MEE 30002 Control Engineering Group Assignment 2017

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Contents

1-Outline

Your group is designing a pumping system for controlling water quality being recycled within an industrial process.

- The water leaves the process and is collected in a large holding tank (10 m high). When the water reaches or exceeds 9m in the tank, a valve opens at the bottom of the holding tank and water is dumped into the drainage system until the level in the holding tank is 7m.
- In the holding tank, a chemical is added to adjust the pH down to a particular set point. This is currently performed manually.
- Water is irregularly pumped back into the process from the holding tank but only after it is confirmed that the pH of the water in the tank is below a certain pH value.
- Typically, the water flow required for the return line from holding tank varies from 100 to 200 litres per minute (depending on changes in demand from the plant).
- A pump capable of delivering 200 litres per minute with 300 kPa of head is available for pumping water from the holding tank back into the factory.
- There is approximately 150 kPa of losses in the pipe network (excluding the control valve) associated with the water return line at 200 litres per minute.
- A ball valve is currently positioned manually to control this flow-rate back from the tank but this does not provide very satisfactory control.
- The company wants to automate the system using a PLC based control system and feedback control loops where necessary.

2.0: Interpretation of the problem and assumptions

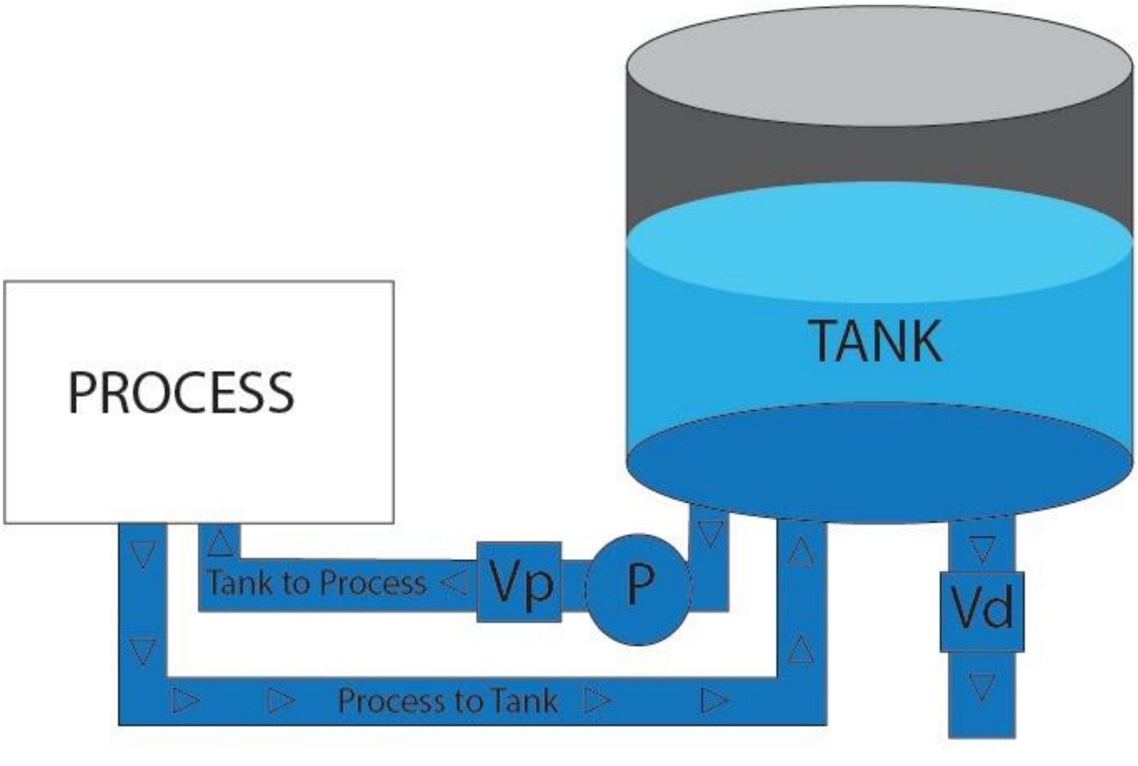


Figure 1

Diagram of how the problem is interpreted by the group. The symbols being Vp being for Valve to flow into the process, P for pump and Vd for drainage valve.

2.0.1-Assumptions

- The process for emptying the tank is using a manual release valve at the base of the tank.
- The tank is also being slowly filled via an additional source (rainwater runoff) hence the worry of overflowing.
- The ‘process’ results in little water wastage and running out of water isn’t a large concern.
- The PH change due to the ‘process’ is small enough and the acceptable PH values have enough margin of error that once the ‘process’ has begun the water should continue to flow until the ‘process’’ completion, regardless of the PH change resulting from the ‘process’
- Any water entering the tank is either the correct PH or more alkaline than the required PH of the water.
- The tank is relatively accessible to allow the installation of sensors and equipment.

2A-Water height control

“Select a suitable device for measuring the height of the water in the holding tank. Provide technical specifications of the device and justify your choice. Please describe any auxiliary equipment that needs to be considered”

Mechanical float switch system

Floats placed at appropriate heights of 9m and 7m can be used to trigger the opening and closing of the release valve.
When calibrated for the correct heights, a float system can be a reliable, accurate and cheap method of controlling the height of the water in the tank. However only gives limited information about the height of the water.

Self starting siphon

Utilising a self-starting siphon (by having a pipe start at the 7m go up to the 10m and then down and out the bottom of the tank) would allow the water to self-regulate its height. With no moving components the apparatus should have a very long service life and wouldn’t be subject to power loss, or faulty components. This method would be the cheapest, easiest method for height control. Unfortunately its only real drawback is its inability to work with other processes in this project.

Pressure transducer

Using a pressure transducer would allow the height to be measured cheaply and accurately. It would also allow relevant information to be used when adding the PH changing chemical as the volume would be able to be calculated.

Sonar depth gauge

A sonar depth gauge would allow an accurate readout of the depth of the water that could be utilised by other process’, however it is one of the more expensive methods of measuring water height.

Wire resistance

Water level can be measured with a wire, that, when submerged under water, its resistance changes indicating that the water has reached its height, this can trigger the valve to open when the water is at 9m of height, then simply when the 7m wire sensor is dry for the valve to close.
However the wire can become corroded depending on the water due to direct contact, in addition to the ph variation affecting the reliability and accuracy of the sensor.

Decision

Using a pressure transducer is is the lowest cost method of determining the depth of the water. As the pressure will only reach a maximum of 1bar of pressure it was necessary to find an accurate sensor that operates in this spectrum. Ultimately we went with the sensor below;

DCBox BVS Series Pressure Sensor 0 to 1 Bar:
https://oceancontrols.com.au/ALT-101.html

0 to 1 Bar
8hz
+/- 5% error

This Pressure sensor met all of our criteria with the lowest cost. Choosing this sensor would still require a potential controller and an actuated release valve at the base of the tank in order to start and stop the flow, unlike using a manual system like the self starting syphon or float switches. It would also allow an accurate measurement of height to then derive the volume when adding the PH reducing chemical to the water allowing it to have a double function.

2B: Ph measuring

"Select a suitable device for measuring the pH of the water in the holding tank. Provide technical specifications of the device and justify your choice. Please describe any auxiliary equipment that needs to be considered."

To measure the pH level, a number of options were considered:

In tank measurement

By utilising a PH sensor work in conjunction with the depth gauge, and our theoretically known cross sectional area, we can calculate a relatively accurate quantity of chemical required to regulate the PH in the tank. By utilising a gear motor, peristaltic pump or diaphragm pump this quantity could be accurately added to the tank and given a settling time to diffuse throughout the tank. This time could be decreased by utilizing the already present pump and a three-way valve to mix the chemical throughout the water.

Advantages:

All the water in the tank would be kept within the desired PH range consistently, allowing water to be introduced into the process as demanded

Disadvantages:
Water has to be agitated in addition to wait times between ph reading. This however would only be an initial concern as over time the ph in the tank will be stabilised and uniform, ready for use

Process Exit measurement and adjustment

Assuming the tank is constantly being filled and emptied, an additional sensor could be attached to the 'process'' output and chemical could also be added relative to the water velocity to attempt to keep the ph in the system constant. This could be expensive due to also requiring the water velocity to be measured and ultimately unnecessary depending on how often the tank is emptied and the range at which the ph is allowed to vary.

Advantages:
Allows corrections to be made for the incoming water from the process as it enters the tank

Disadvantages:
Does not account for other sources of water into the tank.
Equipment needed and estimated cost:

Before and After pump, control valve measurement and adjustment.

Measuring the PH of the water between the tank and the 'process' and adding the necessary chemical would allow the water to be available at any given time. This method could work the best, although would require an additional sensor on the far side of the chemical introduction.

This would be done with a ph sensor in the start of the pipe which senses the ph level of the incoming water.
Then based on known pipe diameter and water flow rate (detecting flow rate would be needed), the correct amount of chemicals would be added to bring it within range.
This is then followed by a 2nd Ph sensor which allows the Ph level to be confirmed and adjusted via feedback to the system if necessary.

Advantages:
Adjustment is more controllable and precise, makes adjustments real time

Disadvantages:
Has to wait for ph to stabilise in the loop before introduction into the process, which means a wait time after water has been requested for this to occur, unless the system ran constantly however this would require a more robust pump and higher energy use

Chosen method of pH measurement

Using PH probe in the tank and adding in the PH lowering chemical is ultimately the decision we went for. While rectifying the outflow to the 'process' could be a 'better' solution it ultimately depends on the needs of the process. If this were an actual job we would also put

forward the outflow processing as a possibility, but initially quote on the basic measurement system to be able to give a lower quote and avoid scope creep.
We Ultimately chose the sensor below;

WA M-12-FLAT Industrial Flat End DJ 3/4 inch MNPT pH Probe

- 6.9 bar @ 80°C
- IP65 rating
- ±59.16 mV / pH unit @ 25°C
- Drift <2mV/week
- 95% reading in 10 seconds
- Asymmetry potential 70.2pH

Additional equipment:

Using PH probe in the tank is really only half of the solution as a delivery method for the chemical is still required. Assuming the chemical is a liquid any of the types of pumps below would be capable of accurately delivering the chemical depending on the waters' purpose, and the properties of the chemical being added. This process would also require a Proportional controller as well as the output value from the pressure transducer.

Gear pump
Not safe if water is for food use, cannot be used for coarse(abrasive), super fine, or solid containing fluids

Peristaltic pump
Very accurate, very slow, very expensive, not particularly reliable.

Diaphragm pump
Would be more suitable in a food
safe operation, not very efficient and will be limited in accuracy by diaphragm size
These can all be controlled accurately with a stepper motor and controller to allow the correct amount of solution to be added as desired.

2C: Control valve via Bolton

"Select the appropriately sized control valve, using the procedure described by Bolton. What sort of valve would you suggest? Explain your choice"

Control Valve sizing equation

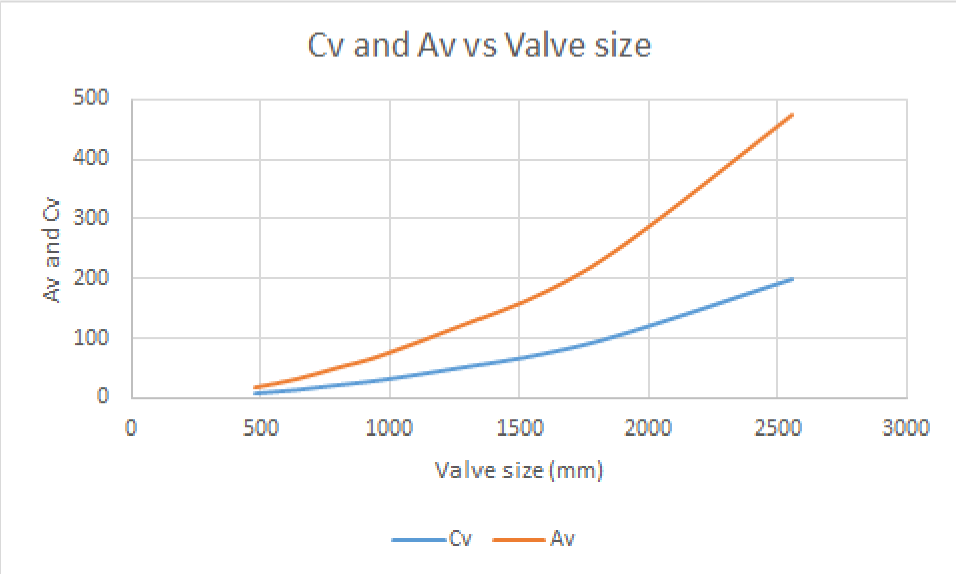
Pump flows 200L/min at 300kPa and 150kPa pressure loss across the system

Q=200L/min
1L=0.001=1/1000m^3
1min=1/60seconds
Q=200/60,000m^3/s=0.0033333m^3/s

Permissible drop across valve (max) is P=300-150=150 kPa

density ==1000kg/m^3

Bernoulli's Equation:
Q=Avp/
Therefore minimum value for Av for this flow rate and allowable pressure drop is:
Av=Qp/=0.00333*150,000/1000=27.2165527*10-5



Graph 1
Graph of how Av and Cv values relate to valve size from the table given on p136 of Bolton(2015)

The minimum value for Av for this application is 27.2165527*10^{-5}

Valve size (Vs)	480	640	800	960	1260	1600	1920	2560
Cv	8	14	22	30	50	75	110	200
Av*10^{-5}	19	33	52	71	119	178	261	474

Table 1
Table of how Cv and Av values relate to control valve diameter as given on p136 of Bolton (2015)

Using interpolation:
Vs=(Vs2-Vs1Av2-Av1)(Av-Av1)+Vs1=(640-48033-19)(27.22-19)+480=573.903mm
The minimum size for the valve should be 573.903mm for the valve.

Valve Profile and design

For a linear relationship in controlling the water flow rate (Q) a linear profile would be prefered for the control valve.

To allow for switching between recirculation (for optional agitation) a shuttle valve can be used to switch between the two output paths. This also allows two valve profiles to be used for the two outputs. Having a fast opening profile for recirculation and a linear profile for the process input for precise control over flow rate.

2D: Feedback loops for automated system

"If this system is fully automated, identify what feedback control loops would be required and draw the relevant block diagrams that show the basic elements of these loops."

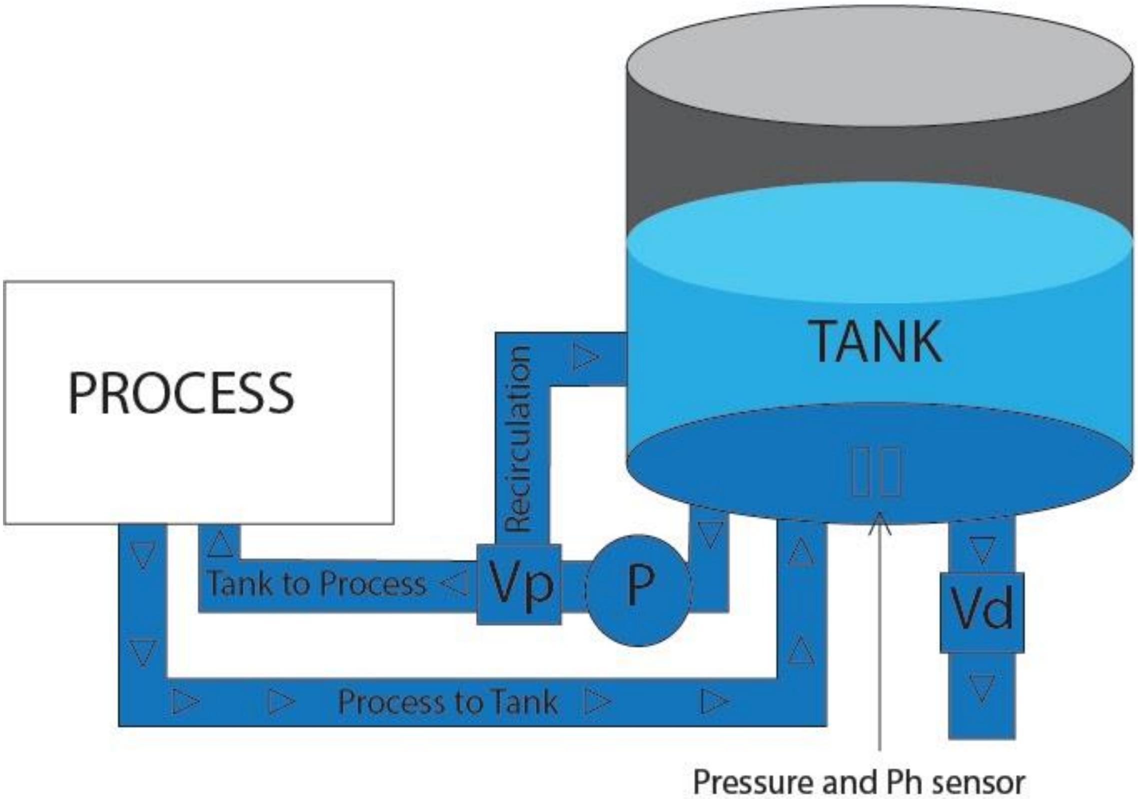


Figure 2

Diagram of how the automated process would be implemented, Vp has been changed to a 3 way valve allowing recirculation for ph/water agitation, A pressure sensor and pH sensor has been added into the bottom of the tank

Drain Valve Control

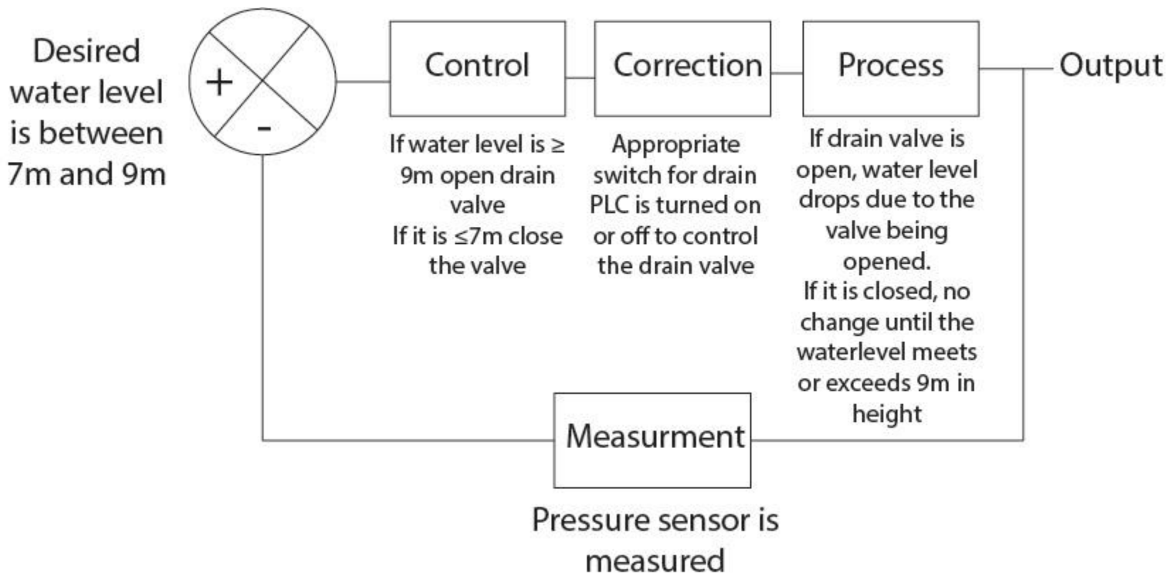


Figure 3
Diagram of the drain valve feedback loop

Using the sensor data we can correspond the sensor current to the height of the water through interpolation.

This way we can find our inputs for the height control and translate the measurement of the sensor into a height.

First is to calculate the pressure of the water
P=gh
$=1000kg/m^3$
$g=9.81m/s^2$

Therefore
P=gh=1000*9.81*h

This creates table 1 below

h (m)	0	1	2	3	4	5	6	7	8	9	10
P pressure (Pa)	0	9810	19620	29430	39240	49050	58860	68670	78480	88290	98100

Table 1: pressure of water at different heights

Using the sensor range assuming it is linear we get this equation
PA(current of pressure sensor in mA)=(20-4100000)*P+4=(16105)*(100*9.81*h)+4

h (m)	0	1	2	3	4	5	6	7	8	9	10
sensor current (mA)	4	5.57	7.14	8.71	10.28	11.85	13.42	14.99	16.56	18.13	19.67

Table 2: pressure sensor current and corresponding heights

Then accounting for the 0.5% error in current we get our range of currents for a given height, this however doesn’t account for all of the error in the sensor.

h (m)	0	1	2	3	4	5	6	7	8	9	10
max current (mA)	4.02	5.60	7.17	8.75	10.33	11.91	13.48	15.06	16.64	18.22	19.79
min current (mA)	3.98	5.54	7.10	8.67	10.23	11.79	13.35	14.91	16.47	18.04	19.60

Table 3: corrected currents for given height

Water height feedback loop Inputs

From this we can get our input currents for the feedback loop.
A water height of 7m corresponds to a current of PA≤14.91mA, which will ensure the drain valve doesn't close too soon
A max water height of 9m corresponds to a current of PA ≥18.22mA, will ensure that the drain valve doesn't open too soon.

Water height feedback loop control

When the measurement is above PA=18.22mA, the controller will close the drain valve on switch which will trigger the PLC circuit to open the the drain valve. When the current drops below 18.22mA the controller will switch the pump on switch to open, however if the circuit has been triggered, the valve open latch will keep the drain valve open until the circuit is broken by either the low pressure switch or manual valve close switch opening.
Between the values of 14.91mA and 18.22mA the switches are in their default states.
Once the current meets or drops below 14.91mA, this indicated that the water level is at the minimum for the drain valve. The low pressure switch is opened, causing the PLC circuit to close the drain valve.
Once the water level rises, causing the sensor reading to go above 14.91mA, the switch is closed and the controller leaves the low and high pressure switches in their default states until the current exceeds 18.22mA again

Water height feedback loop correction

Current	PA≤14.91mA	14.91mA<PA<18.22mA	PA≥18.22mA
High Water level sw	OPEN	OPEN	CLOSED
Low Water level sw	OPEN	CLOSED	CLOSED

Water height feedback loop process and output

Start:
Current reads PA≤14.91mA (at or below 7m water height)
Output: Drain Valve is closed due to water being below 7m, water level rises

Current now reads between 14.91mA<PA<18.22mA (between 7m and 9m of height)
Output: Drain Valve stays closed, water level continues to rise.

Current reads PA≥18.22mA (at or above 9m water height)
Output: Drain Valve is opened due to water being below 7m, water level now drops

Current now reads between 14.91mA<PA<18.22mA (between 7m and 9m of height)
Output: Drain Valve stays open after being triggered, water level continues to drop.

Current reads PA≤14.91mA (at or below 7m water height)
Output: Drain Valve is now closed due to water being below 7m, water level rises again

Ph Feedback Loop

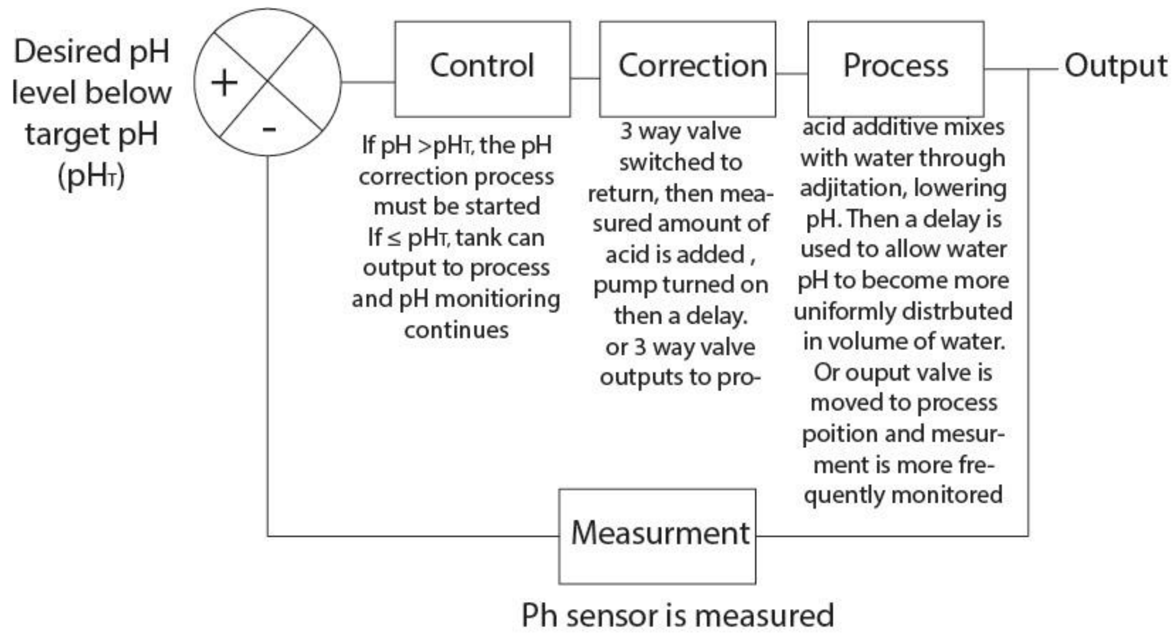


Figure 4
Diagram of the pH control feedback loop

Ph feedback loop Input

All that has been given is that the pH has to be kept below a certain value.
According to the WA M-12-FLAT pH sensor spec sheet, the Ph to Voltage relationship is linear and is ±59.16 mV / pH unit @ 25◦C
This desired input voltage can be calculated by: VT(mV)=pHt*59.16 with it beingVTas the desired input.
The desired pH level pHt will need to be allowed to be added into the system and/or changed.

Ph feedback loop Control

When the pH is above the desired pH level as indicated by being >VT, the process to correct the pH must be started.
If pH is below desired value, the 3 way valve should output to the process in addition to the pump being controlled by the process side of the system so they can introduce water into the process as demanded

Ph feedback loop Correction

When the pH is above the desired pH level as indicated by being >VT the following steps are implemented to correct pH:
1: pump control removed from process and pump is turned off
2: 3 way valve moved to recirculate position

3. Once the tank height is at minimum level, amount of pH correction solution to be added is calculated based on static inputs of:
A=area of tank in m2

pHt=desired maximum pH level that determines VT(mV)=pHt*59.16
pHs=acid solution pH, the pH of the solution that is added to the water to correct it
s=density of the acid solution in kg/m3
hmin=minimum height of water needed for agitation (m)

And dynamic inputs consisting of:
Vw(mV)=input voltage from pH sensor that determines pHw(input pH of water in tank) via pHw=Vw/59.16
PA(mV)=input voltage from pressure sensor that determines h

Using these inputs we can determine the volume or weight of solution to be added
h=height of water in tank=((PA*1.05)-4)*(10516)
Vwater=volume of water tank=h*A
Mtarget=molarity of target ph =10pHt
Msol=molarity of acid solution ph =10pHs
Mwater=molarity of tank ph =10pHw

The Volume of the solution needed is then determined by:
Vtarget=Vwater
Mwater*Vwater+Msol*Vsol=Mtarget*Vtarget
thus:Mwater*Vwater+Msol*Vsol=Mtarget*Vwater
Vsol=((Mwater-Mtarget)*Vwater)/(-Msol)
Vsol=volume of solution in m3 needed to be added to the tank in order to drop pH down to the desired level

Depending on the delivery system, the mass of the solution added may need to be determined
msol=s*Vsol

For example:
If:
pHw=7
pHt=6
pHs=1(if Sodium Bisulfate is used)
s=2,740kg/m3
Vwater=125m3
then
msol=s*Vsol=s*((Mwater-Mtarget)*Vwater)/(-Msol)=2740*((10-7-10-6)*125)/(-0.1)=3.31kg
3.31kg of Sodium Bisulfate would be required to be added

4. Time determined to fully mix water and ph solution
Ttimer (seconds)=set value (s) or 2*Vtank/Q if agitaion is needed
5. The correct amount of the solution would be measured and added automatically
6. Pump turned on and ran for determined time
7. Pump turned off

When the pH is at or below the desired pH level as indicated by being >VT the following steps are implemented:

1. 3 way valve moved to process input position
2. Pump control moved to process input position

Ph feedback loop Process and outputs

When the pH is above the desired pH level as indicated by being >VT:
If height of water is above minimum required, solution is added and mixed into the water via the pump in return flow loop.
After a determined pump run time, pump is turned off and loop is repeated, rechecking pH to determine error and hdue to introduced water into the tank

If water level falls below minimum height during mixing, timer is paused, pump is turned off and resumed when minimum water level height is reached to complete the required mixing time.

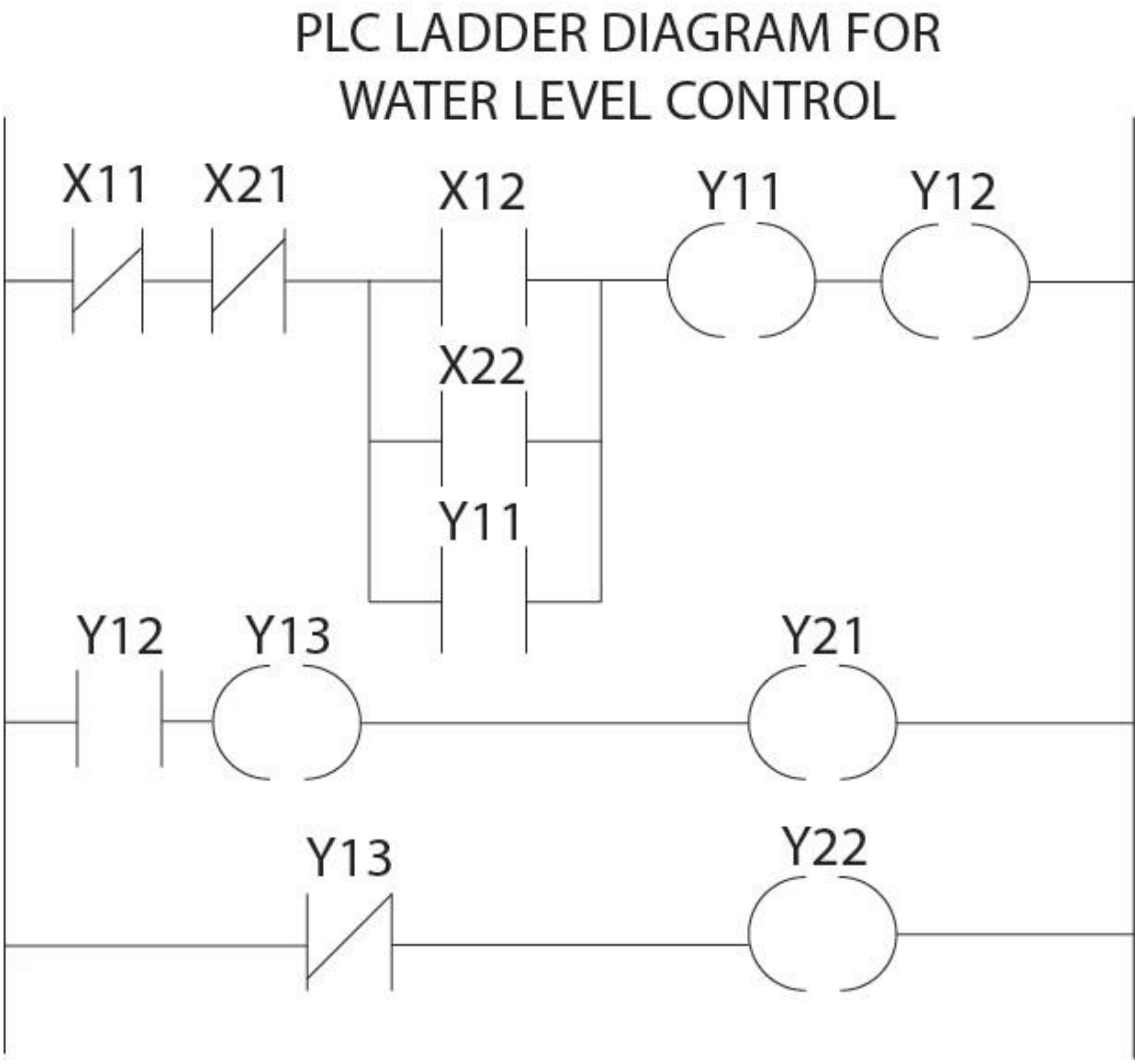
Water is now mixed with the acidic solution with ultimately a pH that is lowered to that of the target

When the pH is below the desired pH level as indicated by being >VT :
3 way valve in process input position
ph level re-checked after and repeat cycle

Water has been determined to have a pH or the target and is allowed to be used in the process as desired

2E: PLC ladder diagram

"A PLC has been selected to co-ordinate the sequences required for operating the system. Propose a ladder diagram that could be used for programming the PLC"

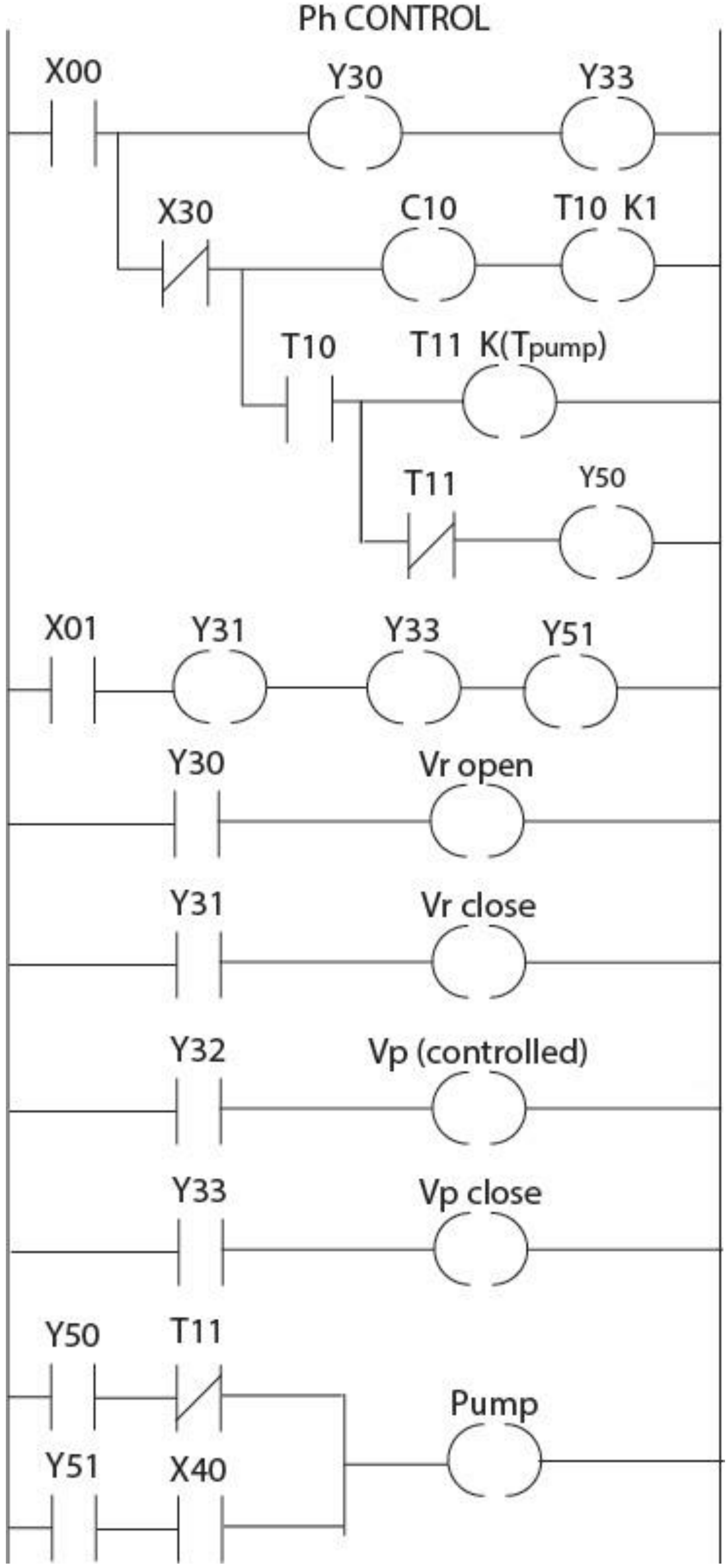


X11: Manual drain valve close switch
X21: Low level pressure switch
- Open when: Water level<7m
- Closed when: Water level7m

X12: Manual drain valve open switch
X22: High water level pressure switch
- Open when: Water level<9m
- Closed when: Water level9m

Y11: Latch to keep valve open when triggered until required
Y12: Valve trigger relay
Y13: Valve stop close relay (when triggered, opens Y13 switch which is normally closed)
Y21: Valve opened position
Y22: Valve closed position

PLC LADDER DIAGRAM FOR
Ph CONTROL



X00: Ph High-opens ph control when pH is too high, closes process control side of system

- Open when: pHwpHt
- Closed when: pHw>pHt

X01: Ph Low-closes ph control and switches to process control side of system

- Open when: pHw>pHt

- Closed when: pHwpHt

X30: Water level-prevents aeration of water if water level is too low for agitation (if agitation is not used, switch can be removed)

- Open when: h<hmin
- Closed when: hhmin

C10: Controller

- Triggers calculation of amount of solution
- Measures and adds solution into the tank
- Calculates pump run time Ttimer

T10 K1: 10 second base time delay multiplied by 1, closes T10 switch when time is reached
T11 Kx: 1 second base time multiplied by Ttimer, opens switch T11 when time is reached
Y50: relay, turns on switch Y50 to allow control of pump by the ph control side of the system
Y51: relay, turns on switch Y51 to allow control of pump by the process side of the system
Y30: Relay for Recirculation valve to open
Y31: Relay for Recirculation valve to close
Y32: Relay for Process valve ladder to open, process valve opening controlled by process to control flow
Y33: Relay to force Process Valve closed

2F: Controller tuning

“How would you propose to tune the controller that will be used to control the delivery of the chemical for modifying the pH in the holding tank? Justify your choice”

Inputs needed for pH control:

- A=area of tank in m2
- pHt=desired maximum pH level that determines VT(mV)=pHt*59.16
- pHs=acid solution pH, the pH of the solution that is added to the water to correct it
- s=density of the acid solution in kg/m3
- hmin=minimum height of water needed for agitation (m)
- Ttimer=time needed for solution to mix with water

Once the desired constant variables are entered into the system, it can then calculate the desired amount of the solution to be added to correct the pH.
Due to how pH changed over time and the volume of the tank, there is a risk that the addition of the pH solution cannot keep up with the rate of change of pH of the water.
This can be corrected with multiplying the calculated solution needed by a percentage ie 10% correction would mean that the solution added is 1.1x the amount calculated to be needed. This can also be changed automatically through the % of error of each cycle of the feedback loop when comparing the rate of change of the pH to the desired pH level.
Otherwise the ph change could be logarithmic and never actually reach the desired pH level

One main issue is the pH sensors accuracy of 95% in the first 10 seconds, so hence the timer has been added to allow for the pH sensor warm up time and may need to be adjusted

Water height control could encounter error, however the error is current only equates to about 10m maximum difference between the sensed and actual height.

Calibrating the sensors initially would be best one in a controlled environment to ensure accuracy after installation (ie a known pH for the sensor according to the manufacturer's guidelines and a known water depth for the pressure sensor

Once thing to note is the pH sensor varying by about 2mV every week, so may need checking regularly ie every 5 weeks, to ensure accuracy

In summary, the tuning would be done with a combination of automated correction in addition to manual adjustment of the system to ensure accuracy and stability in addition to easiness of fine tuning the system

2G: Problems with current arrangement and flowback process

“Assuming that you have successfully automated the flow back into the process from the holding tank, can you foresee any problems with the current arrangement, in terms of process stability, and environmental controls. Discuss these issues and propose possible solutions”

- This setup assumes all water entering the system is alkaline(or neutral), if the water supplied ever becomes an acid below the working standards an additional chemical additive may need to be considered.
- If the ‘process’ itself changes the acidity of the water, the valve supplying water may have to close in order to add additional ph reducing chemical. This could lead to much worse problems.
  This is currently compensated somewhat by the pressure sensor input into the Ph Control accounting for the extra volume but not the pH of the extra volume.
  To properly compensate for incoming flow without interruption to pH correction, an additional pH sensor on the factory output pipe could allow the factory output flow to be fully compensated for by assuming the h from the previous reading is the water from the factory and combining it with the factory output’s ph thus:

- The specified setup doesn’t allow for consistently monitored and adjusted ph level due to the pauses between adjustments. Using a ph level probe and the velocity of incoming water the the ph level of the tank could be kept consistent and would allow the system to run at any given moment rather than potentially waiting for the ph system to add and mix chemicals to level out the water.
- Agitation is not deemed to be needed as it was not utilised previously
  However if it is needed a much larger pump will be needed due to the flow rate of the current pump taking to long to fully circulate and mix the water in the tank. Ie if the vol of the water is 125m^3(5mx5mx5m) then the flow rate to mix that volume at a rate of 0.0033m^3/s would take 37,500seconds which is 10.4 hours, this is way too long so an additional pump for the purpose for agitation would need to be added if that is the case
- The tank doesn’t have a minimum level at which it will fill itself from mains water/an auxiliary tank, this may never be necessary as the return water could have negligible losses, but with an unknown process this could be a concern.
- If the water entering the tank is outside the wanted ph value and continuously entered the tank it could prevent the system from allowing water into the factory.

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