

Chemical Engineering Experimentation over the Internet

Jim Henry
University of Tennessee at Chattanooga
615 McCallie Ave.
Chattanooga, TN 37403
Phone: 423-425-4398
Email: jim-henry@utc.edu

Eric Nuttall
University of New Mexico
221 Farris Eng'g Center
Albuquerque, NM 87131-1351
Phone: 505-277-6112
Email: nuttall@unm.edu

Abstract

This paper discusses the implementation of several laboratory systems that are used for remote experimentation via the Internet. The paper discusses the equipment and software developments for four systems that are used in teaching and research in controls systems and unit operations laboratories:

- a three-tank level control system (UNM)
- a twelve-tray distillation column (UTC)
- a shell-and-tube heat exchanger (UTC)
- a gas-fired water heater (UTC)

Each lab equipment system is connected to a dedicated control computer that allows real-time operation and control manipulation of that equipment via the Internet. The interaction is with web browsers with a LabVIEW plug-in. The computers collect all the data from the experiment. The systems are available 24/7 for student use. The experiment control panel can be viewed remotely (by any number of students) as they proceed via the Web and the (data files and graphs) are available on the web as the experiment proceeds and after the experiment is finished.

The paper discusses how the remote experiments are used for teaching and research. We will present the pattern of student use of the equipment and the experiences of the students in developing and using the systems.

The web address (URL) for the labs described here is <http://chem.engr.utc.edu/AICHe/Labs>

Hardware and Software

The engineering laboratories at UTC and UNM for several years has been using desktop computers for data acquisition and control of engineering equipment. The data acquisition and control software is written with LabVIEW software.

More details are given in Henry (1996, 1997, 1998a, 1998b and 2001).

Hardware Stations

Several stations for chemical engineering laboratories are available. They are stations for controls systems experiments, stations for chemical engineering and environmental engineering and stations for mechanical engineering.

- a three-tank level control system (UNM)
- a packed-bed absorption column (UTC)

- a gas-fired water heater (UTC)
- a twelve-tray distillation column (UTC)

All these systems are inherently stable systems when run in open-loop configuration. That is, if you specify a fixed input value, the system will reach a constant steady-state condition.

More complete descriptions of these have been given before (Henry, 1993, and Henry, 1995).

Software

The systems are operated by student operators using the common Web browsers with (free) LabVIEW plug-ins for the browser. The software running on the lab computer operates the equipment under the conditions of parameters as chosen by the student operators.

Details of the systems and experimental work

Three-tank level control system (UNM)

This apparatus consists of three interconnected tanks. Each tank is fitted with a static pressure sensor, which gives a voltage output proportional to the level of liquid in the tank. There are six manual ball valves v1, v2...v6, which can be utilized to vary the configuration of the process or to introduce disturbances. Two diaphragm pumps are utilized in this apparatus. These pumps are designed to give an accurate well defined flow per rotation. The flow rate provided by each pump is proportional to the voltage applied to its DC motor. Liquid is pumped into the tank-1 and tank-2. The apparatus is interfaced to a computer using the National Instruments, DAQ 6024-E data acquisition card. The function of the board and processing of sampled data is carried out in the LabVIEW programming environment. Figure 1 shows the schematic of three-tank system.

Control of the three-tank level process

The objective of a controller for this apparatus is to control the level of liquid in both tank 1 and tank 2. From an inspection of the above equations, it is obvious that the pump flow rate $Q_1(t)$ is used to control the level in the first tank and $Q_2(t)$ is used to control the level in tank2. The schematic of multi-loop control for this process is shown in Figure 2, where it is assumed that PI control is utilized. The system is controlled by a LabVIEW control panel as shown in Figure 3.

To show the capability of this system for education and research, Figures 4-6 show the performance of the system with a PI controller simultaneously controlling the levels in tank-1 and tank-2. These figures are for the standard Ziegler-Nichols tuning (Figure 4), an integral time of ten times the Z-N suggested value (Figure 5), and an integral time one-tenth of the Z-N suggested value (Figure 6).

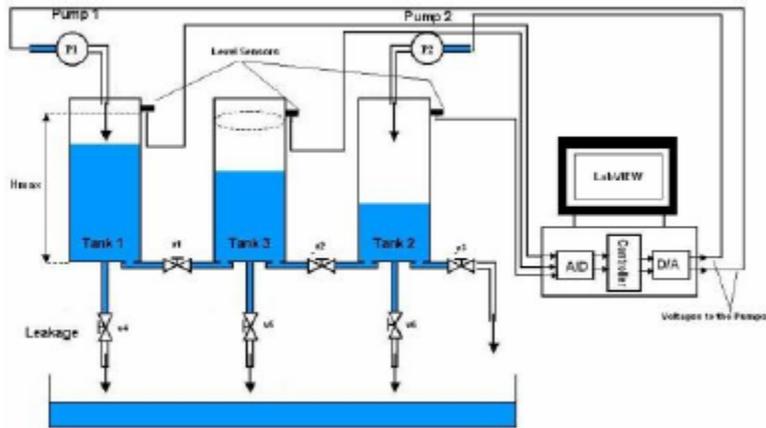


Figure 1: Schematic of the three-tank system

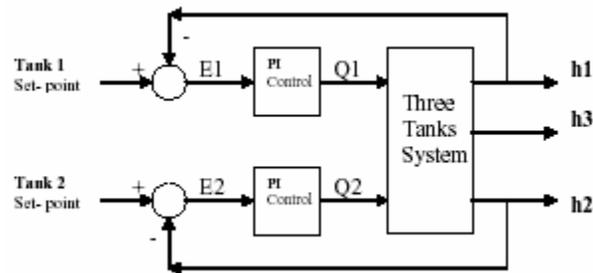


Figure 2: Control plan for three-tank system

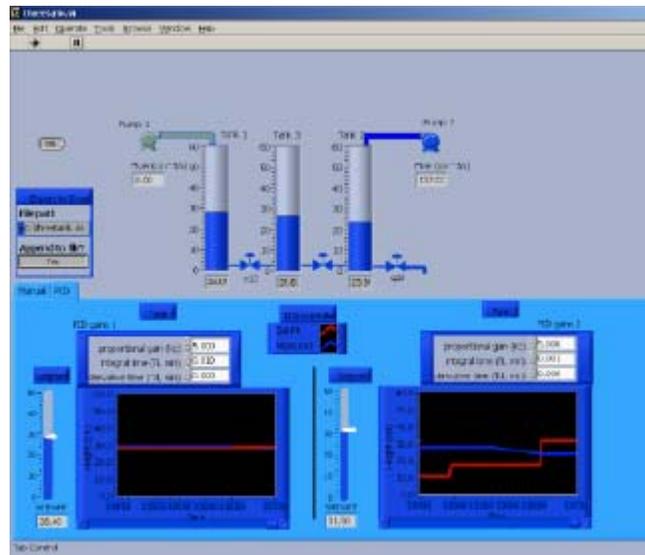


Figure 3: Control panel for three-tank system

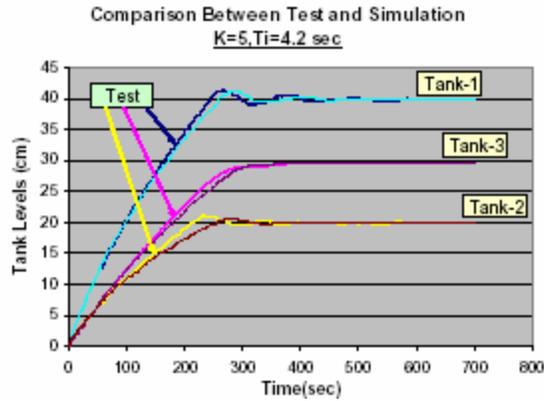


Figure 4: System Response to PI control (base case, $T_i=4.2$ sec)

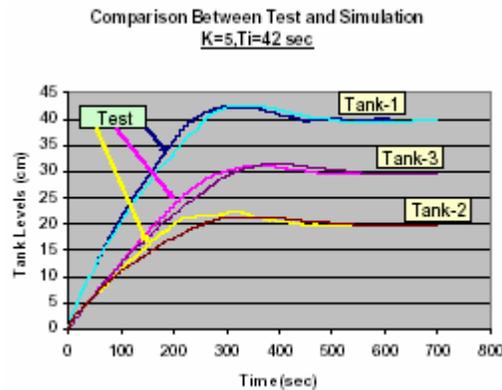


Figure 5: System Response to PI control ($T_i=42$ sec)

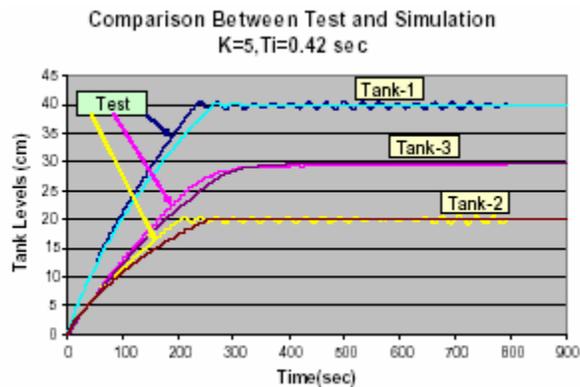


Figure 6: System Response to PI control ($T_i=0.42$ sec)

Conclusions of work with three-tank control system

During the laboratory experiments, the application of PI control to the three-tank system with two inputs and three measurable state variables was examined. The step response and behavior of the PI-controlled system was analyzed and compared with non-linear simulation model. The experiment results showed the proportional controller will reduce, but never eliminate, the steady-state error. These results also showed that implementing the PI controller will have the effect of eliminating the steady-state error, but by increasing the overshoot, it makes the transient response worse. Our experiments showed that the controller settings according to Ziegler-Nichols rules provide acceptable closed-loop response for the three-tank system. Complete details of this work can be found on the Web at <http://chem.engr.utc.edu/AICHe/Labs>

Twelve-tray distillation column (UTC)

The distillation column in the chemical engineering laboratory at UTC can be operated remotely 24/7 by students. The operation is via a remote control panel using a LabVIEW plug-in as described earlier. The column has an electrically heated reboiler that has a variable power input that the operator chooses. The column has a time-division reflux control (modulated reflux/distillate time) under operator control. The column has a variable feed rate available for operator control. The feed mixture is a fixed supply that can be varied on-site and typically is 20% methanol in water. Figure 7 shows some components of the front panel of the distillation control system.

All experimental data is logged and plotted by the laboratory LabVIEW program. The time response graphs and data file of all the experimental variables are available on the Web for monitoring by the operator or another team member (at another location) or an instructor. See, for example, <http://chem.engr.utc.edu/AICHe/Labs> for an example of experimental results.

Several safety features have been built in; one of these is that remote experiments are conducted in 15-minute chunks. Student can run as many of these chunks end-on-end as desired, but if unattended, the system will shut down at the completion of any 15-minute run.

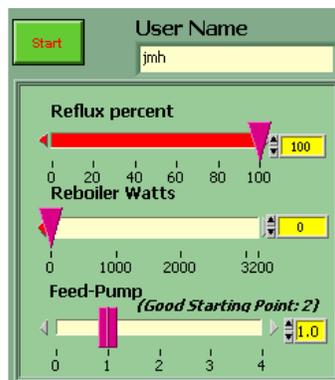


Figure 7a: Operator's control options for distillation column



Figure 7b: Clock time and run time for distillation experiment

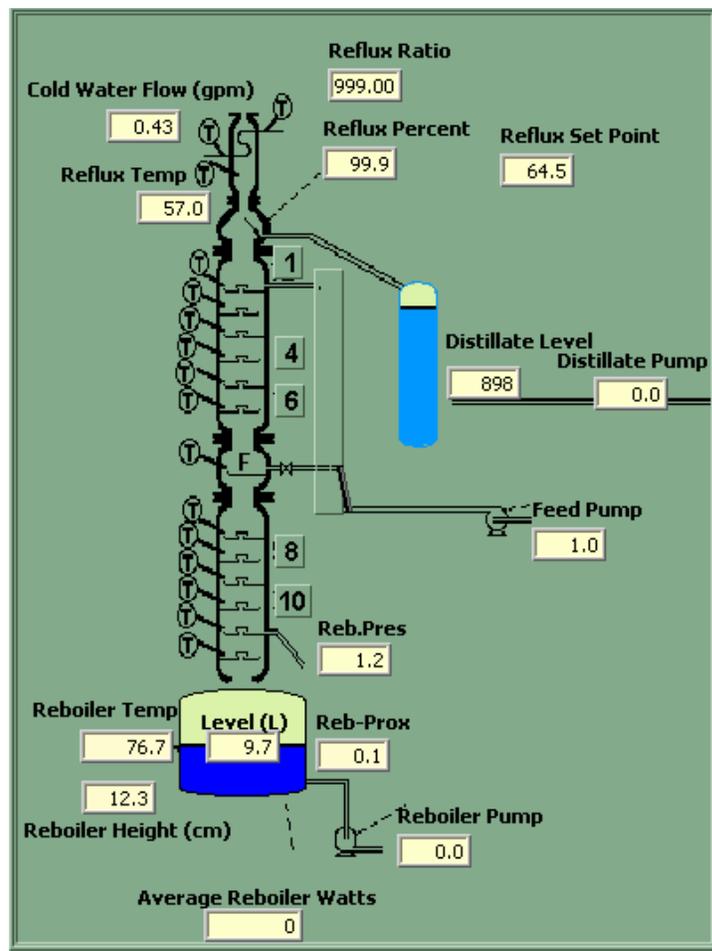


Figure 7c: Live data monitored for distillation column

Shell-and-tube heat exchanger (UTC)

A heat exchanger with a tube bundle in a shell has been available for Web operation and experimentation. Details are at <http://chem.engr.utc.edu/AICHe/Labs>. The system is set up to provide a PID feedback control system for temperature control or for heat exchange experimentation. The control panel is set up to resemble a recording controller in a control room. Figure 8 shows the image of this control panel.

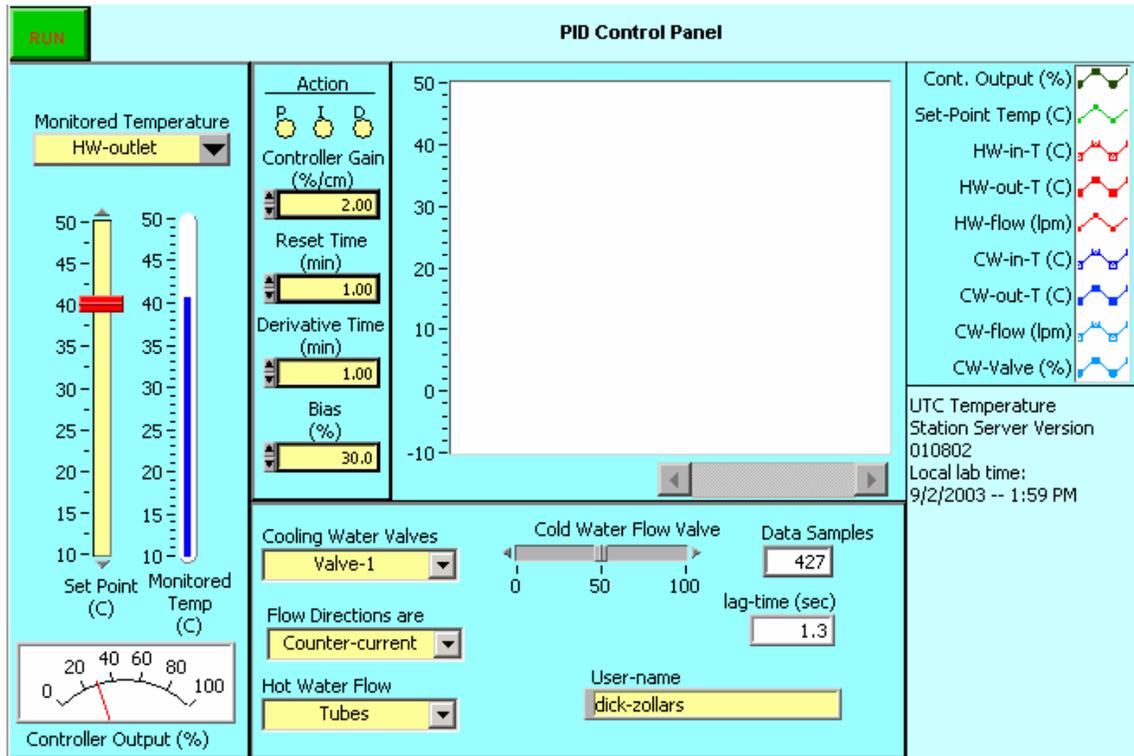


Figure 8: Control panel for heat exchange experimentation

Again, the experiment can be monitored by several people at once as well as watching the progress of an experiment by way of dynamic data files and results graphs.

Gas-fired water heater (UTC)

A residential style gas-fired water heater has been installed and can be operated on the Web. The student-operator can control the water flow rate through the unit and observe temperatures of the inlet and outlet water streams and the inlet air and outlet flue gas. The system is excellent for showing energy balance procedures and for showing transient operation of equipment.

Figure 9 shows the remote control panel for the gas-fired water heater. As described above, the experiment can be monitored by several people at once as well as watching the progress of an experiment by way of dynamic data files and results graphs.

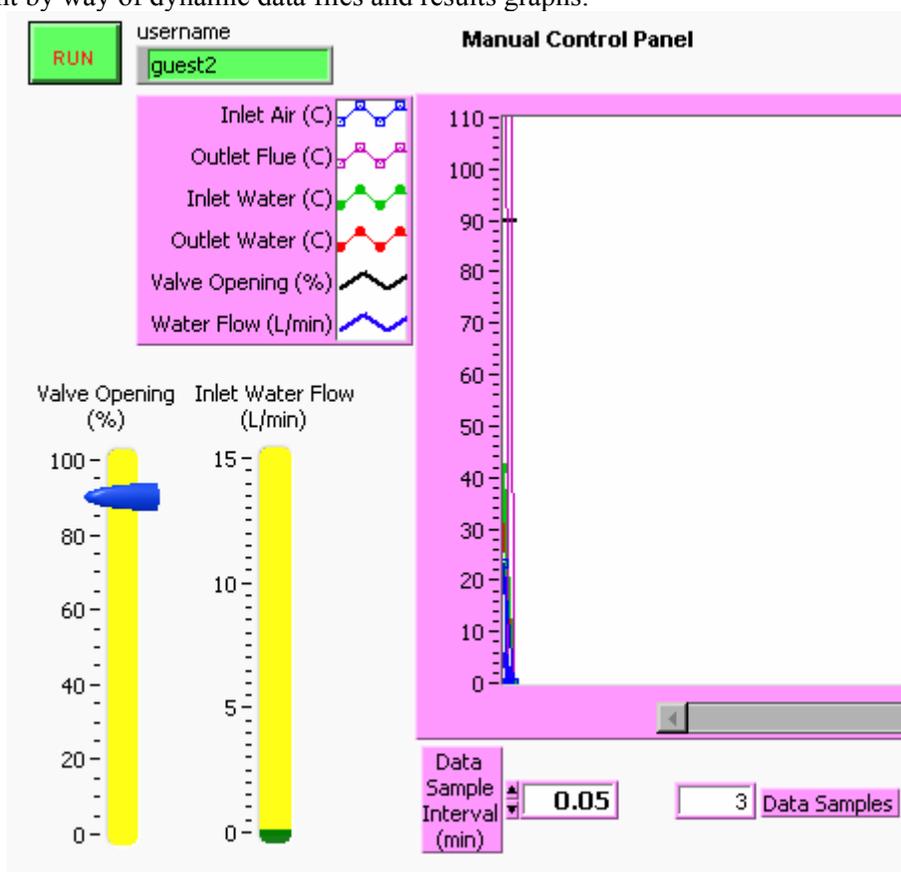


Figure 9: Remote control panel for gas-fired water heater

Observations and conclusions

The Web accessible experiments in chemical engineering are providing an auxiliary to traditional hands-on experimentation. They have been shown to be reliable over an extended period of time. Students generally show a positive attitude to running experiments remotely. It has been observed (Colton, 2003) that there is a richness of results that result from experimentation that is collected from as many variables as is typical of these Internet connected experiments.

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Bibliography

Colton, Clark, (2003), "Heat exchanger experiment at MIT," International Conference on Engineering Education, July, 2003, Valencia, Spain.

Henry, Jim, (1993), "Engineering Controls Systems with LabVIEW," Scientific and Engineering Applications for Macintosh, Woburn, MA, August, 1993. Available via Web at <http://chem.engr.utc.edu/Henry-Pub>

Henry, Jim, (1995), "LabVIEW Applications in Teaching Controls Systems Laboratories," ASEE Annual Meeting, Anaheim, CA, June, 1995. Available via Web at <http://chem.engr.utc.edu/Henry-Pub>

Henry, Jim, (1996) "Web-based Controls Laboratory Hardware and Software," available via Web at <http://chem.engr.utc.edu/Henry-Pub>

Henry, Jim, (1998a) "Laboratory Teaching via the World Wide Web," ASEE Southeastern Meeting, Ireland, FL, April, 1998. Available via Web at <http://chem.engr.utc.edu/Henry-Pub>

Henry, Jim, (1998b), "Running Laboratory Experiments via the World Wide Web," ASEE Annual Meeting, Seattle, WA, June, 1998. Available via Web at <http://chem.engr.utc.edu/Henry-Pub>

Henry, Jim, (2001), "Web-Based Laboratories: Technical and Pedagogical Considerations," AIChE Annual Meeting, Reno, NV, November, 2001. Available via Web at <http://chem.engr.utc.edu/Henry-Pub>

Biographical Information

JIM HENRY

Jim Henry is Professor of Chemical and Environmental Engineering at the University of Tennessee at Chattanooga. Dr. Henry has also worked for a U.S. Department of Energy research lab, DuPont Company and Chevron Oil.

For the past 12 years, he has focused on developing data acquisition and control application in laboratories for controls systems, chemical and environmental engineering. He also teaches the courses in principles and in design of chemical and environmental engineering processes. His research is in the area of applied control systems, fuzzy control and distillation control.

ERIC NUTTALL

Eric Nuttall is Professor of Chemical and Nuclear Engineering at the University of New Mexico. He directs graduate student research on in situ bioremediation as well as teaches an annual course on bioremediation.