A PILOT-SCALE HEAT RECOVERY SYSTEM FOR COMPUTER PROCESS CONTROL TEACHING AND RESEARCH

P. J. CALLAGHAN, P. L. LEE
and R. B. NEWELL
University of Queensland
St. Lucia, Qld, Australia 4067

IN THE LAST two decades efficient energy utilization and process integration have become increasingly important to chemical plant economics. Plant design for these factors has meant higher levels of process interaction, often with positive feedback, which require improved control. A typical example is the heat recovery circuit in reactor or distillation systems.

Process equipment used in the laboratory to investigate the control problems created by tighter process integration is more convenient. This can be summarized as

- **Lower cost of pilot-scale equipment, and**
- **Loss of production and or product quality are not issues during process experimentation.**

However, instrumentation and control equipment is "off the shelf" as is found in industry and hence is a significant cost factor. The aim in building process control rigs for undergraduate teaching and graduate research is to create rigs that are

- **Flexible enough to demonstrate a number of basic principles**
- **Sufficiently complex to demonstrate common process control problems such as nonlinearities and interactions between variables**
- **Economical**

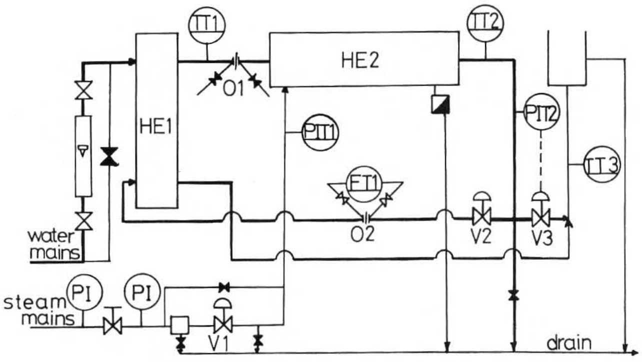


FIGURE 1. Schematic diagram of pilot-scale heat recovery circuit.

The pilot-scale heat recovery system is a valuable teaching and research tool. It is sufficiently flexible to demonstrate basic principles and yet sufficiently complex to demonstrate common process control problems such as nonlinearities and interactions between variables.

Due to the important role of real time computing in process control, it is essential to provide teaching and demonstration facilities of such techniques. In addition, most advanced control strategies require the use of process control computers for successful implementation.

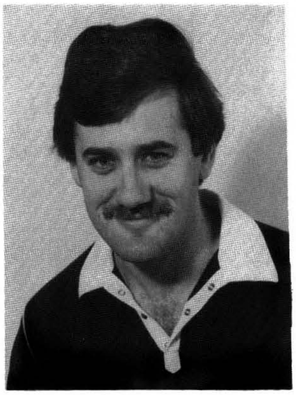
TABLE 1
Equipment Details

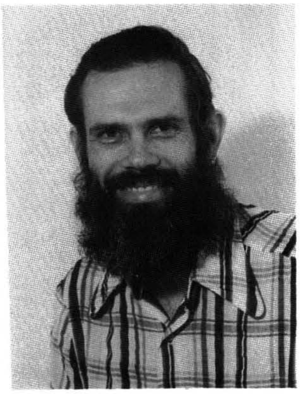
Valves V1 and V2	Fisher Control Valves, size 34 and 30 respectively
Valve V3	Badger Meter Inc, size B
Double pipe exchanger	2.43m long, 13mm diameter copper pipe, 38mm diameter copper jacket
Plate heat exchanger	Alpha Laval P20-HB
Rotameter	Metric Series 18 with S.S. plug
dp Cell	Taylor Instuments, 0-5″H_2O
Pressure transmitter PIT1	Beckman, 0-500 kPa
Steam supply pressure to experimental apparatus	0.2MPa
Pressure transmitter PIT2	Honeywell, 0-500 kPa

PILOT-SCALE HEAT RECOVERY CIRCUIT

A schematic diagram of the laboratory rig is shown in Figure 1. Mains water is preheated in a pre-heat plate heat exchanger, HE1. After preheating it flows through a steam heated double pipe heat exchanger, HE2. After the double pipe exchanger the water splits either to be used in the preheat plate heat exchanger or to bypass the heat exchanger. When the streams rejoin they are fed to a constant head drain. A control valve, V3, is installed in the bypass line and may be used to regulate the bypass flowrate. Equipment details are given in Table 1.

There are two manipulated variables in the system: a control valve in the steam line, V1, and a control valve, V2, in the hot line after the double pipe exchanger leading to the preheat plate exchanger. They can be used to control any of the dependent variables, but typically the final mixed temperature, TT3, and the temperature out of the double pipe exchanger, TT2, are used. A standard differential-pressure bypass control loop is usually implemented to maintain the pressure drop across the plate heat exchanger constant.





P. J. Callaghan received his BEChem and his MEngSci degrees from the University of Queensland in 1984 and 1986. His Master's programme centered on the development and use of a predictive control algorithm for the heat exchange system described in this paper. He is currently employed by Akoa Ltd. as a control engineer. **(Not pictured)**

P. L. Lee received his BEChem from RMIT in Melbourne and his PhD from Monash University in 1980. He worked in the design and commissioning of computer control systems for both continuous and batch plants for three years before coming to Queensland. His early research was on the control of the unstable steady state in an exothermic CSTR. His interests include multivariable self-tuning and adaptive control of fermentation and heat recovery systems. **(L)**

R. B. Newell received his BScApp and BEChem from Queensland and his PhD from the University of Alberta. He also has a DipEd in Tertiary Education from Monash. He joined the staff at Monash University in 1974 and moved to Queensland in 1980. His early research was in the multivariable control of a pilot plant evaporator, unstable steady state control in a CSTR, and multilevel hierarchical optimization. Current interests include optimization of the Australian oil refinery and transportation system, combined fuzzy and deterministic control, and selftuning and adaptive control of heat recovery systems. **(R)**

PROCESS-CONTROL SYSTEM INTERFACE

An interface box between the process instrumentation and the control system is located on the rig. This box displays all rig variables, both manipulated and controlled, *i.e.*, the steam pressure, the hot side water flowrate to the plate heat exchanger, and the three temperature measurements and the valve positions. The interface box is supplied with 240V AC power and supplies 24V DC for instruments and transducers. Standard signals are 0-5V for control signals and 1-5V for measurements. The interface box also has the facility to switch the manipulated variables from remote to local, by interrupting the signal from the control system and supplying a manual signal.

Figure 2 shows the responses in the exit tempera-

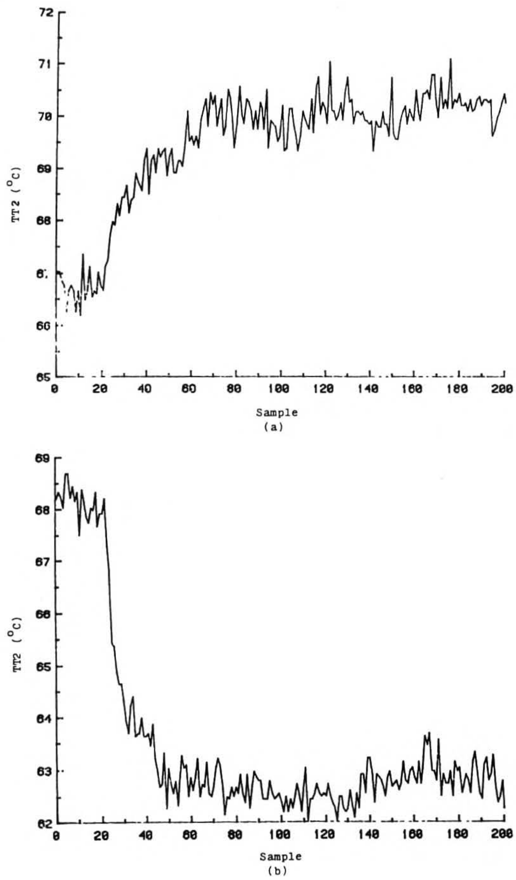


FIGURE 2. Step test responses for TT2 due to a 10% step (a) up and (b) down in VI after sample 20.

ture to 10% step changes up and down in the steam. The sample time during the collection of this data was five seconds. Note that both magnitude and shape of responses differ, illustrating non-linear behaviour. Also the need for filtering is apparent from this raw data.

CONTROL SYSTEM EQUIPMENT

Basic Data Collection and Regulatory Control

The control system used to monitor and control the pilot-scale apparatus is arranged as shown in Figure 3. This equipment is arranged in a hierarchical manner, consisting of two layers: a primary data collection and regulatory control level, and an advanced control level.

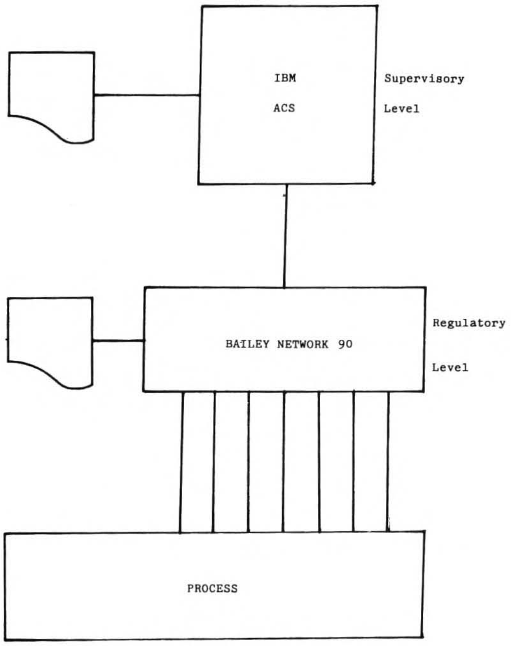


FIGURE 3. Control system equipment.

The primary data collection and regulatory control functions are performed using a Bailey Network 90 distributed control system. The heart of the system is a "multi-function controller," which is a micro-processor based controller. It performs all of the regulatory control functions and coordinates the operation of the analog-to-digital input and digital-to-analog output cards. Operator interface is provided by means of a color CRT display. This display is capable of showing schematic representations of the pilot-scale equipment with measurement data displayed, controller faceplate displays, trend plots of measurement inputs, and combinations of the above types of displays.

Advanced Control Function

The advanced control functions, such as implementing multivariable predictive controllers are performed using the IBM Advanced Control System (ACS) previously described in this journal by Koppel and Sullivan [1]. However, this application uses ACS in a real-time environment.

The University of Queensland installation consists of an IBM 4341-2 mainframe with 8 Mbytes of memory, 12 terminals and 2 printers in two clusters, line-printer, 1.8 Gbytes of disc storage, a tape drive and a Series/1 minicomputer with direct process I/O and connections to the Bailey Network 90 system.

UNDERGRADUATE COMPUTER-BASED PROCESS CONTROL INSTRUCTION

The experimental rig has a number of interesting characteristics that make it particularly suitable for teaching real-time process control:

- **Non-linear behaviour. This is shown in Figure 2, which illustrates the different time constants for a step increase and a step decrease in the steam supply valve V1. The time constants are approximately 96 and 45 seconds respectively.**
- **Interacting behaviour. This is illustrated by examination of the relative gain array for this process shown in Table 2.**
- **The inherent noise in the measurements, again illustrated in Figure 2.**

The following teaching experiments utilize this rig:

*1. **Examination of digital filtering.** Students are asked to examine the effects of different filter bandwidths and different filter types (exponential, Butterworth, union). This short experiment is used in teaching real-time computing and would be expected to take one hour of laboratory time.*

*2. **A cascade loop** controls the double pipe exit temperature with a slave loop controlling the pressure in the steam jacket via the steam valve. This experiment only utilizes the Bailey Network 90 system and students are expected to complete this experiment in one and a half hours.*

*3. **Feedforward control.** A feedforward controller compensates for disturbances in the feed flowrate by adjusting both the steam and water valves. This experiment, combined with a model identification exercise usually takes about three hours of laboratory time.*

*4. **Decoupling control.** Two feedback loops or two interacting feedback loops are used as a basis for in-*

troducing the concept of process interactions. The students are then expected to design and implement a decoupled controller using lead-lag compensators. This experiment normally takes six to nine hours to complete.

5. ***Adaptive control.*** *An adaptive single loop controller adjusts the steam valve to control the exit temperature. This experiment, used in a fourth-year elective control course, makes use of the ACS system and would normally involve fifteen hours of laboratory time.*

POSTGRADUATE PROCESS CONTROL RESEARCH

Current research utilizing the rig is on a predictive control design technique described by Maurath, *et al.* [2]. The basic predictive control algorithm uses a model to predict the output for a number of future moves due to the previous inputs. An error is formed by subtracting the prediction of the output from the setpoint. This error vector is then used to calculate a change in the manipulated variables. The design technique being tested is to use a singular value decomposition to condition the Dynamic Matrix [2] of step responses. Results from this study are reported elsewhere [3].

Future work on the rig will include fuzzy identification and control. A model-based controller designed around a fuzzy model of the process will be used to control the rig. Fuzzy identification techniques will be used off-line to derive an initial model, and on-line to provide continuous updating of the model. The on-line use of fuzzy identification turns the model-based controller into a fuzzy adaptive controller [4, 5, 6].

A reactor heat recovery system is a possible extension to the current rig. This is achievable by using an exponential function on the exit temperature of the double pipe exchanger to move the steam valve. This allows for simulation of variable heats of reaction without the danger and cost of reactants. In this mode only one manipulated variable is possible, i.e., the water valve (V2).

CONCLUSIONS AND SIGNIFICANCE

The pilot-scale heat recovery system is a valuable teaching and research tool. It is sufficiently flexible to demonstrate basic principles and yet sufficiently complex to demonstrate common process control problems such as nonlinearities and interactions between variables.

The process control system equipment allows students to obtain experience in real time computing, at several process control functional levels.

TABLE 2
Relative Gain Array

	TT2	TT3
V1	0.22	0.78
V2	0.78	0.22

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4. Graham, B. P. and R. B. Newell, "Computer Control of Difficult Processes," *Chemeca* **84,** Vol 2, pp. 743-749 (1984).
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ChE letters

UPDATED REFERENCES

Dear Editor:

In a recent paper, "A Course in Mass Transfer with Chemical Reaction," *Chem. Eng. Ed.*, **21**, No. 4, 164 (Fall 1987), W. J. Decoursey refers to *Gas Liquid Reactions* by P. V. Danckwerts as a source in English for the seminal papers by S. Hatta which were published in Japanese [*Technol. Repts. Tokoku University,* **8**, 1 (1929); **10**, 613,630 (1931); and **11**, 365, (1932)]. Complete translations of the latter articles have been published in *International Chemical Engineering,* **18**, 443-475 (1978). The readers of this article may also be interested to know that a translation of the closely related pioneering paper by G. Damkohler, "The Influence of Diffusion, Fluid Flow and Heat Transport on the Yield in Chemical Reactors," *Der Chemie-Ingenieur,* **3**, Part I (1937), has recently been published in *International Chemical Engineering,* **28**, 132-198 (1988).

Stuart W. Churchill
University of Pennsylvania