Demonstration and Assessment of

A SIMPLE VISCOSITY EXPERIMENT FOR HIGH SCHOOL SCIENCE CLASSES

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The objective of this demonstration and assessment was to develop an instructional model to inform and enthuse students about chemical engineering. Figure 1 shows the number of B.S. degrees granted nationally in chemical engineering.[1, 2] Rhinehart observed a 13-year-cycle period for the production of B.S. degrees in chemical engineering at Oklahoma State University, dating back to the 1930s.[1] It is not clear at this time if the 13-year-cycle period for chemical engineering degrees awarded will hold,[1] but it is clear that the peak has dropped from approximately 7,500 degrees awarded to approximately 6,500 degrees awarded, representing a 13% decline. Rhinehart attributes the cycling to B.S. chemical engineering supply/demand being out of phase but does not discuss the magnitude of the peaks. Halford,[3] however, suggests the decline is due to a rising attraction of potential chemical engineers to the environmental engineering and bioengineering fields. The cause of the decline in chemical engineering enrollment has not been determined conclusively, but—regardless of the cause—the effect is that when enrollment is low, administrators may question the benefit of maintaining an expensive chemical engineering program.[1]

B.S. chemical engineers are indirectly supplied by the nation's high schools. Therefore, one potential approach to positively impact enrollment in chemical engineering undergraduate programs is to conduct outreach programs for high schools. Ross and Bayles[4] describe a method for incorporating high school outreach into chemical engineering courses. Their goal is to provide role models for high school students by assigning chemical engineering students enrolled in their courses to participate in an outreach project. In contrast, this work describes an outreach program administered and conducted by professors for the purpose of informing high school students about chemical engineering and attracting them to the profession.

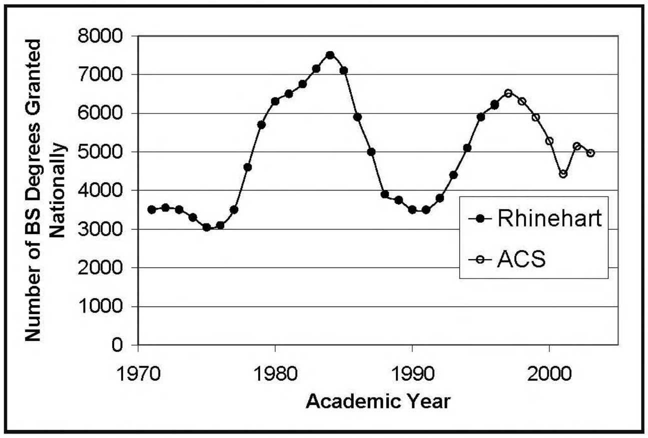

Figure 1. Annual national B.S. chemical engineering degrees awarded.

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The overall objectives of this demonstration were twofold. First, the authors wanted to develop a presentation giving an overview of the field of engineering with emphasis on chemical engineering. Second, the authors wanted to conduct a simple experiment with the high school students so that they have an opportunity to learn a chemical engineering concept and be exposed to principles and problems that practicing chemical engineers will expect to encounter.

PRESENTATION DESCRIPTION

The demonstration was conducted at Martin Luther King, Jr., High School in Dekalb County, Georgia, in November of 2004. A junior/senior-level physics course (a chemistry course may also be appropriate) was chosen for an introductory presentation followed by hands-on viscosity experimentation. Twenty-six students participated in the demonstration during a class period of 90 minutes.

General engineering, chemical engineering, and the concept of viscosity were discussed first. In the general discussion of engineering, the major engineering disciplines were described in basic terms (*e.g.*, civil engineering was described as the branch of engineering responsible for designing municipal structures such as bridges and roads).

After a general discussion on engineering, the presentation was focused on chemical engineering. The facilitator discussed the kinds of jobs that chemical engineers are responsible for and the types of engineering fundamentals that chemical engineers study. The job areas described included petrochemicals, intermediate chemicals, food processing, cleaning products, plastics, and pharmaceuticals. When describing what chemical engineers study, several core examples were included. The list of what chemical engineers study included accounting for material flows (material and energy balances), how fluids move (fluid mechanics), how heat is transferred, and how materials react to create new things (reaction engineering). The students were informed that the viscosity experiment for the day was related to fluid mechanics. During the discussion on heat transfer, the example of an egg cooling was introduced. As expected, the students had a good idea about how long it would take for an egg to cool under different conditions (free vs. forced convection, in air vs. in cool water) but overall were surprised that it is something that chemical engineers expect to predict theoretically and/or empirically. During the discussion of reaction engineering, the example of how an antacid helps indigestion was introduced. The students were aware of acid/base reactions from their chemistry class, but again didn't realize that chemical engineers are involved in producing the antacids (bases) that are administered to neutralize excess stomach acid.

The presentation ended with a discussion on viscosity. Viscosity was described as a fundamental physical property in the study of how fluids move or how "thick" and "slippery" a fluid is. Several examples including paste, pancake syrup, water, and motor oil were discussed. Viscosity was not mathematically defined during the presentation, and a discussion on Newtonian vs. non-Newtonian fluids was not included because the facilitators thought that it was beyond the scope of what was appropriate for a high school science class.

APPARATUS AND THEORY

The viscometer used for the demonstration has been described previously.[5] Briefly, the viscometer is a tank-tube viscometer as illustrated in Figure 2. It consists of a tank and a vertical drain tube attached at the bottom of the tank. In addition, a balance, a thermometer, a stopwatch, and a bottle of water at room temperature are required for the experiment. The viscosity of a fluid is inferred from the drain rate of the fluid through the drain tube of the viscometer tank. The drain rate is dependent on the viscosity of the fluid and follows the behavior described in Eqs. (1) through (4). The detailed derivations of these equations have been described previously.[5]

$$\ln\left(\frac{H+L}{h+L}\right)=\left(\frac{gR_o^4\rho}{8\mu R^2L}\right)(t) \tag{1}$$

$$h=H-\frac{m}{\pi R^2\rho} \tag{2}$$

$$-\ln\left(1-\frac{m}{(H+L)\pi R^2\rho}\right)=\left(\frac{gR_o^4\rho}{8\mu R^2L}\right)(t) \tag{3}$$

$$m^*=-\ln\left(1-\frac{m}{(H+L)\pi R^2\rho}\right) \tag{4}$$

where

- H: initial height of the fluid in the tank (9.3 cm, illustrated in Figure 3)
- h: height of the fluid in the tank
- L: length of the drain tube (56.4 cm)
- g: acceleration due to gravity
- R_0: equivalent radius of the tank
- ρ: density of the fluid
- μ: viscosity of the fluid
- t: drain duration
- R: radius of the drain tube (0.0509 cm)
- m: accumulated amount of a fluid drained from tank 5
- m^*: left-side value of the viscosity equation, as shown in Eq. (3)

During the experiment a tank with a rectangular cross section, illustrated in Figure 3, was used instead of a tank with a radial cross section. This modification was made because the tank with the rectangular cross section is easier to fabricate. Thus, the equivalent radius R_0 was computed with the following equation

$$R_o = \left(\frac{DW}{\pi}\right)^{1/2} \quad (5)$$

where

W: width of the rectangle (25.4 cm)

D: depth of the rectangle (3.81 cm)

The experimental procedure for determining the viscosity of water using the tank-tube viscometer is as follows:

- *Fill the reservoir with water.*
- *Set up the balance with automatic data acquisition so that the data from the balance are input directly into Microsoft Excel in real time. Use a sampling rate of 1/s.*
- *Remove the end cap on the drain tube and allow the water to collect on the balance.*
- *After ~ 90 s, stop the data acquisition.*
- *Plot m* [left-hand side value of the viscosity equation as shown in Eq. (3)] vs. t (time) and obtain the slope of the line.*
- *Extract μ from the expression of the slope as illustrated in Eq. (6).*

$$\mu = \left(\frac{gR_o^4\rho}{8\ R^2L}\right)\frac{1}{slope} \quad (6)$$

- *Measure the temperature of the water used in the experiment.*
- *Compare the experimental μ to the literature value.*
- *Calculate the measurement error based on a percent difference.*

In addition to the experimental procedure outlined, brief explanations on linear regression, Microsoft Excel features, and standard deviation (σ) were provided to the class. Units were not discussed and, due to time limitations, only one experimental run was performed.

RESULTS AND DISCUSSION

The viscosity experiment was demonstrated using water at room temperature. The experiment was successful with a measurement error of ~3% which is the typical result obtained in a simple viscosity experimental setting with the tube-tank viscometer in the absence of a temperature regulating circulator.

Facilitator's Perception

Overall, the students were enthusiastic and attentive, suggesting that the activity was structured appropriately to maintain the interest of a high school student. The students were also willing to interact with and participate in the presentation and the hands-on viscosity experimentation. The experiment could be improved by structuring it for more student participation. Ideally, there should be one station per four students so that the students can perform the experiment themselves. Excluding the computer and the balance, the fabrication cost is ~$100 so the concept is economically feasible. Also, if time permits, it would be illustrative to measure the viscosity of more than one fluid. For example, in addition to measuring the viscosity of water, one could measure the viscosity of an alcohol and its aqueous solutions or water with the viscosity modified by adding a second component such as sugar.

Student Survey

Students were asked to rate the following five questions on a scale of one to 10 before and after the demonstration, where

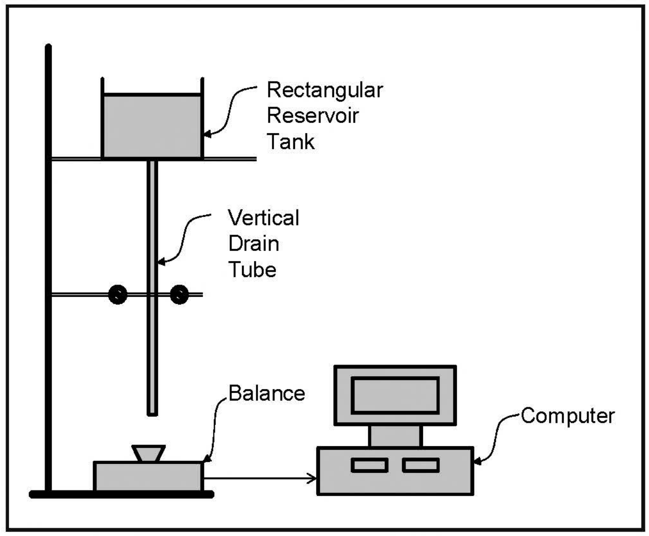

Figure 2. *Set-up of a viscosity experiment.*

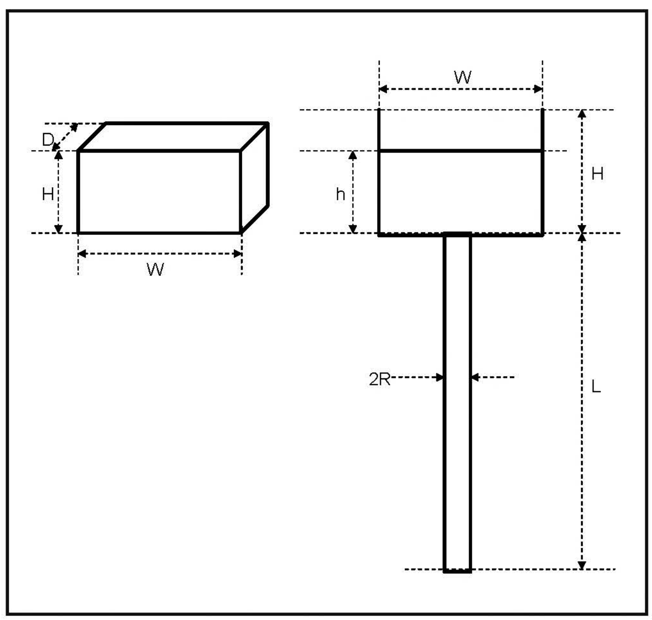

Figure 3. *Tank-tube viscometer.*

one is "no knowledge" and 10 is "very knowledgeable":

1. How much do you know about engineering?
2. How much do you know about chemical engineering?
3. How much do you know about viscosity?
4. How interested are you in engineering?
5. How interested are you in chemical engineering?

The students were also asked to comment on what they liked most about the presentation/experiment and what could have been improved.

Survey Results

Table 1 shows the results from the survey given to the students. The results summarize the students' knowledge and interest before and after the presentation followed by the hands-on viscosity experimentation. The table also shows the difference between the two values and the statistical significance of the results. Using a paired-sample t test, it was concluded that the students gained by at least 36% in the knowledge of and interest in general engineering, chemical engineering, and the viscosity topic. In the future, however, a short test may be more informative than the student self-assessment for determining how much the students learned during the demonstration. Overall, the survey shows that the students are more interested in general engineering, but their interest in chemical engineering increased between 95% and 230%.

Survey Comments

Approximately half of the students indicated that the most interesting part of the demonstration was the experiment. The other half indicated that they enjoyed learning about different types of engineering and/or learning about chemical engineering. Most students didn't comment on potential improvements, but of those who did, the majority indicated that more audience (*i.e.*, student) participation was preferred.

SUMMARY AND OUTLOOK

An experiment/presentation appropriate for high school students was developed and demonstrated. Based on the survey results, the students gained by at least 36% in the knowledge of and interest in engineering, chemical engineering, and fluid viscosity. Furthermore, interest in chemical engineering increased between 95% and 230%.

Based on the survey results and the facilitator's perception, for any high school experimental demonstration, a significant portion of the time allotted should be devoted to talking to the students about engineering and chemical engineering. In the future, the facilitators would like to contact high schools and offer to send them simple tank-tube viscometer kits so that a viscosity experiment can be incorporated into their existing curriculum. Also, the facilitators would like to develop a program so that undergraduates can participate in the viscosity experiment at local high schools as one of the department's outreach efforts.[4]

ACKNOWLEDGMENTS

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TABLE 1
Student Survey Results

Description		Knowledge			Interest	
		General Engineering	Chemical Engineering	Viscosity Concept	General Engineering	Chemical Engineering
Before Demonstration	Average	3.7	2.6	1.6	4.2	2.1
	Standard Deviation	1.9	1.9	1.3	3.0	1.5
After Demonstration	Average	8.3	8.5	8.0	7.3	5.5
	Standard Deviation	0.9	1.1	1.7	2.2	2.5
Difference Between Before and After Demonstration	Average	4.6	5.8	6.3	3.1	3.4
	Standard Deviation	2.1	2.3	2.0	2.8	2.5
t ($t_{\alpha = 0.005}$ = 2.807)		10.7	12.4	15.4	5.4	6.7
99% confidence interval		3.4-5.8	4.5-7.1	5.2-7.4	1.5-4.7	2.0-4.8