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Bridging the Gap between Academia and Industry Rose-Hulman Institute of Technology Unit Operations Laboratory

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Abstract—**This paper describes the deployment of an industrial Process Automation System (PAS), in the Chemical Engineering Unit Operations (UO) laboratory at Rose-Hulman Institute of Technology and its incorporation in the undergraduate curriculum. The UO laboratory has over a dozen of pilot-scale process units (skids) and creates an environment very similar to a typical chemical, petrochemical or pharmaceutical plant. Students learn how to maintain their process under control, take it safely from one operating condition to another, collect and analyze data using a process historian, respond to process alarms and remotely troubleshoot their experiments with limited process information.**

I. Introduction

THE field of Process Control in the process industries has entered a new stage marked by enormous advances in computers and instrumentation. In order to respond to the new reality and to better prepare our graduates for industry, we have revised the process control component in the Chemical Engineering curriculum at Rose-Hulman Institute of Technology. The backbone of the new process control experience is an industrial Process Automation System (PAS), namely DeltaV by Emerson Process Management. The paper describes the deployment of the PAS in the Unit Operations (UO) laboratory and its incorporation in the undergraduate Chemical Engineering curriculum.

The UO laboratory is well recognized for its educational value in the Chemical Engineering curricula. It is often the only place where exposure to industrial practice and new technologies occurs within the typical four-year engineering curriculum. This is especially relevant in the Process Control area, where the gap between classroom-based training and the real world is a core issue. One of the major goals of the current process control experience in the Chemical Engineering curriculum at Rose-Hulman Institute of Technology is to expose all chemical engineering students to industrial grade process instrumentation, control system architecture, and control and tuning algorithms. Another goal is to introduce students to the industrial practices of data storage, management and retrieval.

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II. Description of the Unit Operations Laboratory

A. Overview

The UO laboratory in the Chemical Engineering department at Rose-Hulman Institute of Technology occupies 6,500 ft^2 of laboratory space and has over a dozen pilot-scale process units (skids), such as heat exchangers, pumps, distillation column, chemical reactors filtration units and a fermentor. Most of them have been designed for manual operation with local gauges and manual switches. During the past five years several of the existing experiments have been re-designed and converted to run under the PAS. Each one of the redesigned UO skid is treated as a plant area and is functionally isolated from the others. Students can control the experiments and access the data historian through operator stations in a centralized control room or through remote operator stations located in close proximity to each experiment. Closed circuit TV cameras monitor critical process areas and are accessible through the school network.

B. Layout of the Process Automation System Deployment

The layout of the process automation system deployed in the UO laboratory is shown in Fig. 1. The system has four controllers with associated I/O modules, two engineering stations, two operator stations, one process historian and four remote operator stations. The total number I/O points connected to the system is around 150.

The control system network (CLAN) is a stand-alone redundant network connecting the controllers, the engineering and operator workstations and the process historian. For security reasons it is not connected to the

Institute network.

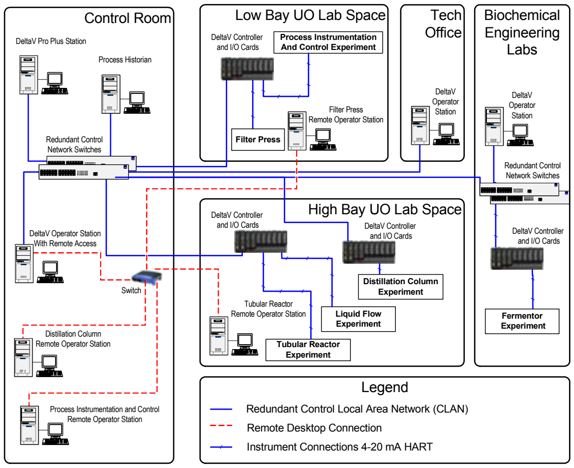

Fig. 1. Layout of the industrial process automation system deployed in the Unit Operations laboratory. The system has four controllers with associated I/O modules, two engineering stations, two operator stations, one process historian and four remote operator stations. Six experiments are operated by the system.

One of the engineering stations has the capability to be accessed remotely through remote desktop connection via a computer switch. It can support up to eight simultaneous remote sessions. There are four remote operator stations that use this type of access to the control system. The remote desktop access to the control system reduces the cost of the installation because the hardware requirements for the remote operator stations are less demanding than the requirements for the regular (engineering or operator) stations. In addition, students can use their laptops to connect to the control system via the remote desktop facility. There is also a wireless router (not shown in the figure) connected to the remote desktop switch that allows wireless access to the control system within the Chemical Engineering building.

Most of the instrument signals are 4-20 mA with HART communication. All thermocouples (around 40) and a few of the RTDs are terminated at the I/O back plane using appropriate input modules.

C. Description of the Experiments Operated through the Process Automation System

1. Distillation Column

The P&ID of the distillation column experiment is shown in Fig. 2. The column is two stories high, made of glass. There are 17 sieve trays, 6 inches in diameter, a total condenser and a thermosiphon reboiler. The top of the column is open to atmosphere. The column separates a binary mixture of isopropanol and isobutanol. Electric heating rods are used in the reboiler. The feed can be introduced at trays 7, 9 or 11.

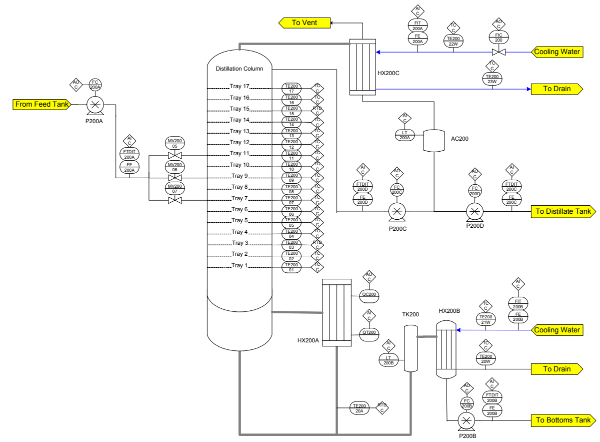

Fig. 2. PID of the distillation column. The column separates a bimary mixture of isopropanol and isobutanol at atmospheric pressure.

The flow rates of the feed, distillate, bottoms and reflux streams are measured by Coriolis flow meters and manipulated by variable speed magnetically coupled gear pumps. There are sampling ports that allow the collection of samples from the process streams for off-line composition analysis. The stream composition is determined off-line by measuring the density of the samples. Two magnetic flow meters measure the flow rates of cooling water in the condenser and the bottoms product cooler. There are thermocouples and RTDs at various locations. Material and energy balances can be readily performed based on the existing measurements.

In the normal control configuration, the feed flow rate, the reflux flow rate and the reboiler heat duty are fixed. The bottoms flow rate is manipulated in order to maintain constant level in the reboiler. The distillate flow rate is manipulated in order to maintain constant level in the accumulator. Two close circuit cameras monitor the levels in the accumulator and the reboiler and send their feed to a TV monitor in the control room.

In the inferential control configuration, the reflux flow rate is manipulated in order to maintain constant temperature at tray 15. In the advanced control configuration, the reflux flow rate and the reboiler heat duties are manipulated in order to maintain constant temperatures at trays 15 and 3, respectively.

2. Instrumentation and Control

The P&ID of the instrumentation and control experiment is shown in Fig. 3. The main purpose of this experiment is to introduce the students to industrial grade process instrumentation. Water is pumped from a tank through three flow meters utilizing different technologies for measuring flow: Coriolis, vortex shedding and orifice / differential pressure.

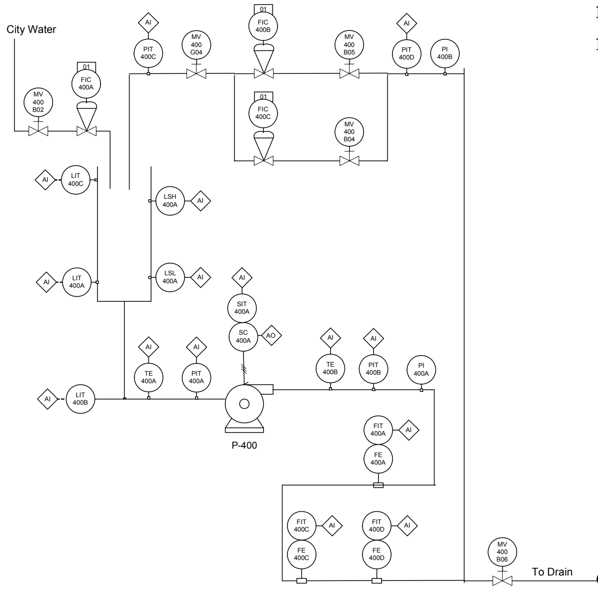

Fig. 3. PID of the instrumentation and control experiment.

There are three devices that measure the water level in the tank: one ultrasonic and two differential pressure transmitters. One of the differential pressure transmitters is correctly installed on the tank wall while the other one is installed on the exit pipe from the tank and produces erroneous measures in the presence of flow. In addition to the continuous level measurements, there are two vibrating fork level point devices used as high and low level switches.

A variable frequency drive (VFD) is used to change the pump speed and manipulate the water flow through the system. Flow rate can also be manipulated by three control valves with different flow characteristics. Two of the control valves have positioners while the third one does not.

The setup can be operated in closed or open system modes. In closed system mode there is no water entering or leaving the system and the tank level remains constant. In open system mode water goes in and out of the system and the tank level varies depending on the inlet and outlet flow rates. When in open system mode, the experiment can be run as a variable demand or a variable supply operation.

3. Tubular Reactor

The P&ID of the tubular reactor experiment is shown in Fig. 4. Two reagents, ethyl acetate aqueous solution and caustic solution, are mixed at a desired ratio and send through a tubular reactor at a desired flow rate. Two magnetic flow meters measure the flow rates of the individual components. Two control valves with positioners work in tandem to maintain the specified ratio. A third control valve, also with a positioner, manipulates the total flow rate through the reactor.

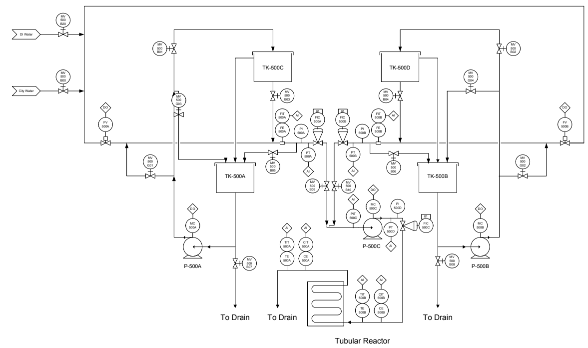

Fig. 4. PID of the tubular reactor experiment.

The reactor is 75 feet long, 0.5 inches ID. It can be operated in laminar, transitional and turbulent (plug) flow regimes. The composition is determined by conductivity measurements. Two conductivity probes measure the conductivity at the inlet and the outlet of the reactor. Based on their readings, the conversion in the reactor can be calculated.

4. Plate-and-Frame Filter Press

The P&ID of the plate-and-frame filter press experiment is shown in Fig. 5. It is used to separate slurry of calcium carbonate in water. Only one frame with two plates is employed.

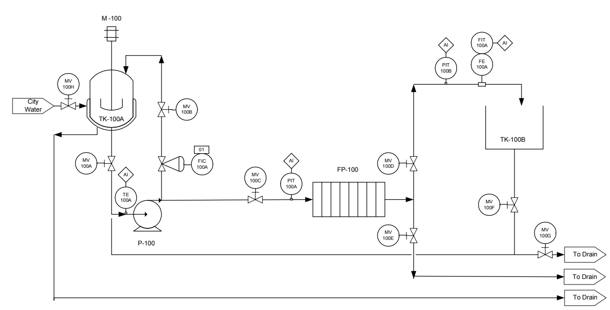

Fig. 5. PID of the filter press experiment.

Two pressure transmitters measure the pressure before and after the filter. A magnetic flow meter measures the flow rate of the filtrate. A control valve manipulates the flow rate through the bypass line so that a specified constant pressure drop across the filter is maintained.

The solid content of the slurry and the cake is determined by analyzing samples in a microwave dryer. The collected data in this experiment are used to calculate the filter medium resistance, the specific cake resistance and the cake compressibility.

5. Fermentor

The fermentor in the UO laboratory has an in-situ sterilizable culture vessel with 20 L working volume and can support both microbial and cell culture applications. The P&ID is shown in Fig. 6.

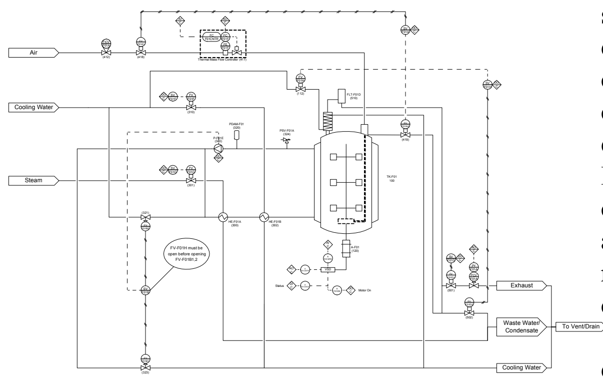

Fig. 6. PID of the fermentor experiment.

Currently, the equipment and the control system are still being configured and tested for fermentation runs in batch operating mode. The only functionality of the unit studied in the UO laboratory so far has been the temperature control in the jacketed vessel.

6. Liquid Flow

The liquid flow experiment examines friction losses in various pipes and fittings. It has only two instruments, a Coriolis flow meter and a differential pressure transmitter. Both instruments have local displays that are used by the students for data collection.

III. Student Activities in the UO laboratory Related to Process Control

A. Description of the UO Laboratory Courses

The Chemical Engineering curriculum at Rose-Hulman Institute of Technology has three UO laboratory courses. The first one is during the Spring quarter of the junior year. Students complete only one experiment. They spend one afternoon a week (4 hours) in the laboratory during the first six weeks. The last four weeks in the quarter are allotted for data analysis, report writing and oral presentations.

The other two laboratory courses are during Fall and Winter quarters of the senior year. They meet two afternoons (total of 8 hours) a week. Students complete two experiments in each of these courses. Students spend six sessions in the laboratory for each experiment and the rest of the time is dedicated to written and oral reports.

B. Maintaining Processes under Control

The main purpose of the industrial process automation system deployed in the UO laboratory is to enable the safe and reliable operation of the experiments. In many cases students' objectives are not related to process control but the use of the control system enables them to achieve their objectives. For example, the control system maintains the distillation column safely at steady state at the specified operating conditions, so that students can complete material and energy balances as well as tray efficiency calculations. In the plate-and-frame filter press experiment the control system maintains a constant pressure drop across the filter, so that students can calculate the filter medium resistance, the specific cake resistance and the cake compressibility.

This activity is similar to what most industrial process engineers do on a daily basis when using the control system to operate their processes. Students become familiar with the operator displays and the standard controller faceplates. They learn how to operate the controllers in manual (MAN) and automatic (AUTO) modes and immediately understand the meaning of the terms "set point tracking" and "bumpless transfer".

C. Changing Operating Conditions

Another task common to most process engineers is moving the process safely from one set of operating conditions to another. In many cases this cannot be achieved by the push of a single button. Students need to understand the process and the control strategies involved in it. They also need to recognize that control systems have limitations and in some cases the process has to be manually taken from the old operating conditions to the vicinity of the new operating conditions.

For example, in the tubular reactor experiment, the control system can maintain the flow rate through the reactor at set point very well, but the process will become unstable if a set point change from laminar to turbulent regime is executed in automatic mode. In this situation students have to switch from automatic to manual mode and move the system manually towards the new operating conditions.

D. Data Collection, Monitoring and Retrieval

The control system historian keeps a record for most of the I/O points in the system. The data are stored on the historian for two years. At the end of the two year period the data are backed up and removed from the machine.

For each experiment there are process history view charts (trend displays) that show the change of the selected process variables in time. Students monitor these charts in order to visualize the trajectory of each variable. The trend displays are often used to determine when the experiment has reached steady state. Since data are stored for two years, students can compare their data to historical data in order to identify and troubleshoot abnormal situations. An Excel add-on allows data from the historian to be imported and manipulated in Excel.

E. Experience with Control Instrumentation

One of the goals in the UO laboratory is to provide hands-on experience with industrial grade process instrumentation. The instrumentation and control experiment presents a unique opportunity to study the installation and operation of a wide variety of instruments. This opportunity is seldom available to process engineers because the instrumentation in a real plant is not always readily accessible.

Students examine and compare three different technologies for measuring flow rate: Coriolis, vortex shedding and orifice / differential pressure. They are also shown proper and improper installation of a differential pressure transmitter for measuring level in a tank and can see firsthand the consequences. Students determine the installed characteristics of control valves and can clearly observe the difference between valves with and without positioners. Students are introduced to variable frequency drive (VFD) technology and its application to flow manipulation.

Students use a Field Communicator device to examine the local settings of the various instruments. In some cases they re-span the sensor ranges and calibrate the control valves. They also check the instrument configuration in the control system database to ensure that it matches the instrument settings in the field.

F. Experience with Process Documentation

The documentation associated with the UO laboratory experiments follows industrial standards and best practices. Students work with process and instrumentation diagrams (P&ID) as well as with loop diagrams. They become familiar with the standard symbols used to denote process control instruments on the P&IDs. The loop diagrams provide insight into the electrical connections, something that is not covered in the typical Chemical Engineering curriculum. An example of a loop diagram is shown in Fig. 7.

G. PID Control of Non-Linear Processes

Two of the experiments, the plate-and-frame filter press and the tubular reactor, exhibit strong non-linearities. Both of them have standard PID controllers that require different settings of the tuning parameters in the different operating regions.

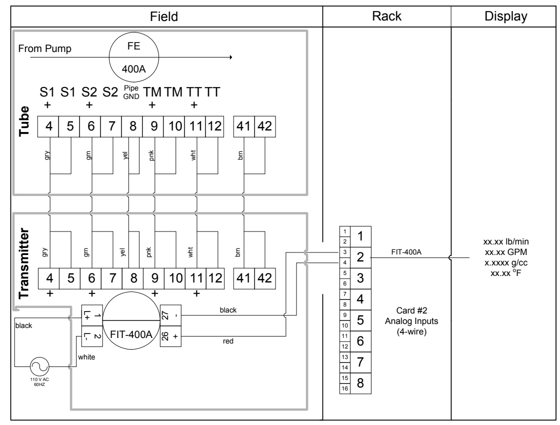

Fig. 7. Loop diagram for the Coriolis flow meter in the instrumentation and control experiment.

When performing these two experiments, students become aware of the limitations of the PID controllers in non-linear systems. The scheduling of the controllers is deliberately not automated, and the tuning parameters must be entered manually by the students. In some instances, students are asked to retune the controllers for the new operating conditions.

H. Advanced Process Control

This is a relatively new application that is currently being developed as part of a graduate project. The goal is to achieve dual composition control in the distillation column using the built-in MPC capabilities of the control system. Once in place, it will be incorporated into the regular UO laboratory experiment objectives.

IV. Collaboration with Industry

Bridging the gap between industry and academia requires an effort on both sides. Academia cannot do this alone. Industry has to help academia in this challenging task. At Rose-Hulman Institute of Technology we were fortunate to work with a lot of industrial partners who believed that industry is responsible for the direction of control education at the undergraduate level.

The deployment of the industrial process automation system in the UO laboratory would have been impossible without industrial collaboration. We worked with a number of industrial partners who provided significant financial and technical support. Atanas Serbezov and Ronald Artigue each spent one sabbatical year in industry performing process control related activities. Technical advice from process control professionals was received in numerous areas, from the control system architecture to the re-design of the experiments and the documentation associated with it.

V. CONCLUSION

The incorporation of an industrial process automation system in the UO laboratory has enabled us to bridge the gap between industry and academia in the area of process control. Even when the objectives of the UO laboratory experiments are not directly related to process control, students gain valuable practical experience working with the control system. They learn to maintain their process under control, take it safely from one operating condition to another, collect and analyze data using a process historian. Students become proficient using and creating standard process documentation. They also have an opportunity to examine common industrial process instrumentation.

To further bridge the gap between industry and academia, we have proposed to combine the industrial process automation system with high fidelity process simulation and create a “Virtual Plant” environment that will be integrated in the Chemical Engineering curriculum. This will bring the educational experience of our graduates much closer to the current industrial practice in a very cost effective manner. The “Virtual Plant” environment will provide a vehicle for enhanced learning of process engineering principles at various levels of understanding - from process plant awareness for freshman and sophomore students to detailed process equipment and control operations for junior and senior students.