results in a higher pressure drop compared to the pressure drop in the packed bed. The blue line indicates data from experimental pressure drops that resulted from decreasing the flow rate.

A decreasing flow rate causes some of the repacked particles to be retained at the top. However, some of the particles descend and leave a clear gap in between the repacked particles at the top and those below. This effect is called hysteresis. There are several deviations for lower flow rate ranges. These deviations may arise because the pump that was used for lower flow rate ranges was a syringe pump for the increasing flow rate. Then, a shift to a centrifugal pump connected to an electrical power supply was needed for higher flow rate ranges. The blue blip on the plot reflects why the measurement of the lower ranges was not very accurate – the centrifugal pumps range for lower flow rates is not accurate. More data points will be collected to obtain more accurate results in future experiments.

Classroom Implementation, Data Assessment and Dissemination of Fluidized Bed LCDLM

Consent Form, Pre- and Posttest Assessment, Classroom Worksheet, Pre- and Post-Homework and Motivational Survey

This FB DLM initially will be tested in a classroom for the first time in Spring 2023 at Washington State University (WSU). A faculty member from the Chemical Engineering Department will be our first collaborator for the student data assessment. Student data will be collected in a similar manner to our group's previous data assessment on different DLMs [10]. Measurements of student learning will be collected by surveys approved by the WSU Institutional Review Board (IRB). These surveys are labeled Pre- and Posttest. Grading of these surveys will use anonymized codes assigned for each student's name as well as not knowing the answers that pertain to the Pre- or Posttest to prevent potential bias in grading. Then, the graded surveys will be separated as Pre- and Posttest for assessment. Usually, student data is collected in one year with the hands-on activity and the next year without the hands-on activity to compare the hands-on activity usefulness with a control group. But since Spring 2023 will be the first year of this FB DLM implementation, data assessment will be slightly different than how we usually do. Just for this first year of implementation, to be able to compare the hands-on survey results with a control group, assessment of the learning of 45 students will be planned to follow the steps shown in Table 1:

Table 1. *Implementation plan steps for fluidized bed LCDLM.*

Implementation Plans
1. Students will give consent with a consent form
2. Students will take Pretest without being exposed to any lecture on the packed bed/fluidized bed topic
3. Professor will lecture per usual
4. Students will take Posttest 1 after the lecture
5. Next class, FB DLM experimentation will be conducted over 50-mins of class time
6. Students will take Posttest 2 after the FB DLM experiment

Pretest vs Posttest 1 data will be kept as our control and Pretest vs Posttest 2 data will help us to understand if the FB DLM activity has a positive impact on student learning on the related topic. In addition to that, Posttest 1 and Posttest 2 comparisons will help us to see if this tool is beneficial for student learning compared to verbal-only lectures. Since this tool will be used for the first time in Spring 2023, pilot testing is expected to provide some ideas to enhance the implementation strategies as well as to modify classroom materials associated with the DLM activity. In this first year of assessment, Pre and Posttest will include an open-ended question to determine the most common misconceptions in this topic and will help us to shape this activity parallel with student needs. We are not planning to keep the open-ended question in the following years but only for this first year, our focus will be on identifying student misconceptions to work on module enhancement for upcoming years.

We will work on the classroom materials to be used during the implementations. We will develop a worksheet to design experiments that can reasonably be conducted with the use of FB DLM activity during a 50-min class time. The sample worksheet is shown in Figure 5. The student learning objectives shown in Table 2 will be refined to their final form as we keep working on classroom implementations. We are considering giving students pre- and post-homework. We might assign students a pre-homework prior to FB DLM implementation and a post-homework as we complete the classroom experiment to reinforce the concept being taught.

Table 2. *Worksheet learning objectives for fluidized bed LCDLM.*

Student Learning Objectives
Students should be able to:
1. explain why a packed bed becomes fluidized;
2. explain the different contributions to pressure drop in the packed bed;
3. explain the meaning of the minimum fluidization velocity; and
4. compute the pressure drops (ΔPs) across the bed.

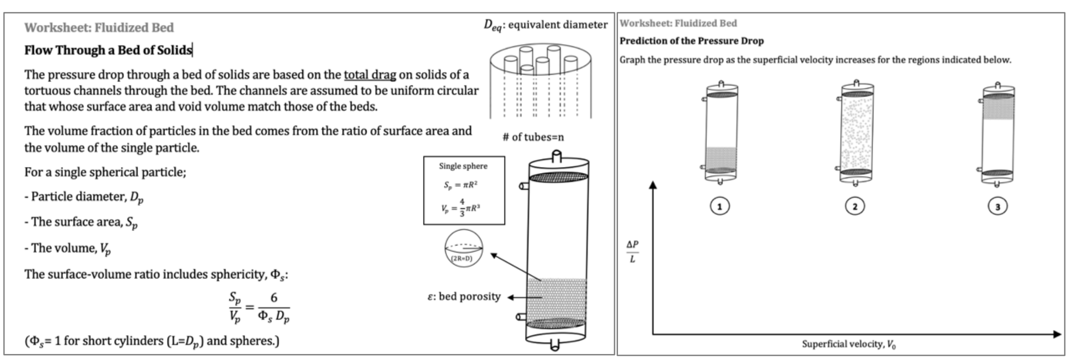

Figure 5. *Sample worksheet for fluidized bed LCDLM*

We will also prepare a motivational survey to assess the quality of cognitive engagement which refers to measure how much attention and commitment a student has toward learning [11]. The motivational instrument was adapted from a psychometrically validated ICAP [12] framework that allows to make claims to measure student cognitive engagement in these activities [11]. This information will help us to shape our learning activities to meet student needs.

In this first year, both assessments of IRB-approved surveys, and the worksheet, our focus will be on identifying student misconceptions and determining how to repair these misconceptions will help us to focus our repairs on the most important concepts in this topic. As we reiterate our classroom implementation strategies, we plan to implement this module across the country at different institutions. Our ultimate goal in this project is to provide a learning tool that can enhance learning in packed bed/fluidized bed topics across different universities, to clear up student misconceptions, and prepare them for real-world applications.

Over the past five years, we have disseminated our LCDLM pedagogy through workshops we conduct each year in different locations or virtually. As instructors adopt our DLM pedagogy, we expand our hub-based propagation and manage our implementations through regional hubs. The same strategy will be used to disseminate new this new FB DLM once we are confident about the adoption and compatibility of this tool with the student learning objectives of other institutions and in different courses.

Conclusion and Future Directions

Our group worked on a new modules for students to experience hands-on learning without needing bulky and costly equipment. A newly constructed FB module, which we built from hardware store equipment with minimal additional modifications, will be presented as an instructional YouTube video for those who would like to build the module themselves.

Initial laboratory testing of FB DLM has shown that the module agrees with the fluidization theory. However, more data will be collected for lower and higher Reynolds number regions for accuracy of this module. In addition to module testing, we observed the hysteresis effect as the particles repack on top then the flow rate is reduced. This phenomenon is something that we did not expect to see, and we will study it further. Eventually, hysteresis might be one of our emphases during the classroom implementation of this module.

We will work on implementation strategies and accompanying classroom materials to be used during implementations for FB DLM as we move forward. Student learning will be measured by IRB-approved Pre- and Posttest assessment. Worksheets and pre- and post-homework plans will be refined to find the most efficient way to use these additional supplies in learning. FB DLM implementation strategies are defined in this paper and we will present our FB DLM cumulative Pre- and Posttest results in the upcoming years as we collect more student data. Once we finalize the module development as well as the associated classroom materials, we will work on instructional YouTube videos for student learning as well to benefit students in distance learning. With these instructional YouTube videos, we will encourage students to improve their learning even outside of the classroom.

We have some ideas to improve FB module i.e. laser cutting a ruler to the white mounted board to read the pressure drop measurements, closing the manometer tubes to prevent water from leaking, and coloring the water applications to observe fluidization inside the column.

We aim to reach out to more students as we expand our DLM pedagogy across the country and we aim to have our DLMs adopted by more students from different universities as we continue to develop and refine these DLMs. The results obtained thus far, even if they are only from initial testing, are very promising. Our previously developed DLMs have been successfully implemented in many universities and it will be exciting to see these two new modules in practice within the framework of similar strategies.

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