This column addresses aspects of lifelong learning for current students, alumni, and faculty. Examples of student and faculty activities that involve industrial practice and engagement as well as continuing education are welcome. These topics may not always lend themselves to the traditional scholarly format with formal assessment and extensive literature review but may be more editorial in nature. Please submit manuscripts to Professor Lisa Bullard at lisa_bullard@ncsu.edu

THE VALUE OF AN INDUSTRIAL INTERNSHIP FOR A GRADUATE STUDENT EDUCATION

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For major corporations, a portfolio of internal research and development balanced by external engagement with academia provides a competitive advantage. One method by which this is accomplished is through internships offered to Ph.D. graduate students. The intern directly addresses research questions related to a current manufacturing process or ongoing development program through the completion of a collaborative project while he/she gains a background in industrial research that, with successful recruiting, can be leveraged to solve future challenges for the company. At the same time, the academic institution strengthens its ties with the corporation, opening the opportunity for further interactions with the school and its research groups. Typically, an internship may be within the student's field, but not the student's expertise or thesis. In such a circumstance, while the student may learn about a different area, the internship would not contribute to his/her thesis. A better option is for the assigned project to be within the scope of the student's thesis, as in the internship described in this work.

In this particular case, the internship came about as the result of an ongoing collaboration to study trickle bed reactor hydrodynamics between Dr. Arvind Varma's research group at Purdue University and the Reaction Engineering group at Dow, a part of Engineering and Process Sciences (E&PS) in Core R&D. The work completed during this collaboration comprises the graduate student's Ph.D. thesis on trickle bed hydrodynamics, with a focus on the effect of catalyst support properties. Prior to beginning the internship, the student had evaluated the effect of catalyst support particle size distribution on the hydrodynamics under trickling flow.[1] While gaining insight into hydrodynamics at the lab scale provides useful information, for results to be relevant to industry, it is important to understand to what degree hydrodynamics vary with vessel scale.

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Trickle bed reactors are used throughout industry for hydrodesulfurization, hydrogenation, and selective oxidation reactions and are characterized by cocurrent downflow of gas and liquid reactants through a packed bed of catalyst.[2] The multiphase flow results in hydrodynamics that impact reactor performance.[3] Therefore, understanding how the hydrodynamics change as a function of different bed and operating variables, and determining how these interactions vary with vessel scale, can increase economic profit. In the trickle flow regime, hydrodynamics are described by the parameters of liquid holdup and pressure drop, which are impacted by changes in gas, liquid, and bed properties. The effect of these variables may be evaluated at room temperature and pressure with air and water as fluids and with no reaction. Generally, observations are expected to be independent of scale if the ratio of vessel to particle diameter is greater than 20, which would indicate the absence of wall effects. However, prior results internal to Dow had shown a decrease in pressure drop with increase in vessel diameter, even though this criteria was satisfied. Therefore, the technical goal of the internship was to evaluate the effect of vessel diameter on the hydrodynamics under trickling flow for beds packed with activated carbon. Because the internship arose from an ongoing collaboration, the student had the opportunity to pursue work related directly to his thesis, which is mutually beneficial to the student and the company.

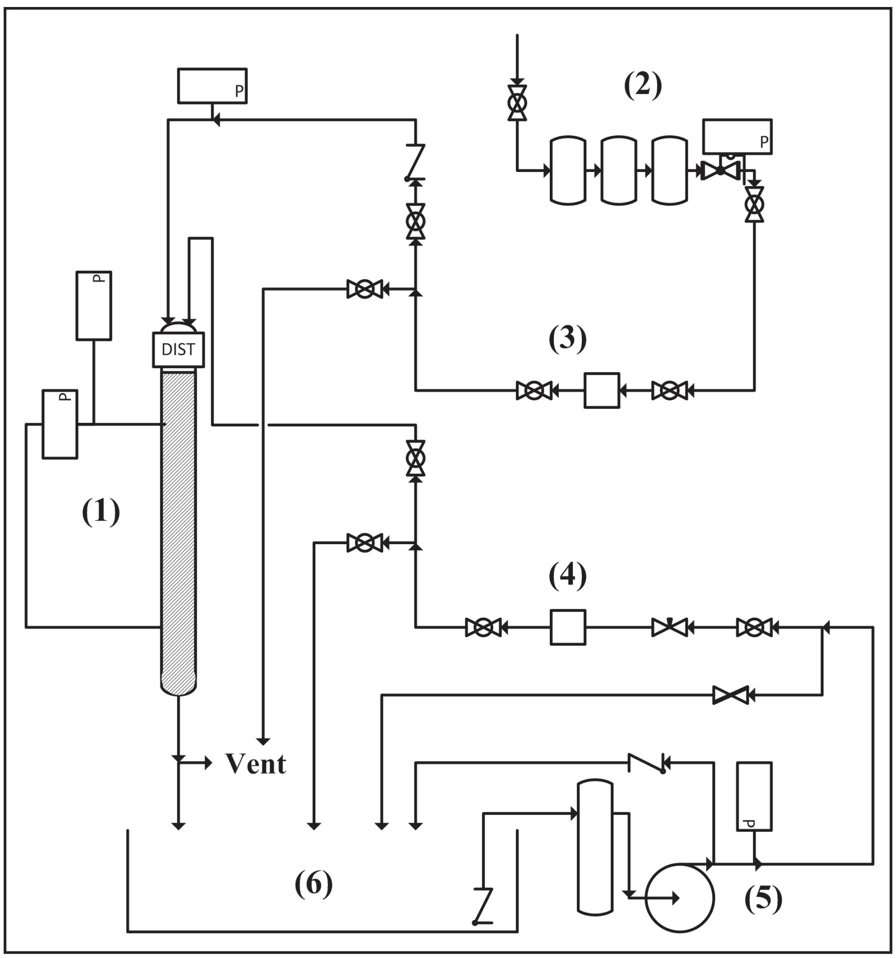


Figure 1. *Diagram of the setup including (1) column, (2) air supply, (3) air flow control, (4) water flow control, (5) pump, and (6) liquid reservoir. The system is analogous for 1⁄2” and 6” ID vessels. Boxes with a “P” indicate pressure transducers.*

PRIOR EXPERIENCE GAINED ON CAMPUS

Beyond general exposure to the variety of reactor types within the graduate reaction engineering course, the primary learning the student brought to the internship came from practical aspects of the lab work and a deep understanding of the literature associated with the project. This included criteria regarding reactor sizing, methods for packing of catalyst in trickle beds, and knowledge of the pre-wetting methods necessary to achieve reproducible results.

PROJECT OVERSIGHT

During the course of the internship, the student was in regular communication with his direct supervisor, who set up initial orientation and training, checked on the student’s progress, and acted as liaison in meeting appropriate personnel. Additional project oversight came from weekly meetings with the student’s industry advisor, who was also serving on the student’s thesis committee and was the primary contact throughout the collaboration. Lastly, the student submitted an internal report at the end of the internship and presented his work to E&PS employees. While input was provided to the student in order to meet project goals, the overall effort was largely self-guided because of the familiarity the student already had with the project. Thus, the internship in this case provided a more realistic work experience where the student was responsible for the direction and completion of the project.

REVIEW OF PREVIOUS WORK AT DOW AND PROJECT DEFINITION

Before starting the internship, while the issue regarding the effect of scale was known to the student, the details of the project and previous internal efforts were not provided due to intellectual property issues. Once at Dow, the intern had to determine the direction of the project by evaluating all of the available resources, including Dow proprietary material and personnel. The review of intellectual resources allowed the student to determine that the previous researchers used an inconsistent pre-wetting procedure for the activated carbon-packed bed in attaining the earlier results.

SAFETY REVIEW AND EXPERIMENTAL PROCEDURE

Concurrently with the problem review, the student worked with the lab technician to design and build the experimental setup and with network and communication services to set up the instrumentation. Relative to academic research, industry requires working with a greater number of other employees. While their expertise is available, competing priorities required development of soft skills by the intern. While project setup was ongoing, the student initiated the management of change (MOC) process. The MOC process guides the safety review for a project to ensure safe operation. Although the experiments used air and water, a thorough safety review was required because the setup was new. In general, safety practices, such as the MOC process, are more thorough in industry, where methods learned in the plant may be applied in the lab. Appropriate safety practices and review provide opportunity not only to make a project safer but also more effective. The safety practices learned in an industrial internship can be applied by the student in his or her research group and school.

The diagram of the resulting setup after the MOC and construction were completed is shown in Figure 1. Manual control valves controlled the air and water flow, and flow meters measured the flow rates. Air passed through the bed and was vented to the atmosphere, while water was recycled from a reservoir. Two columns were used, one with a 1⁄2" diameter and another with a 6" diameter. In the 6" column, water passed through a distributor while in the 1⁄2" column, water was introduced by a 1⁄4" tube in the center of the column. Columns were packed with 20-50 mesh Nuchar RGC activated carbon. The Sauter mean diameter of the particles was 620 μm. The void fraction was determined to be 0.370 ±0.006 for both columns, based on the envelope volume and mass of the particles added to the columns. The columns were clear acrylic to visually monitor flow regime, which is the contacting pattern of the gas and liquid flowing through the column. In this work, all data were gathered in the trickle flow regime, where gas is continuous, and liquid flows as a stable thin film over the particles.[2] Phenomenological models for trickle flow define a hydrodynamic state based on bed and fluid variables.[4,5] For a given state, a specific pressure drop and liquid holdup are defined. Experimental measurement of the pressure drop for a set of operating variables defines the hydrodynamic state. In this study, pressure drop was monitored by a differential pressure transducer mounted across a 24" section of the bed. Comparison of pressure drops will verify whether or not hydrodynamics are affected by vessel diameter.

With the setup in place, an appropriate pre-wetting procedure was developed. The activated carbon used in this study was not readily wetted by the water when flowing from top down both with and without air flowing. With the air flowing, the water did not uniformly wet the packed bed of particles. Without air flowing, the liquid would not penetrate the bed, instead flooding the area above it. To overcome this, a new pre-wetting procedure was developed (Figure 2). After flooding water above the bed with the outlet closed and the air line

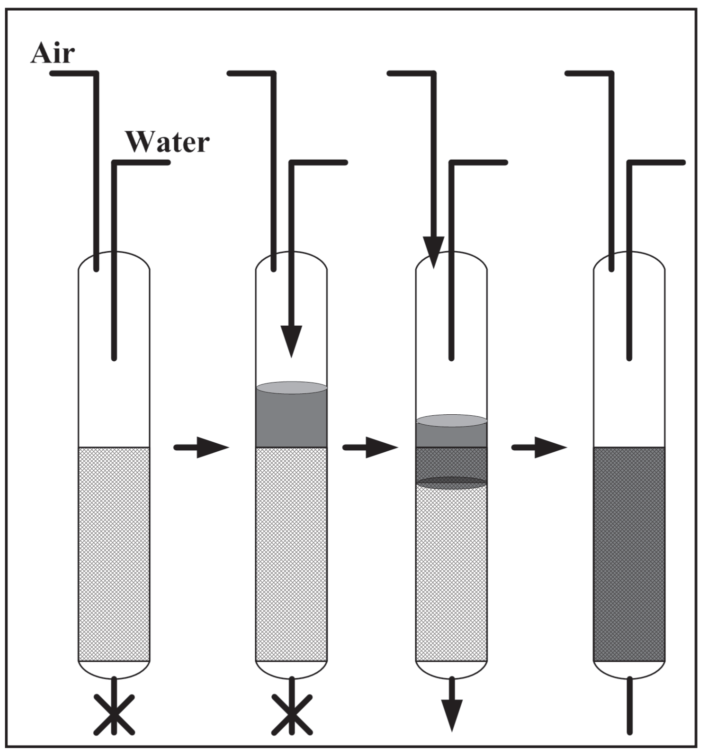
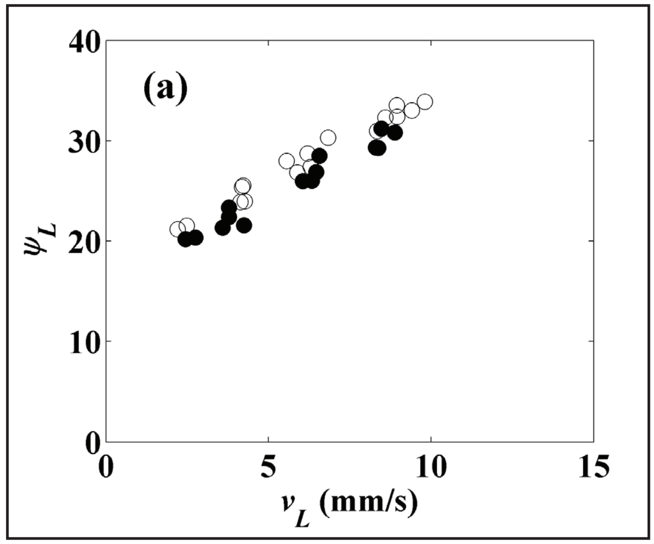


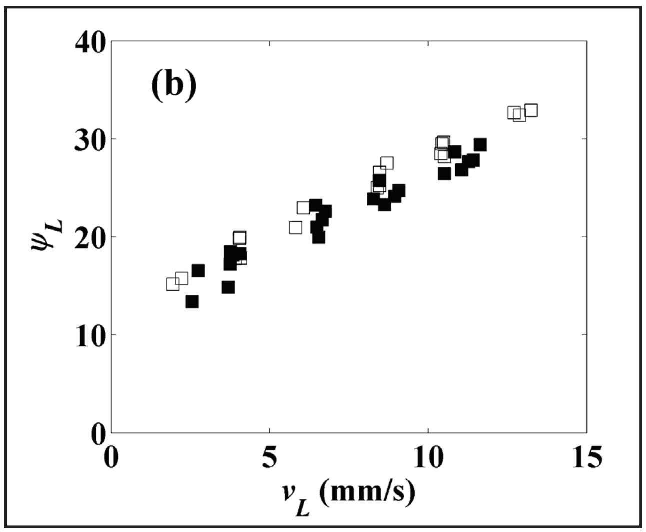
***Figure 2.** The pre-wetting method developed for the activated carbon used in this study, where a slug of water (in dark gray) is forced through the column.*

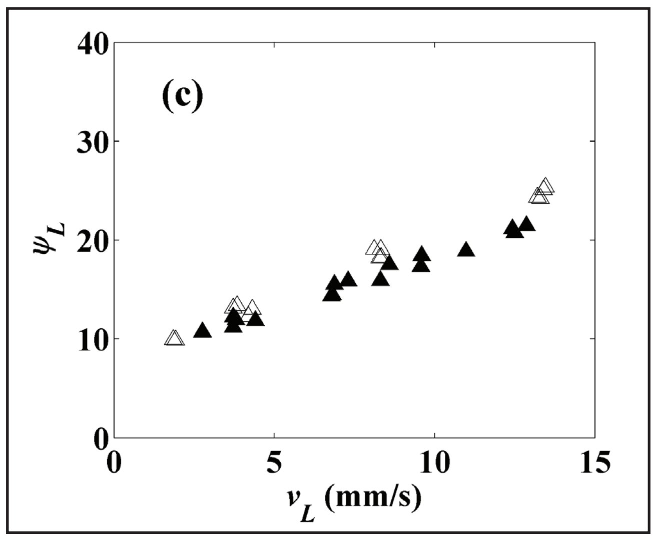
opened to vent, air was introduced to force the liquid slug through the bed, thereby uniformly wetting the particles. After this procedure, air was introduced at a fixed superficial velocity, and the liquid flow rate was increased until pulsing flow was observed. The liquid flow rate was then decreased until the trickling flow regime was reached, where data were then gathered with decreasing and increasing liquid flow rate.

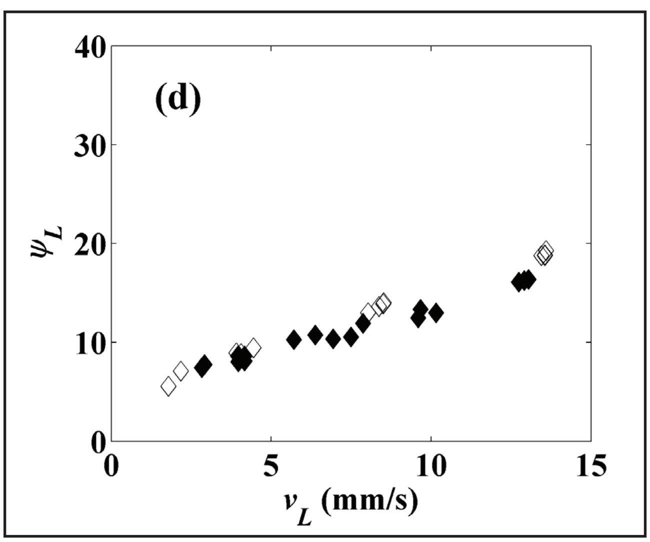
TECHNICAL RESULTS

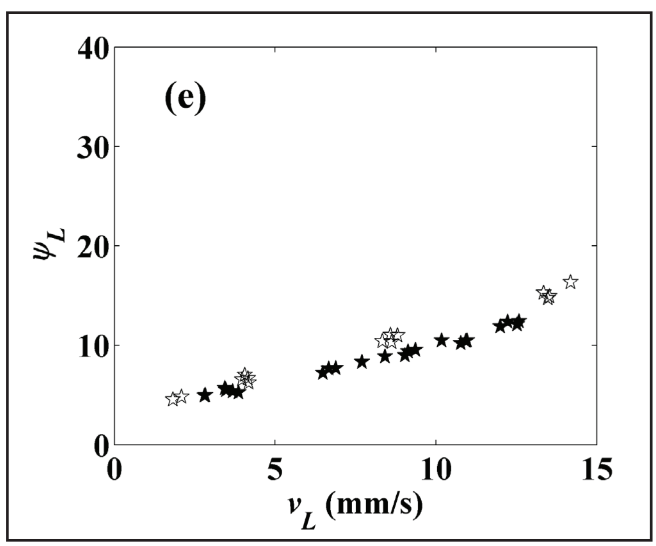
Experimental results comparing dimensionless pressure drop, ψ_L, between the 1⁄2" and 6" ID columns packed with the activated carbon are shown in Figures 3. For a given gas and











Figures 3. *Dimensionless pressure drop for the 1⁄2" (empty symbol) and 6" (filled symbol) columns with varying v_L for a fixed v_G:* ***a)*** *310 mm/s,* ***b)*** *220 mm/s,* ***c)*** *110 mm/s,* ***d)*** *60 mm/s, and* ***e)*** *30 mm/s.*

liquid superficial velocity (v_G and v_L, respectively), pressure drop was slightly lower (by only ~5%) in the 6" ID vessel than the 1⁄2" ID vessel. This is in contrast to previous work at Dow, which at v_G = 10 mm/s and v_L = 4 mm/s had observed a 40% decrease in dimensionless pressure drop between the 1⁄2" and 6" ID vessels (from 5.2 to 3.1, respectively). Relative to this observation, the difference between the pressure drop in the 6" and 1⁄2" ID vessels evaluated in this study is minor. For trickle bed reactors, wall effects are expected to impact hydrodynamics only for $d_R/d_P < 20$.[6,7] The $d_R/d_P > 20$ for the activated carbon in this study ensured that wall effects (or the impact of vessel diameter) were not expected to occur, which is supported by the experimental results.

DISCUSSION

Factors influencing project success

Summer internships last approximately three months. This is a limited amount of time for an individual to conduct a research project, particularly one with an experimental component. The primary factor leading to the success of the project was the background knowledge and lab experience the student already had from his thesis research. Another factor that made the project successful was use of safe chemicals at low temperature and pressure; this expedites the MOC (safety review) process. Additionally, a thorough review of the internal resources allowed the student to ask the right questions and develop a correct procedure. Lastly, use of non-proprietary material to study a fundamental issue allowed for ease of publishing with respect to intellectual property. In the case where a more complicated system were to be used, it is recommended that the experimental setup be manufactured and approved prior to arrival of the student. One improvement that could be made to the internship process would be to provide the student with copies of proprietary company reports and other documents describing relevant past work prior to the project start.

Benefits to industry, academia, and the student

The results attained demonstrate the significant benefits of aligning an internship with the student's thesis. The company directly benefits by having an individual with the correct expertise solve a relevant problem. The student benefits by adding to his or her thesis work and gaining a well-grounded understanding of the practical motivation for his/her research. This is in contrast to the alternative where the internship is focused on a different topic. In the latter case, the gains made by both the company and the student will be less. Furthermore, the time spent away would not be in support of the student's thesis, effectively delaying completion of the degree. Rather, internships that are related to a student's thesis should be pursued whenever possible, and are most likely to originate from existing collaborations or relationships of the academic advisor with industry.

Alongside the benefits to a student's thesis that occur in this case, the student is also able to learn new procedures and practice his or her networking, teamwork, presentation, and project management skills as well as gain an understanding of work culture in industry. Additionally, the contacts made enhance the existing collaboration and bring opportunities for the student's academic advisor and school. A further benefit of this work is that it shows the complexities that arise in real problems; this demonstrates the continued need for lecturers to stay well-informed of their respective fields and connect basic fundamentals to actual practice. From the perspective of the company, a relevant problem is solved, recruiting is improved at the school, and research directions may be provided to the school that lead to a greater number of graduate students with a background relevant to industry.

CONCLUSION

An experimentally based project was completed as part of an internship at Dow. This work included review of internal literature, design, setup, safety review, running experiments, analysis, and reporting of the results. The data showed that, by using a thorough pre-wetting procedure, vessel diameter did not have a significant effect on the hydrodynamics, which confirms the lack of wall effects expected for high values of d_R/d_P. The primary factor in the success of this work was that the project was within the scope of the graduate student's thesis. As such, he was able to apply the knowledge he already had regarding trickle bed hydrodynamics to solve a problem of industrial importance. The learning that resulted for industry and academia included the technical result itself and associated methods, while the student also learned about the work and safety culture in industry. More broadly, the stronger ties resulting from the collaboration may have a role in enhancing education at the school.

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NOMENCLATURE

- d_P particle diameter, m
- d_R reactor column diameter, m
- L bed length, m
- g gravimetric constant, m/s^2
- v_L liquid superficial velocity, mm/s
- v_G gas superficial velocity, mm/s
- ΔP pressure drop, Pa

ρ_L liquid density, kg/m^3

ψ_L dimensionless pressure drop ($\psi_L = -\frac{-\Delta P}{\rho_L Lg} + 1$)

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