A FLEXIBLE PILOT-SCALE SETUP FOR REAL-TIME STUDIES

IN PROCESS SYSTEMS ENGINEERING

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The inclusion of process control experiments in chemical engineering curriculums and the introduction of new process control experiments[1, 2, 3] indicate recognition of the importance of real-time experiments in process systems engineering. The experiments allow an instructor to reinforce and demonstrate theoretical systems concepts presented in lectures. Laboratory systems experiments in an academic setting provide the students with an invaluable opportunity to familiarize themselves with important practical issues (*i.e.*, nonideality of industrial processes), such as process-model mismatch, measurement noise, inadequate number of measurements, digital measurements, actuator saturation, unmeasured disturbances, and process nonlinearity—issues often neglected in computer simulations.

This manuscript describes a low-maintenance, low-safety-risk, flexible, 0.9-m × 1.5-m × 2.4-m, pilot-scale setup that can be used for training students and carrying out research in process systems engineering. It briefly states typical applications of the setup. Detailed specific sample applications of the setup, together with real-time results, will be presented in forthcoming paper(s).·

The setup was built in the Department of Chemical and Biological Engineering at Drexel University and is located in the Process Systems Engineering Laboratory. The setup allows one to study a variety of process-systems engineering concepts such as design feasibility, design flexibility, control configuration selection, parameter estimation, process and instrument fault detection and identification, controller design and implementation, instrument calibration, and process modeling. Notable features of the setup are its flexibility and low safety risk (because it uses water only). The setup can be single-variable or multivariable, mildly or strongly nonlinear, interacting or noninteracting, and/or single- or multi-tank.

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TYPICAL APPLICATIONS OF THE PILOT-SCALE SETUP

With the flexibility to operate in various configurations, and its many sensors and actuators, the setup allows real-time study of a variety of process-systems engineering concepts. Figure 4 shows the variables that can be measured and/or adjusted in this setup. Below is a brief description of typical real-time studies that one can perform using the set-up.

Process Modeling

Given the online measurements, models including first-principles, empirical (black box), or hybrid (first-principles/empirical)[7] can be developed to describe water temperature and/or level in one or both tanks. In the case of empirical and hybrid modeling, the students can be taught model-parameter estimation as well. Hybrid model parameters include the resistances of the tank exit pipes as well as the overall heat transfer coefficients of the coiled copper tube banks. The model structure is obtained from mass and energy balances in the cases of first-principles and hybrid modeling, and from prior process knowledge (an assumption) in the case of empirical modeling. The empirical modeling can be off-line or online. In the latter case, one has to use a model identification method.[7]

Process Design Analysis

The setup can be used to analyze the following process design aspects:

- ***Feasibility.*** *Given desired steady state values of temperature(s) and level(s), and nominal values of temperature and flowrate of the disturbance stream (inlet stream with no control valve), students are asked to evaluate theoretically and experimentally the feasibility of the design to operate at the desired steady state; that is, to check whether the design can provide heater power, water flowrate, and energy (through the heating/cooling coils) adequate to operate the process at the desired steady state.[8] For example, a desired water temperature below the city water temperature is definitely infeasible.*

- ***Flexibility.*** *Flexibility is feasibility in the presence of uncertainties such as disturbances and parameter uncertainties/variations. In this analysis, the students are asked to evaluate the feasibility of the design to operate at a given steady state when the temperature and flowrate of the disturbance stream vary within a given range.[8] Students can map theoretically the disturbance region in which the design is feasible and then verify the region experimentally.*

Process Control

The setup can be used to carry out the following process control studies:

- ***Measurement Selection.*** *Many control problems with one or more objectives can be posed, with students then asked to list the measurements needed to achieve the control objective. These objectives include control of temperature and/or level in Tank 1, and/or control of temperature and/or level in Tank 2. For example, for control of temperature in Tank 1, at least, the temperature measurement T5 is needed.*

- ***Control Configuration Selection.*** *After choosing the necessary measurements, students can be asked to propose a set of manipulated inputs that can be used (adjusted) to realize the control objective(s). The*

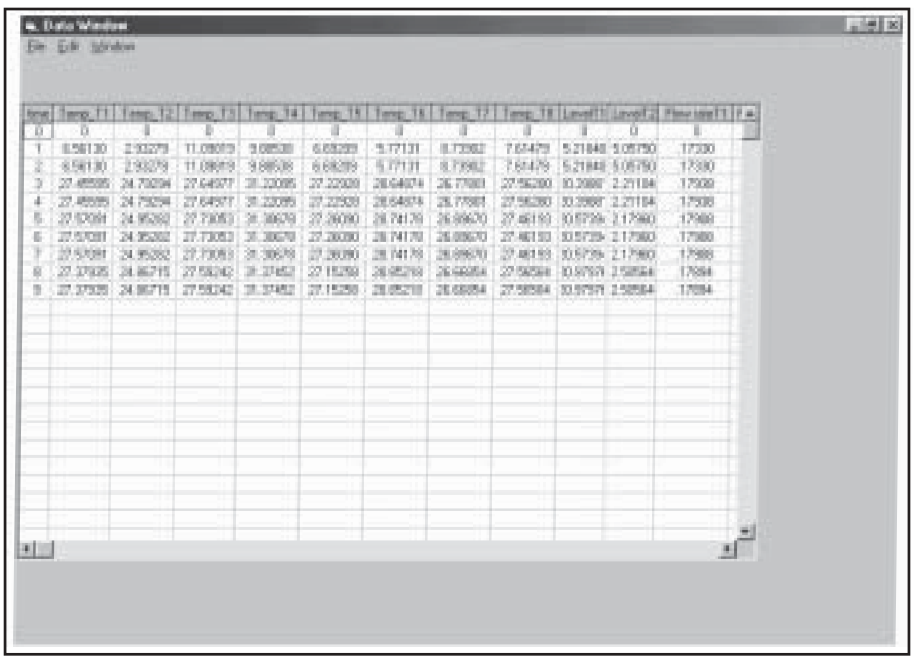

Figure 3. *Front-end interface for temperature control and data storage.*

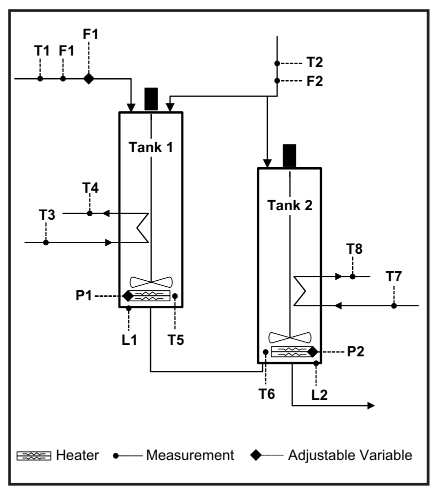

Figure 4. *Adjustable and measured variables of the setup.*

between the raw digital signal (that the computer sends to the data acquisition board) and the actual value of the corresponding physical variable. For example, the control valve calibration curve can be obtained by measuring the flowrate with the rotameter at different, constant, raw digital signals set at the computer. For a sensor, a calibration curve is obtained by finding the relation between the raw digital signal that the computer receives from the data acquisition board and the *actual* value of the corresponding physical variable. For example, an RTD is calibrated by placing it in beakers of water at different known temperatures and recording the value of the corresponding steady-state, raw, digital signal received by the computer. A typical calibration curve is presented in Figure 5. It shows how the flowrate of the water stream through the control valve depends on the raw digital signal.

Calorimetric Studies

The electrical heaters can be used to simulate heat of reactions. An exothermic reaction or set of exothermic reactions can be considered and simulated on the microcomputer, and the rate of heat production by the simulated reaction(s) is then sent to the heater to set the heater power to the calculated rate of heat generation. Material and energy balances for the tanks, considered with the temperature and flowrate measurements, can then be used to estimate the power to the heaters; that is, the rate of heat production by the simulated reactions.

CONCLUSIONS

This manuscript describes a low-maintenance, low-safety-risk, flexible, pilot-scale setup that can be used for training students and carrying out research in process systems engineering. It briefly states typical applications of the setup. Detailed specific sample applications of the setup together with real-time results will be presented in forthcoming paper(s). The setup allows one to study a variety of process systems engineering concepts in real time. Among these concepts are design feasibility, design flexibility, control configuration selection, parameter estimation, process and instrument fault detection and identification, controller design and implementation, instrument calibration, and process modeling. The setup can be used to provide graduate and undergraduate students with hands-on experience and to carry out research in process systems engineering.

ACKNOWLEDGMENTS

The authors would like to thank Srinivas Tatiraju, Neeraj Zambare, and Roberto Pena for their input into the project, and Dan Lau for his essential role in assembling the setup. The authors would also like to thank the Department of Chemical and Biological Engineering at Drexel University for supporting this project.

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