Wastewater Treatment Example

Although the IP3416 does not have a built-in PID loop function, one is easy to implement in RLL. A common use for a PID loop is in the wastewater treatment process. Figure 1 depicts such a process. Wastewater is held in a holding tank and is distributed into a mixing chamber. The water is then mixed with chemicals to neutralize the water. The amount of chemicals mixed in depends on how caustic or acidic the water is. After mixing, the water is pumped into a discharge tank. If the water is still not neutralized it is then recirculated through the system. This is where the PID loop takes affect.

We need a method to input a number from 0...14.0, for the pH setpoint. For this, we will use 2 BCD thumbwheel switches and one toggle switch. The thumbwheel switches will be used to input the lower two digits and the toggle switch will be used to input the most significant digit of the pH setpoint.

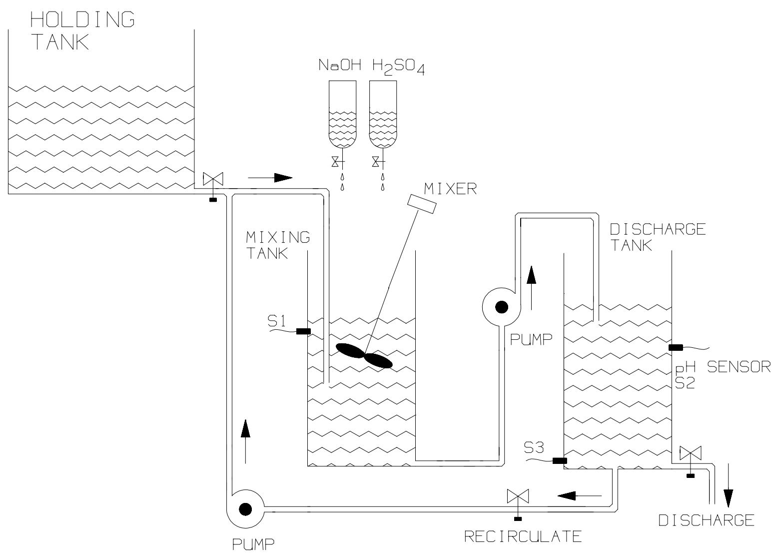

Figure 1 Water Treatment System

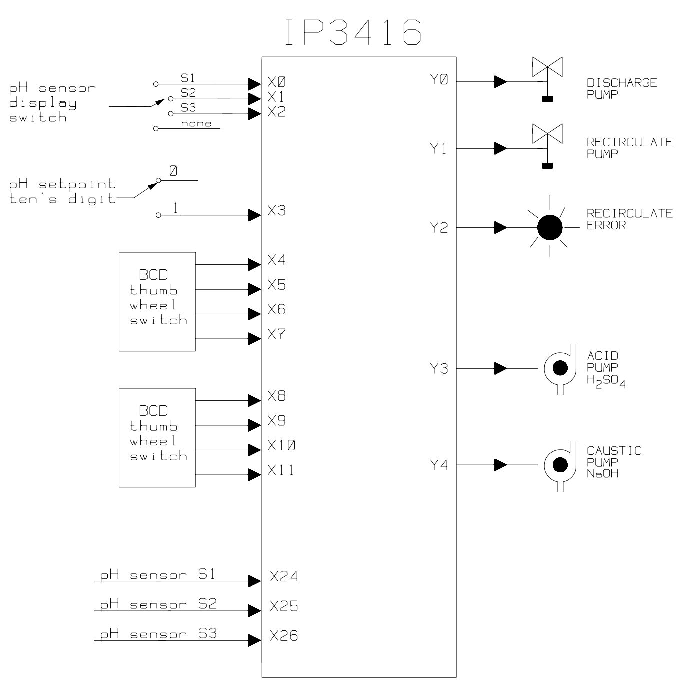

Figure 2. Water treatment system hardware diagram

We are also going to want to see the current pH reading of each of the sensors. Therefore, we will use a selector switch connected to X0, ..., X2 to select between the sensors. The three pH sensors will be connected to analog inputs X24, X25 and X26.

We need to control two valves, one to discharge the water and another to circulate the water. We also need to control the pumps that perform the discharge and recirculation of the water. We will use Y0 and Y1 for the valves and Y3 and Y4 for the two pumps.

Y2 will activate an error indicator to indicate when the water has been circulating too long. This will inform the operator there is an error in the system, which will probably, indicated the chemical tanks have to be filled.

Let's implement the method for entering a pH setpoint. The following code will translate the status of the BSD thumbwheel switches and the toggle switch into a decimal number and place it into C1.

```
      |                                        |
      | X3                             C1      |
     1|-|/|--------------------------[0]-------|
      |                                        |
      | X3                             C1      |X3 = Tens' digit of thumbwheel
     2|-| |--------------------------[100]-----|switch to input setpoint.
      |                                        |
      | X4                             C1      |
     3|-| |--------------------------[C1+10]---|
      |                                        |
      | X5                             C1      |(X7,X6,X5,X4) is units' digit
     4|-| |--------------------------[C1+20]---|of the BCD thumbwheel switch.
      |                                        |
      | X6                             C1      |
     5|-| |--------------------------[C1+40]---|
      |                                        |
      | X7                             C1      |
     6|-| |--------------------------[C1+80]---|
      |                                        |
      | X8                             C1      |(X11,X10,X9,X8) is tenths'
     7|-| |--------------------------[C1+1]----| BCD digit.
      |                                        |
      | X9                             C1      |
     8|-| |--------------------------[C1+2]----|
      |                                        |
      | X10                                    |
     9|-| |--------------------------[C1+4]----|
      |                                        |
      | X11                            C1      |C1 is pH setpoint
    10|-| |--------------------------[C1+8]----|= 0...140
```

To make things easier later on, we will convert the setpoint from pH to an analog value this is performed by the following code,

```
      |                                        |
      |                                C11     |
    11|------------------------------[C1*117/20]
      |                                        |Convert pH*10 in C1 to
      |                                C11     |C11 = 204...1023
    12|------------------------------[C11+204]-|
```

Let's implement some diagnostics. We want to view the status of the different pH sensors. We will use the selector switch connected to X0, ..., X2 to select which sensor to display. However, if no sensor is selected then display the pH setpoint.

```
      |                                        |Selector switch OFF will
      | X0     X1     X2               R12     |display setpoint in
    13|-|/|---|/|---|/|--------------( )-------|internal units
      |                                        |
      | X0                             C0      |Switch at 1st position selects
    14|-| |--------------------------[C12]-----|sensor S1.
      |                                        |
      | X1                             C0      |Switch at 2nd position selects
    15|-| |--------------------------[C13]-----|sensor S2.
```

```
   |                                       |
   | X2                            C0      |Switch at 3rd position selects
 16|-| |-------------------------[C14]-----|sensor S3
   |                                       |
   |                               C0      |pH*100
 17|-----------------------------[C0-204]--|= (A24-204)*12/7
   |                                       |
   | R12                                   |
 18|-| |-------------------------[C1*10]---|Display pH * 10.
   |                                       |
   | R12                                   |Display selected sensor
 19|-|/|-------------------------[C0*12/7]-|reading in pH * 100.
```

Now we must put in logic to control the pumps of the neutralizing agents, sulfuric acid (H_2SO_4) and caustic acid (NaOH). C9 will be the manipulative value of the PID loop. It will determine the duration between the injections of neutralizing agents. A short duration between injections will indicate the mixture is too alkaline or acidic. R2 will indicate if the mixture is alkaline or acidic. This will determine which pump we need to control. R2 and C9 are both generated later in the program.

When we are close to a neutral mixture, we do not want the pumps to turn on. We will use a setpoint tolerance of ± 0.1 pH. In rungs 20 and 25 we check for this range and only start the timing if it is not within the range.

```
   |                                       |
   |                               C0      |5 corresponds to .1 pH
 20|-----------------------------[C2-5]----|tolerance
   |                                       |
   | R2     R8     R31    T6           T7      |If effluent is too alkaline,
 21|-|/|---|/|---|/|---|/|--------(C9)------|turn on acid pump.
   |                                       |
   |                                       |Each cycle T7 will be off for
 22|---------------------------------------|.48 to 65.53 seconds and
   |                                       |on for 0.25 seconds.
   | T7                            T6      |
 23|-| |-------------------------(20)------|
   |                                       |
   | T7                            Y3      |Y3 = Acid pump, injecting
 24|-| |-------------------------( )-------|2 ml of 4N H2SO4 per stroke.
   |                                       |
   |                               C0      |C0 here overflows if it is
 25|-----------------------------[C2+5]----|NOT too acidic.
   |                                       |
   | R2     R8     R31    T8           T9      |If effluent is too acidic,
 26|-| |---| |---|/|---|/|--------(C9)------|turn on caustic pump.
   |                                       |
   |                                       |
 27|---------------------------------------|
   |                                       |
   | T9                            T8      |T9 cycles every .73 to 65.78
 28|-| |-------------------------(20)------|seconds when it is active.
   |                                       |
   | T9                            Y4      |Y4 = Caustic pump, injecting
 29|-| |-------------------------( )-------|1.5 ml of 6.25N NaOH / stroke.
```

What happens if we are continually turning on the caustic and acidic pumps and the mixture does not neutralize? The pumps could be down or the holding tanks of the neutralizing agents could be empty. We need a method for the system to alert the operator, that there might be a problem. We will check the status of the recirculation valve. If it is on for more than 180 seconds then light a warning light, but if it is on for more than 360 seconds, blink the warning light to grab the immediate attention of the operator.

```
   |                                       |
   | T0                             T1     |
 30|-|/|-------------------------(50)------|Generate a 1 Hz clock T1.
   |                                       |
   | T1                             T0     |
 31|-| |-------------------------(50)------|
   |                                       |Y1 = Recirculation valve.
   | Y1                             T16    |Recirculating for 180 seconds
 32|-| |-------------------------(180)-----|or longer times out T16.
   |                                       |
   | Y1                             T17    |Recirculating for 260 seconds
 33|-| |-------------------------(360)-----|or longer times out T17.
   |                                       |
   | T17   T16                      Y2     |From 180 to 360 seconds, Y2
 34|-|/|-+-| |--------------------( )-------|will be steadily ON.
   |     |                                 |Beyond 360 seconds, Y2 will
   | T1  |                                 |blink.
 35|-| |-'                                 |
```

We have to give the system time to stabilize between computations of the PID loop. Therefore, we will only compute the PID loop once per second. The following two lines of code perform this,

```
   |                                       |
   | T1    R91                      R1     |R1 pulses once per second.
 36|-| |---|^|--------------------( )-------|
   |                                       |
   | R1                                    |Update the following PID loop
 37|-|/|-------------------------(J)-------|once per second.
```

Now we must compute the PID loop calculation, but first we must read the necessary pH sensors. They will be read once at the beginning of the PID loop, so the same number will be used throughout the PID calculation.

```
   |                                       |
   |                                C12    |C12 is analog reading of
 38|------------------------------[A24]-----|effluent pH.
   |                                       |
   |                                C13    |C13 is analog reading of
 39|------------------------------[A25]-----|pH between the two columns.
   |                                       |
   |                                C14    |C14 is analog reading of
 40|------------------------------[A26]-----|discharge pH.
```

Let's compute the error between the pH setpoint and the pH value read at sensor 1. This will tell us what the pH is of the material in the mixing chamber. If it is too alkaline or acidic we will inject more acidic or caustic material into the mixture. This was done on rungs 20-29. Since the IP3416 does not handle signed arithmetic we will store the sign of the error in R2. If R2 is ON then we have a negative error which will indicate the mixture is too acidic and R2 OFF will indicate a positive error and the mixture to alkaline.

```
   |                                       |
   |                                C2     |Error C2 = S1 - setpoint.
 41|------------------------------[C12-C11]-|
   |                                       |R2 mean effluent less alkaline
   | R31                            R2     |Now (R2,C2) = (sign, mantissa)
 42|-| |-------------------------( )-------|e.g., (1,32767) means -1.
```

Now we must compute the error between the pH setpoint and the pH value read at sensor 2. This sensor will give us the pH value of the material that was discharged from the mixing chamber. This will be used in the PID loop to determine how much and how often we should inject the neutralizing agents into the mixing chamber. The more alkaline or acidic the discharge, the more neutralizing agents needed. This is where the PID loop comes into place. If we always injected the same amount of agents, then we will oscillate around the neutral point, never coming close to a neutral mixture. The PID loop will cause it to initially oscillate, but it will then stabilize. R3 will be used to hold the sign of the error of S2.

```
   |                                  |
   |                        C3        |Error C3 = S2 - SP.
 43|------------------------------[C13-C11]-|
   |                                  |
   | R31                    R3        |R3 means mixture less alkaline
 44|-| |-------------------------( )-------|
```

Now we will calculate the error at sensor 3. This sensor will determine if the material has been neutralized and if it should be discharged. R4 will be used as the sign of the error.

```
   |                                  |
   |                        C4        |Error C4 = S3 - SP.
 45|------------------------------[C14-C11]-|
   |                                  |
   | R31                    R4        |R4 means discharge less
 46|-| |-------------------------( )-------|alkaline.
```

As we have indicated above, the PID loop is made up of three terms, error, integral and differential. We have already computed the error terms. Now let's compute the integral term into (R6,C6). We will be using the sum of the error to approximate the integral.

```
   |                                  |
   | R3                     C6        |(R6,C6) = integral, where
 47|-|/|-------------------------[C3/5+C6]-|R6 is sign & C6 is mantissa.
   |                                  |If (R3,C3) and (R6,C6) both
   | R3    R6    R31        C6        |positive, limit sum to a
 48|-|/|---|/|---| |--------------[32767]---|maximum of 32767.
   |                                  |If (R3,C3)/5 is at least as
   | R3    R6    R31        R6        |positive as (R6,C6)is negative
 49|-|/|---| |---| |--------------(R)-------|change sign of sum (R6,C6).
   |                                  |
   | R3                     C0        |Note that negative number
 50|-| |-------------------------[-C3/5]---|(R3,C3) has to be handled
   |                                  |cautiously.
   | R3                     C6        |
 51|-| |-------------------------[C6-C0]---|
   |                                  |If both (R3,C3) and (R6,C6)
   | R3    R6    R31        C6        |negative, limit sum to the
 52|-| |---| |---| |--------------[0]-------|minimum (1,0) = -32768.
   |                                  |If (R3,C5)/5 is more negative
   | R3    R6    R31        R6        |than (R6,C6) is positive,
 53|-| |---|/|---| |--------------(S)-------|change sign of sum.
```

Now we will combine the proportional and integral terms and place this value into C8. (R8,C8) now will be the manipulative variable.

```
   |                                  |Compute C8 = integral * kI
   | R6                     C8        | + proportional * kP
 54|-|/|-------------------------[C6/5+C3]-|= +-...32767 / 5 +- 0...819
   |                                  |
   | R6                     C8        |Again, negative (R6,C6) has to
 55|-| |-------------------------[-C6/5]---|be processed differently.
   |                                  |
   | R6                     C8        |
 56|-| |-------------------------[C3-C0]---|
   |                                  |(R8,C8) has a range of
   | R3    R31              R8        |-6553-819 ... +6553+819
 57|-| |---|/|-+-----------------( )-------|= -7372 ... +7372.
   |           |                      |Watch out for the tricky math
   | R6    R31 |                      |here.
 58|-| |---| |-'                      |
```

Let's compute the absolute value of the manipulative variable and place it into C9. This value is used to determine how much neutralizing agents are to be injected into the mixture.

```
   |                              |
   |                              C9       |
 59|------------------------------[C8]------|
   |                                        |
   | R8                           C9       |C9 = absolute value of C8.
 60|-| |--------------------------[-C8]-----|
   |                                        |
   |                              C0       |
 61|------------------------------[C9-45]---|Make C9 at least 45.
   |                                        |
   | R31                          C9       |
 62|-| |--------------------------[45]------|
   |                                        |
   |                              C9       |Now C9 = 5...819.
 63|------------------------------[C9/9]----|
   |                                        |
   |                              C9       |Final C9 = 6553...40.
 64|------------------------------[32767/C9]|
```

Now we have to determine if the mixture should be recirculated (not neutral yet) or discharged (solution is neutral).

```
   |                                        |
   | R4                           C0       |If error (R4,C4) is positive,
 65|-|/|--------------------------[C4-18]---|check if it is at least 18.
   |                                        |
   | R4                           C0       |If error (R4,C4) is negative,
 66|-| |--------------------------[C4+18]---|check if it is at most -18.
   |                                        |
   | R31                          Y1       |In either case, recirculate.
 67|-|/|--------------------------( )-------|Y1 = recirculation valve.
   |                                        |
   | Y1                           Y0       |
 68|-|/|--------------------------( )-------|Y0 = discharge valve.
   |                                        |
   |                                        |
 69|------------------------------(E)-------|
```