Fundamentals of Engineering Design for Chemical Engineering 1st Year Undergraduates

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Work in Progress: Fundamentals of Engineering Design (FED) for Chemical Engineering 1st Year Undergraduates

This is a work-in-progress report on continuous improvement of our first-year chemical engineering design / laboratory course. Such courses continue a tradition identified several decades ago of the importance of freshman engineering experiences [1, 2]. We present a modified structure of our traditional introductory course successfully running since 2006. This course, and the modifications described herein, allow the instructors to demonstrate strong connections between principles of engineering science and engineering solutions that affect environmental safety and economy.

This one semester (14 weeks), three-hour weekly class includes two balanced lecture and laboratory components per week. Class size varies from 20 to 30 students in each section. Students work in teams of 2 to 4 students, depending on the enrollment. The current laboratory setting limits us to 18 teams. The course consists of two major components: i) a 9-week long laboratory component with several small-scale experiments, successively completed by the teams, and ii) a major "design" component which incorporates lessons learned in the small experiments. The entire course is developed with the goal to enable students with the necessary knowledge and skills to succeed in the final project.

In the 10th week, the teams receive a request from "stakeholders" to build a scaled-down model of a chemical plant to demonstrate their ability to perform full-scale design. The instructor, teaching assistant, and a member of the on-site student AIChE chapter represent the stakeholders. The request contains functional and quality requirements: (1) Environmental safety, (2) Sustainability, (3) Manufacturability and (4) Cost. These requirements stimulate class discussions about materials, safety, and quality. The student performance assessment is done based on the individual reports, quality of the flow system, team work, demonstration of the flow system, and a team *PowerPoint* presentation to the stakeholders.

Each experiment requires hands-on construction of a portion of a piping flow system that eventually is integrated into the final experiment. These exercises also include operation, measurement, computer-based data processing, and result reporting.

Plastic (e.g. PVC) components (e.g. pipe, valves, fittings) are used. These are low cost, and easily replaceable. Our experience shows a low (< 2%) annual rate of attrition of these components. Prudent choice of vendors keeps down the cost of other components such as gauges, flow meters, and pumps.

Students learn about the importance of making seals, such as with O-rings, and in pipe thread connections with Teflon tape. Hand tools are also used, such as pipe wrenches and pliers.

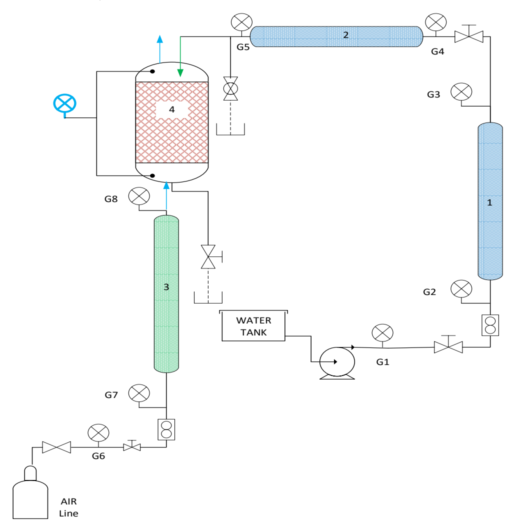

Figure 1. Example of the layout of the final design: model of the real-world unit operation designed for a customer. See details in text.

The final experiment is in-line with the request from the stakeholders. A typical design of the scale-down operation unit is illustrated in Figure 1. This setup is inspired by permanent, pilot-scale units operated by our seniors in the capstone laboratory course. The FED system includes a packed column with two counter flows: gas line and water line. Each fluid line contains physical models of the elements important in unit operations.

Examples include packed pipes (1-3), a packed column imitating a scrubbing process (4), liquid transport element (centrifugal pump), and measuring devices (Bourdon gauges and variable area flowmeters).

This scale-down design is validated by the measurements of selected pressure drops and comparison of the experimental values to predicted values. The teams of students build their own versions of this flow system with consideration of safety, quality, and economical constraints.

As mentioned above, there is a lecture each week. The first lecture covers a discussion of the origin of pressure in liquids and gases, and pressure exerted on a solid body. A demonstration of the force acting on the surface of a rubber slab that results in its visible deformation, and the discussion of the physics of this deformation, serves as a transition to a discussion about how fluid "deforms" under pressure, and from where the fluid obtains the energy to flow. We emphasize mass and energy conservation in a flow system for each concept introduced and discussed in class.

Once fluid flow is introduced, the students then learn about ideal, loss-free flow in a pipe, and methods to characterize the flow. They learn how to measure the static pressure using a Bourdon gauge, and how to calculate dynamic pressure knowing volumetric flow rate measured by a variable area flowmeter. The measurement is an important concept for a future engineer.

To teach students basic concepts of measurement and statistical analysis, we use Jenga game blocks with slightly modified dimensions. Each student has a set of six blocks: five modified and one reference. They measure linear dimensions, calculate averages, find a statistical error, assess accuracy and precision of the measurement, and calculate average volume.

In the first experimental part of the course, FED students get hands-on experience with the piping, flow, and pressure measurements in two laboratory experiments: Flowmeter Calibration and Pump Characterization. They apply the energy conservation equation, and assess losses in the subassemblies they build to characterize a pump and observe its head. A schematic of the subassembly is shown in Fig. 2. The student performance assessments are based on two submitted individual laboratory reports. The instructor provides a template for a laboratory

Further, students learn about the different energy loss mechanisms in a flow system. Discussion starts from "imagine you are a water molecule in a fluid flow…" . Students are asked to consider various conditions; position relative to the pipe wall, surface roughness, presence of small obstacles in the pipe, strong or weak interaction with neighboring molecules, high velocity, low velocity, etc. This allows students to qualitatively arrive at an equation for the pressure drop $\frac{-\Delta P}{\Delta L}$ in a packed column and better understand the concept of the average velocity, $\overline{v_s}$. Once a qualitative equation is obtained, the Ergun equation [3]:

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

is introduced and compared, term by term, with the qualitative expression obtained previously. In the Ergun equation, D_p is the packing particle diameter, ε is the void space fraction, and ρ and μ are the fluid density and viscosity, respectively.

Finally, students work on the complete design and construction of the flow system to satisfy the overall requirements. To validate their design, they take pressure drop measurements as a function of air and water flow rates, perform analyses of the experimental data, and compare the average values of the experimentally measured pressure drops and values predicted by the Ergun equation. Students use *Visio* for schematic preparation, and *Excel* for data presentation and analysis. This final step includes a game-element, as teams participate in a competition to win the bid for construction of an operational unit for stakeholders. The professional and ethical responsibility of each member of the team is assessed during the final presentation of the project to the stakeholders. Finally, a lesson in responsibility is learned as each student team must disassemble its entire setup, and return all components to the correct storage bins.

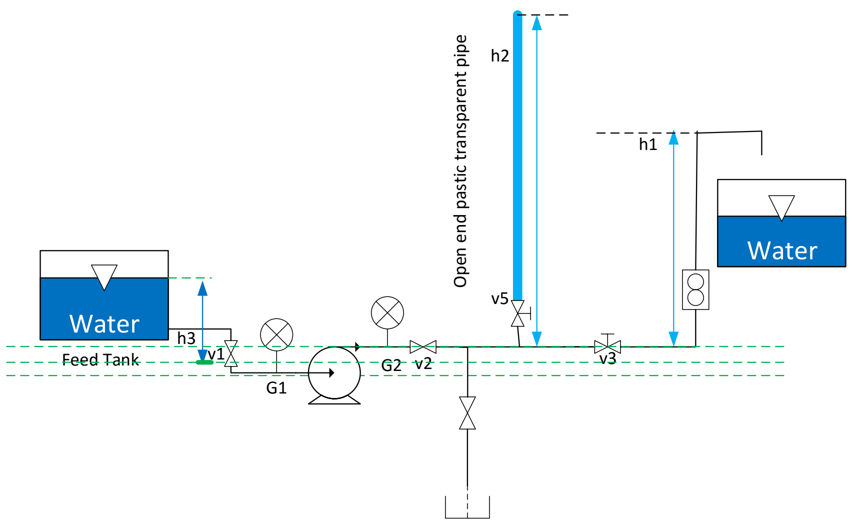

Figure 2. Experimental setup for pump characterization experiment. (Built by students)

SUMMARY

This course is critically important for chemical engineering freshman as it gives them their first exposure to their selected major. Our experiences show that the students respond positively to the course format and content. We look forward to monitoring the progress of the freshman taking the course, and their success in subsequent chemical engineering courses, where they use the foundations learned in FED.

References

1. V. Ercolano "Designing Freshman" *ASEE Prism*, 1996
2. A.J.Marchese, et al., "Design in the Rowan University Freshman Engineering Clinic", *Proceedings of the 1997 ASEE Annual Conference*, Session 3225, 1997
3. S. Ergun, "Fluid flow through packed columns", *Chemical Engineering Progress*, 48, 1952, 9–94.