ChE laboratory

LABORATORY EXPERIMENT FOR THE TRANSIENT RESPONSE OF A STIRRED VESSEL*

R. D. NOBLE[1], R. G. JACQUOT[2], AND
L. B. BALDWIN[3]

A LABORATORY EXPERIMENT has been developed to measure the transient response of a stirred vessel. The experimental apparatus is simple in construction, inexpensive to purchase, and gives good quality data which demonstrate the phenomenon being tested. The apparatus can be used for two different experiments which demonstrate transient behavior, thus further reducing the cost per experiment. Both experiments use salt dilution as the method of demonstration.

In one experiment, the vessel is initially charged with a known volume of water and known weight of salt. A measured inlet flow of water is started and the students determine salt concentration vs. time using a conductivity meter. They then compare their experimental results with theoretical predictions. This experiment demonstrates the effect of volume change in the vessel on transient response.

The second experiment is set up in the same fashion as the first except an outlet flow from the vessel is used so the tank volume remains constant. Students measure the salt concentration in the outlet as a function of time and compare this to theoretical predictions. This experiment demonstrates the effect of inflow and outflow on transient response.

The quality of the data obtained is very good and allows the student to observe the phenomenon and see how the theory is actually applied. Students are also asked to comment on sources of error in the experiment.

THEORY

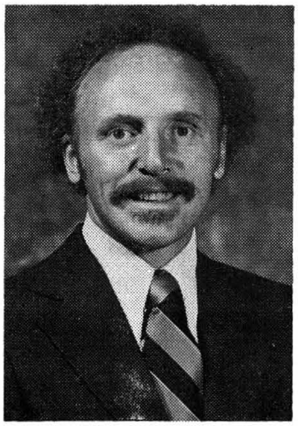
A macroscopic mass balance for a given species (component) in a system is

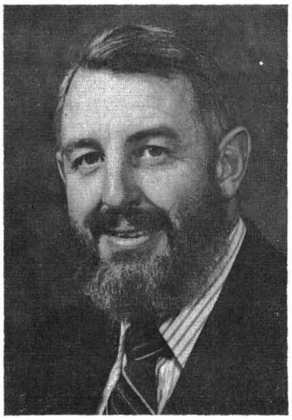
---

*Paper published in Proceedings of Frontiers in Education Conference, Rapid City, SD (1981).

---

1. University of Colorado, Boulder, CO 80303. 2. University of Wyoming, Laramie, WY 82071. 3. University of Wyoming, Laramie, WY 82071.





Richard D. Noble received his B.E. degree in 1968 and M.E. degree in 1969 from Stevens Institute of Technology. In 1976, he received his PhD degree from the University of California, Davis. His current research interests include facilitated transport in liquid membranes, transient heat transfer, and problem solving skills. **(L)**

Raymond G. Jacquot is currently Professor of Electrical Engineering at the University of Wyoming where he served in the various academic ranks and served as Electrical Engineering Department Head for two and one half years. Dr. Jacquot's education includes B.S. and M.S. degrees in Mechanical Engineering from the University of Wyoming and the PhD in M.E. from Purdue. His professional interests are in dynamic systems and control and he is the author of **Modern Digital Control Systems.** He is a member of ASEE, IEEE, ASME and Vice Chairman for Regional Activities for the CoEd division of ASEE. **(C)**

Leonard B. Baldwin is currently Professor of Civil Engineering at the University of Wyoming. He holds B.S. (Physics) and M.S. (Civil Engineering-Mechanics) degrees from Michigan State and the PhD in Civil Engineering from Stanford. He has held academic appointments at the University of Idaho, Michigan State, Tufts, Stanford and Michigan Technological University. His professional interests are in hydraulics of pipelines, hydrology and fluid mechanics. He is currently authoring text material in statics and dynamics with accompanying audio-tutorial tapes and slides. He is a member of ASEE. **(R)**

$$\frac{d}{dt}(CV) + Q_oC_o - Q_iC_i - R = 0 \quad (1)$$

where: V = system volume
C = species concentration
Q = volumetric flowrate
R = generation term
i = inlet
o = outlet

The systems to be studied have no chemical reactions taking place ($R=0$) and are contained in a well-mixed vessel. Therefore, the outlet concentration C_o and the system concentration C are assumed equal. Eq. (1) will be applied to the salt contained in the vessel for each case. Also, the inlet stream contains pure water so $C_i = 0$.

For the first experiment, the outlet flowrate Q_o is zero and Eq. (1) becomes

$$\frac{d}{dt}(CV) = 0 \quad (2)$$

The solution for this equation is

$$C = \frac{C_1V_1}{V_1 + Qt} \quad (3)$$

where the subscript 1 refers to the initial state of the system.

For the second experiment, the volume in the vessel remains constant and the outlet has a constant flowrate. Eq. (1) becomes

$$V\frac{dC}{dt} + Q_oC = 0 \quad (4)$$

The solution to Eq. (4) becomes

$$C = C_1\exp(-Q_ot/V) \quad (5)$$

Eqs. (3) and (5) are the theoretical predictions against which the experimental results will be compared.

EXPERIMENTAL APPARATUS AND PROCEDURE

A schematic of the experimental apparatus is shown in Fig. 1. A cylindrical vessel (nominal size: 10 gallons) has an outlet at the bottom with a valve to adjust or shut off flow. A water line with a valve for flow adjustment serves as the inlet. The water line should have a flexible section at the end so it can be removed from the vessel when necessary. A stirrer is mounted so that the contents of the vessel are well-mixed at all times. To further reduce costs, students can provide the mixing power. Not shown in the schematic is an electrical conductivity meter which is used to measure salt concentration in liquid samples and a stop watch.

The apparatus can be used for two different experiments which demonstrate transient behavior, thus further reducing the cost per experiment.

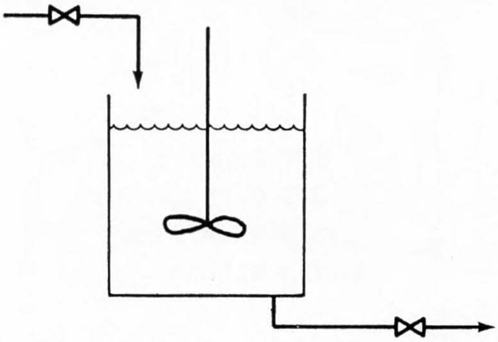


FIGURE 1. Schematic of experimental apparatus

To perform the experiment with the outlet valve closed (amount of salt in system is constant and volume changes with time), a measured mass of salt and volume of water is added to the tank and well stirred. The initial concentration of salt is measured with the conductivity meter. It is important that all the salt dissolve into solution. The inlet line is turned on and the flowrate of water measured. This is done while the line is *not* discharging to the tank. At t=o, the inlet line is placed into the tank and the stop watch started. Samples are withdrawn periodically from the tank and the salt concentration measured. These experimental values are then compared to theory using Eq. 3. Fig. 2 shows some experimental and theoretical results for this experiment.

To perform the experiment with the outlet valve open (volume remains constant and amount of salt decreases with time), the tank is initially filled with water and the inlet flow rate is adjusted until the volume remains constant in the tank with the outlet valve open. The outlet valve is closed and the inlet line removed from the tank. A measured quantity of salt is then mixed into the system and an initial conductivity reading taken. At t=o, the inlet line is replaced in the tank, the outlet is reopened, and the stop watch started. Samples are taken periodically and the salt concentration is measured. Eq. 5 is then used to compare the experimental results with theory. Fig. 3 shows a comparison of theoretical and experimental results.

For both experiments, the student is given the macroscopic mass balance and asked to derive the theoretical result and compare it to the experi-

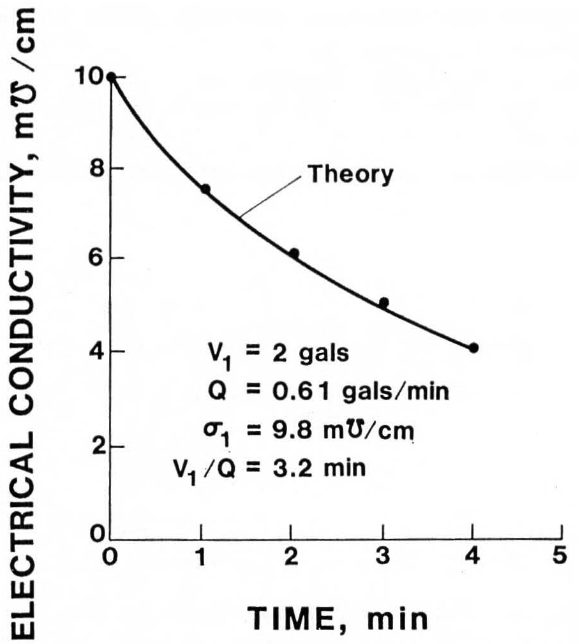


FIGURE 2. Results for closed outlet experiment

mental result. Also, the student is asked to comment on any sources of error in the experiment.

RESULTS AND CONCLUSIONS

As seen by Figs. 2 and 3, the comparison between experimental and theoretical results is very good. The data obtained is very reproducible and consistent with theory. This reinforces the validity and the limitations of the theory for the student and removes it from a strictly textbook context.

The experimental apparatus is simple in design and inexpensive. Yet, it provides the opportunity to perform two different experiments and thereby, further reduce storage space and cost per experiment.

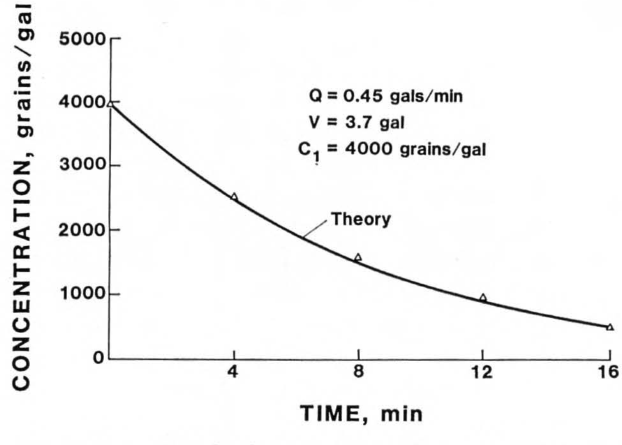


FIGURE 3. Results for constant volume experiment

The experimental procedure is also simple and allows the student to focus attention on the physical phenomenon taking place and not get immersed in the procedural detail. Students can perform multiple experiments since the procedure is simple and short in time. This also reinforces the validity of their results. Multiple tests could also be used to instruct students in data analysis (mean and variance, for example).

It is also quite simple to set up multiple experimental apparatuses so that many different groups of students could perform the experiments simultaneously. After performance, the apparatuses could also be removed and stored so that the space was available for other use.

In conclusion, the following points can be made.

- An experimental apparatus has been described which demonstrates the transient response of a stirred vessel. The apparatus is flexible in application and can be used for two different experiments.
- The experimental results are very good and consistent with theory.
- The apparatus is inexpensive and simple to operate. ☐

ChE letters

SUPPLEMENTS FOR THERMO FILMS

Sir:

For some years I have used the films by Noel de Nevers entitled *Phase Behavior, Parts I and II* in my courses in thermodynamics. Using high-pressure visualization equipment and time-lapse photography, Prof. de Nevers shows examples of phase transitions in both pure and multicomponent systems. The films demonstrate skillfully those aspects of fluid-phase behavior that are frequently discussed by chemical engineers.

Because so much information is presented, however, I have found that students often miss some of the subtleties. In most sequences viewers must watch a moving phase boundary along with temperature and pressure gauges, and then correlate their observations with Prof. De Nevers' commentary. For the beginning student, this can be quite difficult.

To help solve this problem, I have prepared brief summaries of the sequences. These may be discussed with students both prior to and after showing the films and also used as a basis for more lengthy study of phase behavior. I believe that the films, together with such discussions, have great pedagogical value in thermodynamics, and I would be pleased to make these write-ups available to others on request. The two films currently have a rental cost of $14.50 each and may be obtained from the University of Utah, Instructional Media Services, 207 Milton Bennion Hall, Salt Lake City, UT 84112.

Kenneth R. Jolls
Iowa State University