Neutralization Control Unit (NCU)

Operating Manual
1. Background

Complex industrial processes must be controlled well to ensure an economic return on investment, the safety of operating personnel and the local community, and to preserve the environment. Though steady state operations may often be the ideal condition for such processes, the behavior of industrial processes is often not static but very dynamic, requiring control systems to ensure safe and profitable operations. Even what appears to be a simple process can present difficult control challenges. The process for neutralization of an acid with a base is one such – seemingly simple – process.

2. Description of Equipment

Figure 1 shows a schematic of the NCU test facility.

![Figure 1 Nonlinear Control Apparatus (in one of two available control strategies)]
This pilot-scale process utilizes acid (HNO₃) and base (NaOH) streams mixed in a continuously stirred tank. The apparatus contains two complete sets of equipment (one for each section of the course). The NCU uses dilute acid and base solutions (between 0.002-0.007M each, depending on current specifications) for safety and environmental reasons. Automatic control valves are used to regulate the flow rates of the acid and base streams, each of which enters the tank via ¼" steel pipe. An air mixer, manually operated from the field control panel, provides agitation. Centrifugal pumps (not shown) located near each supply tank generate the pressure necessary to provide acid and base feed flows. Differential pressure orifice meters provide measures of flow. The span of these transmitters is 100% ≈ 25 cm³/sec. The small metal tank located in the acid stream pathway is used to introduce a time delay. Each inlet stream contains a recirculation line back to the storage tank. This recirculation line not only protects the pumps during normal operation but also facilitates mixing of the solutions before startup. There is also an overflow line which prevents the tank from spilling onto the floor if the level gets too high.

The inlet streams mix in a Plexiglas tank. A differential pressure transmitter detects the liquid level in each tank. The span of this transmitter is 100% ≈ 50 cm. The pH sensor is located downstream from the mixing tank, thereby introducing a time delay in the pH measurement. The range of this transmitter is 2-12 pH. A dynamic material balance serves to estimate the effluent flow rate, which is controlled by a third automatic control valve.

Honeywell’s Experion PKS (Process Knowledge System) distributed control system (see below) serves as the data acquisition and control platform for the NCU. The system receives process measurements and makes adjustments to the control valve positions to control the flow rates, tank level, and pH. The experiment utilizes cascade control structures commonly used in the process industries. Low-level regulatory loops (secondary or slave controllers) are used to control the acid, effluent, and base flow rates. A higher level (primary or master) controller maintains the tank level at its desired value by manipulating the setpoint of either the acid flow rate controller or the effluent flow rate controller (a button on the schematic switches the level controller’s output between the two secondary controllers). Another higher level controller maintains the pH at its desired value by manipulating the setpoint of the base flow rate controller.

3. Using the Honeywell Experion PKS Control System

Honeywell’s Experion is a distributed control system (DCS) widely used in industry and on many lab experiments here at LSU. In Experion, a Control Module (CM) serves to represent each process variable. Each CM is a collection of Function Blocks (FB) with each FB consists of many values called parameters. Within a CM (and sometimes between CM’s), the FB’s are “wired” together in various ways to monitor and control the process. Operations personnel may enter desired values of many of these parameters via the computer keyboard. The purpose of the next few sections is to explain how to use Experion to run this equipment.

4. Logging in to Honeywell

Access to the Honeywell Experion DCS application is through a virtual machine using VMware Horizon View software. After logging into one of the thin clients in the UO Control
Room, among the icons on the desktop shown is the **UOLAB** icon. Double-clicking this icon should bring up a virtual machine, suitable for operating a Honeywell-controlled unit in UO Lab.

Open the Honeywell Station software either by double-clicking the **Station** icon. If login credentials are proper, the **Station** program appears and – *exercise patience here* – the following default splash screen within it:

The Honeywell login process is now complete.

**5. Overview of Operations**

The system is controlled partially from a manual control panel and partially from a computer schematic.

First, turn on the main power and the acid and base pumps (three light switches on the manual control panel).

From the **Unit** item on the menu, select **NCUn** (where n can be 1 or 2), as designated by supervision or assignment. Operations personnel can run each unit separately, or two different operating teams can run each separately. The **NCUn** P&ID schematic appears. This schematic is much like a Process and Instrumentation Diagram (P&ID) with four controller faceplates.

**6. Controlling From The P&ID Schematic**

A small colored circle containing the tag name of the CM represents each controller, with the values of the setpoint (backlit in green) and the process value (backlit in cyan) near the circle. The first letter indicates the type of measurement - **L** for level, **F** for flow, or **A** for analyzer (pH in this case). To change an analog value from a schematic, click on it - if changes are permitted, its background changes, then enter the new value. The changeable objects in this display are the SP and tuning constant values near each controller, and there are additional objects on the faceplates, as explained below.
The primary value associated with a controller is the measured input, or process value (\(PV\)). In addition to the \(PV\), controllers have many more values, the most important of which is the setpoint, or SP. A typical example of an SP is the speed setting on an automobile’s cruise control - the controller manipulates its output (the throttle position in this case) to move the \(PV\) to the SP and hold it there. The SP (in green) and the PV (in cyan) are shown immediately to the side of the circle representing the controller. Just below these values are the tuning constants (in tan): \(K_c\) (proportional gain), \(\tau_i\) (integral time constant, or reset), and \(\tau_d\) (derivative time constant, or rate). The four small windows to the left and right of the P&ID are the faceplates for four of the five controllers. Honeywell schematics can display only four faceplates at once. To see the fifth faceplate (either the acid flow rate or the effluent flow rate), click on the “Display Fxxx Faceplate” button just above and to the left of the level controller.

From a controller faceplate, you can see the tag name, description, engineering units, instrument range, and several of the most critical parameters on the controller. You can also change many of these parameters. Near the bottom of the faceplate is a drop-down menu box labeled MD, which can be used to select the mode of the controller. Immediately above the mode are the OP (changeable), the PV (not changeable) and the SP (changeable). To change the OP or SP, single-click the value, type in the new value and press ENTER. Change the SP values and tuning constants on the schematic the same way.

### 7. Controller Modes

As mentioned above, a controller has an SP and an OP. Engineering units for the OP are always in percent (0-100%), and the SP has the same engineering units as the PV (in this experiment, the acid and base flow rates are in cc/sec, the tank level is in percent full, and the pH is in pH units).

When the controller mode is MANUAL, the OP holds constant until the operator changes it. When you want to change it, click the OP in the faceplate, type in the new value, and press ENTER. The new OP holds constant until changed again. **Note that you may enter an OP only while a controller is in MAN.** When the mode is not MAN, the controller uses the PV, SP and tuning constants to calculate the OP. When the mode is AUTOMATIC, you may enter a new SP for control. **Note that changing an SP affects the OP only while a controller is in AUTO.**

For practice, change the output of the acid flow rate controller to 50% (wait a few seconds for the \(PV\) to reach a steady flow rate), then to 100% (wait a few more seconds), and then back to −6.9% (−6.9% is known as “tight shutoff” in the Experion system). Notice the small bar under the control valve on the schematic – its length is proportional to the output.

Sometimes controllers are stand-alone (i.e., there are no connections to any other controller), and sometimes they are in a cascade structure (like the level-to-acid flow rate controllers and the pH-to-base flow rate controllers in this equipment - cascade connections are indicated by solid lines with small circles on the schematic). The upper controller in a cascade (the one sending its OP to another controller’s SP) is called the primary and the lower controller (the one sending its OP to a valve) is called the secondary. Secondary
controllers require an additional mode to let the computer system know when to “close the cascade” (i.e., put the cascade structure fully on control). In the Experion system, this additional mode is called **cascade**. When the mode of the primary is **AUTO**, and the mode of the secondary is **CAS**, the cascade is said to be “closed,” and the primary is sending its **OP** to the **SP** of the secondary. When the mode of the secondary is **AUTO**, the operator is responsible for changing the **SP** of the secondary to control the process.

The circle representing a controller appears filled with a color which indicates the current mode of the controller. For all controllers, yellow means the mode is **MAN**. For primary controllers, cyan means the mode of the primary is **AUTO**, but the mode of the secondary is not **CAS** (i.e., the primary is ready to start sending new **SP** values as soon as the secondary goes to **CAS**). For secondary controllers, cyan means the mode is **AUTO** (i.e., any new **SP** must come from you, not from the primary). Finally, for all controllers, white means the mode is in its normal state - entirely on control, which is **AUTO** for primary controllers and **CAS** for secondary controllers. For practice, set both the pH and base flow rate controllers to **AUTO**. Notice that the background of both controllers changed from yellow to cyan. Now set the base flow rate controller to **CAS** (i.e., close the cascade). Notice the change in background colors of both the primary and secondary controllers. Now put both controllers back in **MAN** and set the flow rate **OP** back to -6.9% to stop the flow.

### 8. Sampled Data Control

Unlike dedicated analog instrumentation for process control, the Honeywell Experion uses microprocessor-based digital computers to perform regulatory control tasks, and workstation and server PC’s to configure the system, build control strategies and schematics, and gather and display data. At regular intervals of time, such systems perform needed calculations. The time between two consecutive data readings is called the **sampling time**, and such systems are called **sampled data systems**. The sampling time used in this Experion system is one (1) second. Data collection, control algorithm processing, and the sending of outputs to manipulated devices occur each second.

### 9. Display Navigation

When you logged into Flex Station, you used an item from the menu bar to call up the main NCU schematic. There are several additional ways to go from one display to another. For example, you can enter the tag name of a controller in the Command field at the top of the screen and press **F12** to call up the detail display. Try it with your acid flow rate controller (**F101** for NCU1, or **F201** for NCU2). For a controller, the detail display has 7 tabs. The one labeled **LOOP TUNE** may be useful for tuning your flow rate controllers.

Most of the toolbar buttons are for navigation – some require the entering of a name or number, and some go directly to the display. Most of the same functions are on the function keys. For example, to return to the previous display, click **[◀]**, or press **F8**. To return to the display before that, do it again.

From most displays (both system displays and custom schematics such as **NCUn**), double-clicking any value associated with a CM takes you to its detail display. From a detail
display, click  or press F2 to return to the main NCU schematic. On most custom schematics there may also be buttons to get you from one display to another quickly.

10. Using Trends

There are three buttons on the main NCU schematic to call up trend displays. The buttons under the acid and base control valves display the \textbf{PV}, \textbf{SP}, and \textbf{OP} of both the primary and secondary controllers associated with that control valve. These are very useful while tuning the individual controllers. The third trend button displays the \textbf{PV}, \textbf{SP}, and \textbf{OP} of both the level and pH controllers. This trend shows the interactions between the two controllers. With all controllers on computer control, a well-tuned system brings the system back to steady state (i.e., both level and pH within 0.3\% of \textbf{SP}) within 15 minutes of any reasonable disturbance or setpoint change to the level and the pH controller(s). Click the \textbf{Trend Level \& pH} button.

At the bottom of the trend is the legend with all the \texttt{tag.block.parameters} associated with the traces. The checkboxes in the \texttt{Pen} column indicate which traces are currently on the trend. Click on the chart area of the trend, and a white hairline cursor appears on the chart, and the values at the hairline cursor appear in the \texttt{Reference Value} column of the legend. Along the bottom area of the chart is a horizontal scroll bar which allows you to scroll the chart area back and forth. Along the left axis, you'll find the low and high range of the selected trace. These allow you to change the range of the trace for the selected parameter. Practice by changing the range of the level controller to 20-80 % full.

Immediately above the left side of the chart area is a drop-down list which allows you to select one of the traces (you may also click anywhere on the line for this trace in the legend area). When you select an active trace, it highlights (i.e., becomes thicker) in the chart area. Above the right side of the chart area is the \texttt{Period} drop-down list. This drop-down list allows you to select the period for which you want data displayed in the chart area. To the right of that is the \texttt{Interval} drop-down list. This drop-down list allows you to select the interval between points in the chart area. Practice changing to a different period and interval. Leave the period set to 1 day and the interval at 1 minute for now.

For practice, scroll back until some variation in some of the traces appears. Notice that the timestamps below the chart area change as you scroll. Find some local max or min in one of the traces and click on it. Now change the period back to one hour and notice that the cursor centers on (or at least near) the local max or min. If necessary, move the hairline, so it is precisely on the peak or valley. Notice that the values, as well as the date and time, are shown in the \texttt{Reference Value} column in the legend. Now return the trend to the current time by clicking \texttt{.}

Save all changes you make to the trend by clicking the familiar Windows Save icon just above the right end of the chart area next to the word \texttt{(Modified)}.

11. Saving Data into Excel

Controller tuning – particularly for the level and pH controllers – requires analysis of a great deal of data in the time domain. An Excel™ workbook containing a Visual Basic Add-In is
provided to facilitate the collection of this data. On the Desktop, look for a folder named

**Excel SpreadSheets**

Within that folder, open the folder named

`snr`

Double click on `NCURecorder_n.xls` (where `n` is 1 for NCU1; 2 for NCU2).

The workbook opens with a **Start** button, the experiment name, a drop-down menu box for selection of collection frequency, and a **Stop** button on the top line. Click **Start**, and the workbook starts collecting the relevant data at the specified collection frequency. These data are extremely pertinent to the analysis or your results. While the workbook is collecting data, it may be scrolled, but you should not attempt to do anything else in this instance of Excel until after you click **Stop**. If you do, the collector may stop, and you may lose valuable data.

When you finish a run, click **Stop** and cut or copy whatever data you need to your daily workbook in a separate instance of Excel. Let the workbook collect data while you complete the following step for practice.

### 12. Manual Control

Though not typically required for any particular NCU assignment, the following optional manual control exercises provide practice controlling the experiment manually from the Experion Flex Station:

- Leave all controllers in **MAN**, adjust the acid flow rate **OP** so that the **PV** is about 12.5 cm³/sec, and adjust the base flow rate **OP**, so the **PV** is about 12.5 cm³/sec.
- When the tank level rises above 20% (or if it already exceeds this value), open the effluent valve a little so the pH probe can start reading properly the exiting contents of the tank, but not so much that the level decreases. (Depending on which NCU in use, this could mean either raising or lowering the effluent controller **OP**. Why?)
- When the level rises above the stirrer paddles, go to the manual control panel, turn on the air-operated stirrer, and adjust its speed, so the vortex is about 1 cm deep.
- When the tank level approaches 50%, adjust the **OP** of the effluent control valve until the level becomes steady at about 50%.
- Adjust the acid and base **OP** values to hold the level and pH constant (i.e., less than 1% change in five minutes) with the level anywhere between 45 and 55% and the pH anywhere between 6.5 and 7.5.
- Now simultaneously decrease the acid flow rate **OP** by 15% and increase the base flow rate **OP** by 15%. Wait a few minutes for the level and pH to reach new steady-state values. What should happen to the level? What should happen to the pH? What happens to each? Why?
- Click on the **Stop** button in the Excel workbook.
Practice saving the data to another workbook in a separate instance of Excel (do not copy or cut the buttons or the drop-down list box), then save that workbook to the C:\Temp directory on this workstation, and finally save the copy in C:\Temp to your group’s directory using COPY/PASTE (not SAVE AS…).

13. Shutdown Procedure

Before leaving for the day, each team must execute the following procedure:

- Put all controllers of the assigned NCU into MAN.
- Turn off the agitator.
- **IF THE ONLY REMAINING NCU TEAM**, then, at the manual control panel, turn off both pumps and main power.
- Set both the acid and base flow rate OP values to -6.9%.
- Close the block valve before the acid flow controller (either Valve 7 or Valve 6) and close the block valve before the base flow controller (either Valve 12 or Valve 11).
- Set the tuning parameters of all five controllers to $K_c = 1$, $T_i = 0$, and $T_d = 0$. (If gain scheduling is being used, set all gain values to 1.) In all cases, save a record of the controller parameter settings for reuse later.
- Open the effluent control valve (F100 or F200) to drain the tank completely, and then close the effluent control valve.
- Partially fill the tank with two gallons of municipal water using the one-gallon container at the unit labeled NCU Water Jug. Refill the jug as necessary from the tap at one of the lab sinks.
- Open the effluent valve, drain to 1/3 full (the pH meter should read between 7 and 9 pH S.U.), and then close the effluent control valve (F100 or F200) and the manual valve on the exit line after the control valve (Valve 16 on NCU1, Valve 17 on NCU2).
- **IF NOT THE ONLY REMAINING NCU TEAM**, leave.
- **IF THE ONLY REMAINING NCU TEAM**, Open Valve 8 and Valve 13 completely. Doing this will allow laboratory staff to maximize the flows of acid and base through the mixing loops during feed preparation the next lab day.

14. Tag Descriptions with Engineering Units

<table>
<thead>
<tr>
<th>Tag name</th>
<th>Description</th>
<th>EngrUnit</th>
</tr>
</thead>
<tbody>
<tr>
<td>F101</td>
<td>Tank 1 Acid Flow Rate</td>
<td>cc/sec</td>
</tr>
<tr>
<td>F102</td>
<td>Tank 1 Base Flow Rate</td>
<td>cc/sec</td>
</tr>
<tr>
<td>L100</td>
<td>Tank 1 Level</td>
<td>Percent</td>
</tr>
<tr>
<td>A100</td>
<td>Tank 1 pH</td>
<td>pH (SU)</td>
</tr>
<tr>
<td>F100</td>
<td>Tank 1 Effluent Flow Rate</td>
<td>cc/sec</td>
</tr>
<tr>
<td>F201</td>
<td>Tank 2 Acid Flow Rate</td>
<td>cc/sec</td>
</tr>
<tr>
<td>F202</td>
<td>Tank 2 Base Flow Rate</td>
<td>cc/sec</td>
</tr>
<tr>
<td>L200</td>
<td>Tank 2 Level</td>
<td>Percent</td>
</tr>
<tr>
<td>A200</td>
<td>Tank 2 pH</td>
<td>pH (SU)</td>
</tr>
<tr>
<td>F200</td>
<td>Tank 2 Effluent Flow Rate</td>
<td>cc/sec</td>
</tr>
</tbody>
</table>
15. Manual Valve Descriptions

<table>
<thead>
<tr>
<th>Valve Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Combined (Tank 1 + Tank 2) outlet to drain</td>
</tr>
<tr>
<td>2</td>
<td>Tank 1 outlet to Valve 1 (to drain)</td>
</tr>
<tr>
<td>3</td>
<td>Tank 2 outlet to Valve 1 (to drain)</td>
</tr>
<tr>
<td>4</td>
<td>Tank 1 discharge to inter-tank pump</td>
</tr>
<tr>
<td>5</td>
<td>Tank 2 inlet from the inter-tank pump</td>
</tr>
<tr>
<td>6</td>
<td>Acid to Tank 2</td>
</tr>
<tr>
<td>7</td>
<td>Acid to Tank 1</td>
</tr>
<tr>
<td>8</td>
<td>Acid tank recycle (for mixing)</td>
</tr>
<tr>
<td>9</td>
<td>Acid tank to pump</td>
</tr>
<tr>
<td>10</td>
<td>Acid tank outlet to drain</td>
</tr>
<tr>
<td>11</td>
<td>Base to Tank 2</td>
</tr>
<tr>
<td>12</td>
<td>Base to Tank 1</td>
</tr>
<tr>
<td>13</td>
<td>Base tank recycle (for mixing)</td>
</tr>
<tr>
<td>14</td>
<td>Base tank to pump</td>
</tr>
<tr>
<td>15</td>
<td>Base tank outlet to drain</td>
</tr>
<tr>
<td>16</td>
<td>Tank 1 flow meter outlet to drain</td>
</tr>
<tr>
<td>17</td>
<td>Tank 2 flow meter outlet to drain</td>
</tr>
</tbody>
</table>

16. Safety Considerations

Chemical Hazard

Even though these are very dilute solutions, they can still be damaging, particularly to the eyes. (The pH of the acid is typically < 3 S.U.; the pH of the base typically exceeds 10 S.U.) Wash hands immediately after contacting either liquid. If caustic or acid comes in contact with eyes, immediately flush with plenty of water.

Slipping Hazard

The overflow on the Plexiglas tank keeps it from spilling on the floor under most conditions. However, the level could exceed tank capacity, and a spill could result if both flow rate controllers are set too high, and the effluent valve is not open. Immediately mop up any spills – they are a slipping hazard.

17. Relevant Literature References


