UNIVERSITEIT·STELLENBOSCH·UNIVERSITY
jou kennisvennoot·your knowledge partner

Design Project 488 (2019)

Section Number	Group ID	Student Number	Student Surname	Student Initials	Student Signature (Note 1)
4	G-11	19100108	Matthee	L.H	
		19118910	Möller	H.F	
		18643450	Raga	V.V	
		20237510	van Niekerk	M	
		17174821	Verster	S.L	
Section Description		Hazard and operability study and a basic plant layout and general arrangement.			

Note 1: By signing this submission page, I declare that I have read and understood the meaning and consequences of plagiarism as detailed in the Stellenbosch University Calendar 2019 Part 1. I also declare that I have diligently executed the responsibilities and tasks allocated to me as summarised in the responsibility matrix on the next page.

Document Submission Control				
Date	11 October 2019		**Time**	
Item 1	Introduction			
Item 2	Hazard and Operability Study			
Item 3	Basic Plant Layout			
Item 4	Piping and Instrumentation Diagrams (Pre- and Post-HAZOP)			
Item 5	Plant Layout Diagram			
Item 6	Sizing of Process Units			
Item 7	Updated Process Description			
Item 8	Updated Process Flow Diagram			
Responsible	**Student No.**	**Surname**	**Initials**	**Signature (Note 2)**
Submitted				
Received				

Note 2: The student who signs here was tasked by her/his group to submit the document-set on behalf of the group, but correct and timely submission of the relevant documents remains the responsibility of **the group and each of its members**. Penalties for late or incorrect submission will therefore be applicable to each group member.

<table>
<tr><th colspan="6">Responsibility Matrix
Responsibilities and Tasks per Student</th></tr>
<tr><td>Section No.</td><td colspan="3">4</td><td>Group ID</td><td>G-11</td></tr>
<tr><td>Student No.</td><td>19100108</td><td>Surname</td><td>Matthee</td><td>Initials</td><td>L.H</td></tr>
<tr><td colspan="6">• Preliminary HAZOP study for the dosing water make-up tank, dosing water to TK-202 pump, CH mixing tank, CH dosing pump
• Detailed HAZOP study of all units
• P&IDs post HAZOP
• Summary of changes to P&IDs</td></tr>
<tr><td>Student No.</td><td>19118910</td><td>Surname</td><td>Möller</td><td>Initials</td><td>H.F</td></tr>
<tr><td colspan="6">• Preliminary HAZOP study for the wastewater feed pump, AD buffer tank and AD feed pump
• Detailed HAZOP study of all units
• Footprint sizing of all pumps for plant layout
• Plant layout dimensioning and spacing
• Plant layout details and spacing write-up</td></tr>
<tr><td>Student No.</td><td>18643450</td><td>Surname</td><td>Raga</td><td>Initials</td><td>V.V</td></tr>
<tr><td colspan="6">• Preliminary HAZOP study for the AD and clarifier
• Detailed HAZOP study of all units
• Process plant scale down layout and spacing
• General layout approach write-up
• Top-down view key table</td></tr>
<tr><td>Student No.</td><td>20237510</td><td>Surname</td><td>van Niekerk</td><td>Initials</td><td>M</td></tr>
<tr><td colspan="6">• Preliminary HAZOP study for the wastewater feed preheater and the AD feed heater
• Detailed HAZOP study of all units
• Footprint sizing of all process units (except the pumps) for the plant layout
• Updated PFD and process description
• Final editing of HAZOP study tables
• Final editing of overall document</td></tr>
<tr><td>Student No.</td><td>17174821</td><td>Surname</td><td>Verster</td><td>Initials</td><td>S.L</td></tr>
<tr><td colspan="6">• Preliminary HAZOP study for the degassing tank, sludge recycle pump and centrifuge feed pump
• Detailed HAZOP study of all units
• Final editing of HAZOP study tables
• Final editing of overall document</td></tr>
</table>

DOCUMENT-SET TABLE OF CONTENTS

1 INTRODUCTION

The wastewater treatment plant utilizing anaerobic digestion is considered and a hazard and operability study conducted for selected pieces of equipment. This study will help identify potential risks during the treatment process as well as how to prevent or mitigate their effects. Additionally, equipment sizing for all units will be performed and a preliminary plant layout design included.

2 HAZARD AND OPERABILITY STUDY

A hazard and operability (HAZOP) study is a technique used to identify possible risks as well as how to prevent or reduce their impact. A HAZOP focuses on probable causes for process failure that could compromise human welfare, result in equipment failure and/or environmental damage. HAZOP studies for the units on the relevant attached Process and Instrumentation Diagrams (P&IDs) for the wastewater treatment plant are discussed below.

2.1 HAZOP Meeting Minutes (per unit)

A HAZOP is carried out by a group of people, normally trained engineers, asking questions related to potential deviations from normal and safe operation. The causes, consequences and actions for each deviation identified are recorded to help in the prevention of process failure as well as unsafe conditions. HAZOP studies were performed for each unit in the attached P&IDs DWG-001, DWG-002 and DWG-003 found in Appendix A with the results tabulated below. Furthermore, to ensure safe and optimal operation of the wastewater treatment process, general deviations were identified and their corrective actions provided in Table 1.

Table 1: General deviations and their corrective actions applicable to multiple areas on the wastewater treatment plant.

Plant: Wastewater Treatment Plant			
HAZOP Date: 08/10/2019		**HAZOP Members:** Matthee, L.H.; Möller, H.F.; Raga, V.V.; van Niekerk, M.; Verster, S.L.	
Guide Word	**Deviation**	**Cause**	**Action**
No	No Flow	Hand and isolation valve blockages	Regular inspection and maintenance of all hand valves, especially pertaining to areas where solids handling is prominent.
	Agitation	Motor failure as a result of burnout	Installation of thermal overload interlocks.
		Electrical failure	Inspect and maintain electrical connections.
As well as	Running positive displacement pumps dry	No flow due to blockages in pipelines/valves	This is allowable but should be avoided to limit energy wastage.
	Controller failure	Electrical failure	Regular checks and maintenance should be implemented. In the event of failure the controllers should be switched to manual and controlled by the operators.
	Maintenance	Equipment failure/valve and pipe blockages	All relevant safety procedures and lockout procedure must be implemented prior to conducting maintenance.
	Uncontrolled release of biogas to the environment, resulting in a fire hazard	Equipment and pipe failure	Availability of fire hydrants and necessary Personal Protective Equipment (PPE).

Table 2: HAZOP meeting minutes for the AD Buffer Tank (TK-101).

Plant: Wastewater Treatment Plant		**Area:** 100	**Process Unit:** TK-101	**Reference Drawing:** P&ID DWG-001
HAZOP Date: 02/10/2019		**HAZOP Members:** Matthee, L.H.; Möller, H.F.; Raga, V.V.; van Niekerk, M.; Verster, S.L.		
Guide Word	**Deviation**	**Cause**	**Consequence**	**Action**
No	No flow (Stream 101)	Pump failure (P-101A)	No feed of wastewater to TK-101.	Switch to back-up pump system (P-101B). Switch P-103A on to feed wastewater from the calamity tank (TK-102).
		Blockage in pipeline		Install a strainer (S-105) on Stream 101. Switch P-103A on to feed wastewater from the calamity tank (TK-102).
	No flow (Stream 216)	Pump failure (P-206A)	No ferric chloride dosing in TK-101.	Switch to back-up pump system (P-206B).
		Blockage in pipeline		Install flow indicator (FI-105) on Stream 216 to monitor the flowrate.
	No flow (Stream 102)	Blockage in pipeline	No wastewater to process. Pressure build up in tank. Tank level increase. Pumps (P-102A/B) run dry.	Interlock (I-105) disables AD feed pumps (P-102A/B). Level switch high (LSH-101) with interlock (I-103) to drain to TK-102.
	No agitation (TK-101)	Motor failure	Solids settling. Dead volume in tank.	Thermal overload interlock (I-102) on agitator to prevent motor failure.
Less of	Less flow (Stream 101)	Low level of sump	Pumps (P-102A/B) could run dry resulting in cavitation.	Interlock (I-104) disables AD feed pumps (P-102A/B).

Plant: Wastewater Treatment Plant		**Area:** 100	**Process Unit:** TK-101	**Reference Drawing:** P&ID DWG-001
HAZOP Date: 02/10/2019		**HAZOP Members:** Matthee, L.H.; Möller, H.F.; Raga, V.V.; van Niekerk, M.; Verster, S.L.		
Guide Word	**Deviation**	**Cause**	**Consequence**	**Action**
Less of	Less flow (Stream 101)	Malfunctioning of wastewater feed pump (P-101A)	Low tank level.	Switch to backup pump system (P-101B). Level alarm low (LAL-101) to alert operators of deviations from normal operation. Switch P-103A on to feed wastewater from the calamity tank (TK-102).
	Less flow (Stream 216)	Malfunction of ferric chloride dosing control loop (FIC-101)	Increased level of hydrogen sulphide in biogas produced. Corrosion of equipment.	Install flow indicator (FI-105) on Stream 216 to monitor the flowrate. Regular checks and maintenance on control loop.
More of	More flow (Stream 101)	Accidental start-up of back-up pump (P-101B)	Rapid increase in tank level	Level switch high (LSH-101) with interlock (I-103) to initiate level control valve (LCV-102) enabling flow to calamity tank (TK-102).
As well as	Debris in feed stream	Inadequate straining	Pump damage (P-102A/B). Blockage in pipelines.	Install a strainer (S-105) on Stream 101. Regular cleaning of the strainer.

Table 3: HAZOP meeting minutes for the AD Feed Pumps (P-102A/B).

<table>
<tr><td colspan="2">Plant: Wastewater Treatment Plant</td><td>Area: 100</td><td>Process Unit: P-102A/B</td><td>Reference Drawing: P&ID DWG-001</td></tr>
<tr><td colspan="2">HAZOP Date: 02/10/2019</td><td colspan="3">HAZOP Members: Matthee, L.H.; Möller, H.F.; Raga, V.V.; van Niekerk, M.; Verster, S.L.</td></tr>
<tr><th>Guide Word</th><th>Deviation</th><th>Cause</th><th>Consequence</th><th>Action</th></tr>
<tr><td>No</td><td>No flow (Stream 102)</td><td>Blockage in pipeline
Pipe rupture</td><td>Pumps (P-102A/B) could run dry resulting in cavitation.</td><td>Monitor the flowrate using the flow indicator (FIT-102) on Stream 103.
Interlock (I-105) disables AD feed pumps (P-102A/B).</td></tr>
<tr><td rowspan="2">Less of</td><td rowspan="2">Lower discharge pressure</td><td>Internal wear of the pump resulting in pump inefficiency</td><td rowspan="2">Lower flowrate of wastewater fed to the process</td><td rowspan="2">Switch to back-up pump system (P-102B).
Monitor pressure using pressure indicators (PI-103 and PI-104) on pump discharge lines.
Monitor the flowrate using flow indicator (FIT-102).</td></tr>
<tr><td>Pump failure (P-102 A)</td></tr>
<tr><td rowspan="2">More of</td><td>Higher discharge pressure</td><td>Blockage in discharge pipeline (Stream 103)</td><td>Pump failure
Pipeline rupture</td><td>Monitor pressure using pressure indicators (PI-103 and PI-104) on pump discharge lines.</td></tr>
<tr><td>Higher solids content</td><td>Wastewater feed contains more solids than specified</td><td>Damage to pump</td><td>Install a strainer (S-105) on Stream 101.</td></tr>
<tr><td>As well as</td><td>Pump (P-102B) start-up</td><td>Accidental start of back-up pump (P-102B)</td><td>Pump motor burnout</td><td>Program interlock of pump MCCs allowing only one pump to run.</td></tr>
<tr><td>Reverse</td><td>Reverse flow</td><td>Reverse pressure differential due to suction side pipe rupture.
Pump power loss</td><td>Pump damage</td><td>Check valves on the pump discharge lines (CV-103 and CV-104).</td></tr>
</table>

Table 4: HAZOP meeting minutes for the Wastewater Feed Preheater (E-101).

Plant: Wastewater Treatment Plant	**Area:** 100	**Process Unit:** E-101	**Reference Drawing:** P&ID DWG-001
HAZOP DATE: 02/10/2019	**HAZOP Members:** Matthee, L.H.; Möller, H.F.; Raga, V.V.; van Niekerk, M.; Verster, S.L.		

Guide Word	Deviation	Cause	Consequence	Action
No	No flow (Stream 103)	Blockage in pipeline	No flow to downstream process.	Monitor pressure using pressure indicators (PI-103 and PI-104) on pump discharge lines.
		Pump failure (P-102A)		Switch to back-up pump system (P-102B).
	No flow (Stream 104)	Blockage in heat exchanger (E-101)	No flow to downstream process.	Regular maintenance of E-101. Install pressure indicator (PI-109) on Stream 104 to detect blockage.
	No flow (Stream 114)			
More of	Higher pressure	Blockage in outlet pipeline	Gasket leaks which could result in lower effluent flows and/or cross contamination. Vibrations due to high flow velocities (unstable operation).	Install pressure indicator (PI-109) on Stream 104 to detect blockage. Regularly inspect heat exchanger for leaks.
Less of	Lower pressure	Pump malfunction (P-102A)	Insufficient flow resulting in loss of productivity.	Switch to back-up pump system (P-102B) Monitor pressure using pressure indicators (PI-103 and PI-104) on pump discharge lines.
As well as	Contamination	Corrosion of plates	Mixing of streams; could incur discharge penalties.	Regular maintenance of heat exchanger plates.

Table 5: HAZOP meeting minutes for the AD Feed Heater (E-102).

Plant: Wastewater Treatment Plant		**Area:** 100	**Process Unit:** E-102	**Reference Drawing:** P&ID DWG-001
HAZOP DATE: 02/10/2019		**HAZOP Members:** Matthee, L.H.; Möller, H.F.; Raga, V.V.; van Niekerk, M.; Verster, S.L.		
Guide Word	**Deviation**	**Cause**	**Consequence**	**Action**
No	No flow (Stream 104)	Blockage in pipeline	Heat exchanger overheats, causing stress cracks in the plates.	Install pressure indicator (PI-109) on Stream 104 to detect blockage.
	No flow (Stream 105)	Blockage in pipeline	No process fluid to downstream process.	Install pressure indicator (PI-110) on Stream 105 to detect blockage.
		Blockage in heat exchanger (E-102)	Pressure build up which could cause plate cracking.	
	No flow (Stream 139)	Biogas handling section malfunction	R-101 feed not preheated therefore adverse effect on micro-organism health.	Inspect biogas handling section and take appropriate action if matter persists.
	No flow (Stream 135)	Blockage in heat exchanger (E-102)	Pressure build up which could cause plate cracking.	Install a pressure indicator (PI-111) on Stream 135.
More of	More flow (Stream 139)	Malfunction of steam control loop (TIC-101)	Stream 104 heated too much; adverse effect on micro-organism health in R-101.	Temperature alarm high (TAH-101) installed on Stream 105 to alert operators of deviations from normal operation.
	Higher temperature (Stream-105)	Sudden reduction in flow of Stream 104	Vaporization of process stream.	Temperature monitored and controlled using temperature control loop TIC-101.
	Larger pressure drop	Scaling	Reduced heat exchanger performance.	Regular maintenance of plates.

<table>
<tr><td colspan="2">Plant: Wastewater Treatment Plant</td><td>Area: 100</td><td>Process Unit: E-102</td><td>Reference Drawing: P&ID DWG-001</td></tr>
<tr><td colspan="2">HAZOP DATE: 02/10/2019</td><td colspan="3">HAZOP Members: Matthee, L.H.; Möller, H.F.; Raga, V.V.; van Niekerk, M.; Verster, S.L.</td></tr>
<tr><th>Guide Word</th><th>Deviation</th><th>Cause</th><th>Consequence</th><th>Action</th></tr>
<tr><td>More of</td><td>Higher pressure</td><td>Blockage in heat exchanger (E-102)</td><td>Plate cracking due to pressure hammers.
Vibrations due to high flow velocities (unstable operation).</td><td>Install pressure indicators PI-110 and PI-111 on Stream 105 and Stream 135 respectively to monitor pressure.
Install a pressure relief valve (PRV-103) to steam vent.</td></tr>
<tr><td rowspan="2">Less of</td><td>Less flow (Stream 105)</td><td>Leak in E-102</td><td>Loss in productivity of E-102
Contamination of streams; will not be able to recycle the process water.</td><td>Regular maintenance of heat exchanger plates and gaskets.</td></tr>
<tr><td>Lower efficiency</td><td>Settlement of sludge</td><td>Reduces area available for flow thus reducing heat transfer.</td><td>Regular maintenance of plates.</td></tr>
<tr><td rowspan="2">As well as</td><td rowspan="2">Contamination</td><td>Plate corrosion</td><td rowspan="2">Mixing of streams resulting in contaminated process water which cannot be recycled back to boiler.</td><td>Regular maintenance of heat exchanger.</td></tr>
<tr><td>Cracked plates from pressure fluctuations</td><td>Install a pressure indicator (PI-111) on Stream 135.</td></tr>
</table>

Table 6: HAZOP meeting minutes for the Anaerobic Digester (R-101).

Plant: Wastewater Treatment Plant		**Area:** 100	**Process Unit:** R-101	**Reference Drawing:** P&ID DWG-002
HAZOP Date: 03/10/2019		**HAZOP Members:** Matthee, L.H.; Möller, H.F.; Raga, V.V.; van Niekerk, M.; Verster, S.L.		
Guide Word	**Deviation**	**Cause**	**Consequence**	**Action**
No	No flow (Stream 127)	No methanogenesis reaction	No biogas available for energy generation.	Install a biogas analyser (AIT-103) to monitor production. Remove flow Pressure indicator (PIT-101) to monitor biogas production.
		pH outside optimum bounds		pH monitored and controlled using pH control loop (ARC-101).
		Temperature outside optimum bounds		Temperature monitored and controlled using temperature control loops TIC-101 and TRC-102.
	No flow (Stream 107)	Blockage in pipeline	Increase in liquid level in R-101. Liquid flow into biogas line. No flow downstream.	Monitor via downstream flowrate using flow indicator (FIT-104).
	No flow (Stream 106)	Blockage in pipeline	Increase in R-101 HRT and SRT. Could result in low level in R-101, therefore no feed to downstream processes.	Monitor flowrate using flow indicator (FIT-103). Process interlock (I-108) to disable sludge recycle pumps (P-105A/B) Manually switch off upstream process units and divert incoming wastewater to calamity tank.
	No agitation	Motor overheating	Solids settling in digester.	Thermal overload interlock (I-107) on agitator to prevent motor failure.
		Impeller corrosion		Regular impeller inspection and maintenance.

Plant: Wastewater Treatment Plant		**Area:** 100	**Process Unit:** R-101	**Reference Drawing:** P&ID DWG-002
HAZOP Date: 03/10/2019		**HAZOP Members:** Matthee, L.H.; Möller, H.F.; Raga, V.V.; van Niekerk, M.; Verster, S.L.		
Guide Word	**Deviation**	**Cause**	**Consequence**	**Action**
More of	Higher liquid level	Blockage in discharge pipeline (Stream 108)	Liquid in the biogas line. Tank rupture.	Install level alarm high (LAH-102) to alert operators of deviations from normal operation.
	Increased headspace pressure	Biogas build-up due to blockage in discharge pipe (Stream 127)	Pipe rupture Negative environmental impact due to release of raw biogas.	Pressure relief valve (PRV-101) to flare. Pressure monitored and controlled using pressure control loop (PIC-101).
	Higher temperature	Malfunction of temperature control loops TIC-101 and TRC-102	Death of micro-organisms. Lower biogas production. COD concentration in effluent too high; could incur discharge penalties.	Interlock (I-106) to close temperature control valve (TCV-101) to stop steam flowrate to E-102.
	Higher pH	Increased flowrate of calcium hydroxide slurry (Stream 205)	Death of micro-organisms. Lower biogas production	pH monitored and controlled using pH control loop (ARC-101). Interlock (I-111) to stop VSD of calcium hydroxide dosing pumps (P-202A/B).
	More agitation	Current overload	Motor failure. High shear resulting in micro-organism death.	Thermal overload interlock (I-107) on agitator to prevent motor failure.
	More flow (stream 106)	Increased flowrate	Biomass washout. Bypass.	Averaging level control on Stream 103 (FIC-102) to maintain a relatively constant flowrate.
Less of	Less agitation	Impeller fouling Impeller corrosion	Foaming. Settling of solids. Temperature gradients. pH gradients.	Regular impeller inspection and maintenance. Manually dose anti-foaming agent if/when required.

Plant: Wastewater Treatment Plant		**Area:** 100	**Process Unit:** R-101	**Reference Drawing:** P&ID DWG-002
HAZOP Date: 03/10/2019		**HAZOP Members:** Matthee, L.H.; Möller, H.F.; Raga, V.V.; van Niekerk, M.; Verster, S.L.		
Guide Word	**Deviation**	**Cause**	**Consequence**	**Action**
Less of	Lower pH	Ineffective dosing	Acidification of R-101 contents. No/lower biogas production. Death of micro-organisms.	Ratio control loop (FIC-201 and FIC-202) to ensure the correct concentration of dosing solution. pH of R-101 monitored and controlled using pH control loop (ARC-101).
		Dosing loop malfunction (ARC-101)		Regular maintenance of control loop.
As well as	Hydrogen sulphide (H_2S) production	Ineffective ferric chloride dosing to TK-101.	Equipment corrosion.	Monitor and control flowrate of ferric chloride using flow control loop (FIC-101).
		Malfunction of ferric chloride dosing control loop (FIC-101)		Install flow indicator (FI-105) on Stream 216 to monitor the flowrate. Install an alarm (AAH-103) to alert operators of H_2S formation. Regular checks and maintenance on control loop.
Part of	COD conversion	pH outside optimum bounds Temperature outside optimum bounds	COD concentration in outlet too high. Too little biogas production.	Monitoring via sample port HV-142. pH monitored and controlled using pH control loop (ARC-101). Temperature monitored and controlled using temperature control loops TIC-101 and TRC-102.

Plant: Wastewater Treatment Plant		**Area:** 100	**Process Unit:** R-101	**Reference Drawing:** P&ID DWG-002
HAZOP Date: 03/10/2019		**HAZOP Members:** Matthee, L.H.; Möller, H.F.; Raga, V.V.; van Niekerk, M.; Verster, S.L.		
Guide Word	**Deviation**	**Cause**	**Consequence**	**Action**
Reverse	Flow into Stream 106	Pump failure (P-105A/B and/or P-102A/B)	Pump damage. Heat exchanger flooding.	Check valves (CV-105 and CV-106) on Stream 105 and Stream 120. Check valves (CV-103 and CV-104) and (CV-110 and CV-111) on P-102A/B and P-105A/B discharge lines.

Table 7: HAZOP meeting minutes for the Degassing Tank (S-101).

Plant: Wastewater Treatment Plant		**Area:** 100	**Process Unit:** S-101	**Reference Drawing:** P&ID DWG-002
HAZOP Date: 02/10/2019		**HAZOP Members:** Matthee, L.H.; Möller, H.F.; Raga, V.V.; van Niekerk, M.; Verster, S.L.		
Guide Word	**Deviation**	**Cause**	**Consequence**	**Action**
No	No flow (Stream 128)	Blockage in pipeline	Pipe rupture due to pressure build up. Negative environmental impact due to release of raw biogas.	Pressure relief valve (PRV-102) to flare.
	No flow (Stream 107)	Blockage in pipeline	No feed to downstream processes.	Monitor via downstream flowrate using flow indicator (FIT-104).
	No flow (Stream 108)	Blockage in pipeline	Level increase which could result in liquid entering biogas line.	Monitor level using level indicator (LIT-103). Install a level alarm high (LAH-103) to alert operators of deviations from normal operation.
More of	Higher pressure	Blockage in pipelines	Pipe rupture. Tank rupture.	Pressure relief valve (PRV-102) to flare.

Plant: Wastewater Treatment Plant		**Area:** 100	**Process Unit:** S-101	**Reference Drawing:** P&ID DWG-002
HAZOP Date: 02/10/2019		**HAZOP Members:** Matthee, L.H.; Möller, H.F.; Raga, V.V.; van Niekerk, M.; Verster, S.L.		
Guide Word	**Deviation**	**Cause**	**Consequence**	**Action**
Reverse	Reverse flow (Stream 128)	Reverse pressure differential	Decreased clarifier performance. Negative environmental impact due to release of raw biogas.	Stream 128 repositioned to revert biogas back to R-101. Check valve (CV-114) to prevent reversal of flow.

Table 8: HAZOP meeting minutes for the Clarifier (S-102).

Plant: Wastewater Treatment Plant		**Area:** 100	**Process Unit:** S-102	**Reference Drawing:** P&ID DWG-002
HAZOP Date: 02/10/2019		**HAZOP Members:** Matthee, L.H.; Möller, H.F.; Raga, V.V.; van Niekerk, M.; Verster, S.L.		
Guide Word	**Deviation**	**Cause**	**Consequence**	**Action**
No	No flow (Stream 118)	Blockage in pipeline	Clarifier overflow to environment Pumps run dry (energy wasted) (P-105A/B).	Monitor flowrate using flow indicator (FIT-106). Interlock (I-108) disables sludge recycle pumps (P-105A/B).
	No flow (Stream 109)	Blockage in pipeline	Clarifier overflow to environment.	Monitor overflow flowrate using flow indicator (FI-102).
		Clarifier level low due to malfunction of flow control loop (FIC-105)	No effluent for dosing.	Use process water for make-up of dosing solutions. Install level switch low (LSL-102) with interlock (I-112) to disable P-105A/B.
	No sludge raking	Motor burnout	Lower solids recycle.	Thermal overload interlock (I-109) on agitator to prevent motor failure.
		Rake stuck		Monitor rake status with AG-104 MCC.

Plant: Wastewater Treatment Plant		**Area:** 100	**Process Unit:** S-102	**Reference Drawing:** P&ID DWG-002
HAZOP Date: 02/10/2019		**HAZOP Members:** Matthee, L.H.; Möller, H.F.; Raga, V.V.; van Niekerk, M.; Verster, S.L.		
Guide Word	**Deviation**	**Cause**	**Consequence**	**Action**
More of	Increased sludge raking	Electrical malfunction	Motor burnout.	Thermal overload interlock (I-109) on agitator to prevent motor failure.
	More flow (Stream 108)	Higher S-101 liquid level	Jetting Bypassing, resulting in inefficient solids settling.	Monitor liquid level using level indicator LIT-103 on S-101.
Less of	Less flocculant available	Ineffective flocculant dosing	Inefficient settling due to lack of floc formation.	Flocculant dosing monitored and controlled by the flow control loop FIC-103.
		Malfunction of flocculant dosing loop (FIC-103)		Regular checks and maintenance on control loop.
Less of	Less coagulant available	Ineffective coagulant dosing	Inefficient settling due to lack of floc formation.	Coagulant dosing monitored and controlled by the flow control loop FIC-104.
		Malfunction of coagulant dosing loop (FIC-104)		Regular checks and maintenance on control loop.

Table 9: HAZOP meeting minutes for the Sludge Recycle Pumps (P-105A/B).

Plant: Wastewater Treatment		**Area:** 100	**Process Unit:** P-105A/B	**Reference Drawing:** P&ID DWG-002
HAZOP Date: 03/10/2019		**HAZOP Members:** Matthee, L.H.; Möller, H.F.; Raga, V.V.; van Niekerk, M.; Verster, S.L.		
Guide Word	**Deviation**	**Cause**	**Consequence**	**Action**
No	No flow (Stream 119)	Blockage in pipeline	Pumps run dry (energy wasted) Insufficient recycle of sludge Decreasing process performance.	Flow alarm low (FAL-105) to alert operators of deviations from normal operation. Flow alarm low low (FALL-105) on Stream 108 with interlock (I-108) to disable P105A/B. Monitor pressure using pressure indicators (PI-107 and PI-108) on pump discharge lines.
	No flow (Stream 120)	Blockage in pipeline	Pressure build-up.	Monitor pressure using pressure indicators (PI-107 and PI-108) on pump discharge lines.
		Pump failure (P-105A)	Decreased R-101 performance.	Switch to back-up pump system. (P-105B)
More of	Higher discharge pressure	Pipeline blockage (Stream 120)	No sludge recycle resulting in decreased R-101 performance. Pump failure and pipe rupture due to pressure build-up.	Monitor pressure using pressure indicators (PI-107 and PI-108) on pump discharge lines.
Less of	Lower discharge pressure	Internal wear of the pump resulting in pump inefficiency (P-105A)	Insufficient sludge recycling.	Switch to back-up pump system (P-105B).
Reverse	Reverse flow (Stream 120)	Reverse pressure differential due to suction side pipe rupture.	Pump damage.	Check valves (CV-110 and CV-111) on pump discharge lines.
As well as	Pump-105B start-up	Accidental start of back-up pump (P-105B)	Could result in excess sludge to R-101 resulting in increased level.	Program interlock of pump MCCs allowing only one pump to run.

Table 10: HAZOP meeting minutes for the Centrifuge Feed Pumps (P-106A/B).

<table>
<tr><td colspan="2">Plant: Wastewater Treatment Plant</td><td>Area: 100</td><td>Process Unit: P-106A/B</td><td>Reference Drawing: P&ID DWG-002</td></tr>
<tr><td colspan="2">HAZOP Date: 03/10/2019</td><td colspan="3">HAZOP Members: Matthee, L.H.; Möller, H.F.; Raga, V.V.; van Niekerk, M.; Verster, S.L.</td></tr>
<tr><th>Guide Word</th><th>Deviation</th><th>Cause</th><th>Consequence</th><th>Action</th></tr>
<tr><td rowspan="3">No</td><td rowspan="2">No flow (Stream 121)</td><td>Blockage in pipeline</td><td rowspan="2">No feed to centrifuge.</td><td>Monitor pressure using pressure indicators (PI-105 and PI-106) on pump discharge lines.</td></tr>
<tr><td>Pump failure (P-106A)</td><td>Switch to back-up pump system (P-106B).</td></tr>
<tr><td>No flow (Stream 122)</td><td>Blockage in pipeline</td><td>Pressure build-up resulting in pipe and pump damage.</td><td>Monitor pressure using pressure indicators (PI-105 and PI-106) on pump discharge lines.</td></tr>
<tr><td>More of</td><td>Higher discharge pressure</td><td>Blockage in pipeline (Stream 202)</td><td>No feed to centrifuge.
Pipe and pump damage.</td><td>Monitor pressure using pressure indicators (PI-105 and PI-106) on pump discharge lines.</td></tr>
<tr><td>Less of</td><td>Lower discharge pressure</td><td>Internal wear of the pump resulting in pump inefficiency (P-106 A)</td><td>Insufficient feed to centrifuge.</td><td>Switch to back-up pump system (P-106 B).</td></tr>
<tr><td>As well as</td><td>Pump 106B start-up</td><td>Accidental start of back-up pump (P-105B)</td><td>Excess sludge to centrifuge resulting in negligible recycling and decreased process performance.</td><td>Program interlock of pump MCCs allowing only one pump to run.</td></tr>
</table>

Table 11: HAZOP meeting minutes for the Dosing Water Make-up Tank (TK-201).

Plant: Wastewater Treatment Plant		**Area:** 200	**Process Unit:** TK-201	**Reference Drawing:** P&ID DWG-003
HAZOP Date: 03/10/2019		**HAZOP Members:** Matthee, L.H.; Möller, H.F.; Raga, V.V.; van Niekerk, M.; Verster, S.L.		
Guide Word	**Deviation**	**Cause**	**Consequence**	**Action**
No	No flow (Stream 117)	Blockage in pipeline	Water storage tank can reach low levels or completely empty. Pumps (P-201A/B) could run dry. No flow to the downstream process.	Level alarm low (LAL-201) to alert operators of deviation from normal operation. Low level switch (LSL-201) with interlock (I-201) to disable dosing water pumps (P-201A/B).
	No flow (Stream 201)	Blockage in pipeline	Pumps (P-201A/B) could run dry. No flow to the downstream process.	Monitor flow downstream using flow indicator (FIT-201).
More of	More flow (Stream 117)	Surge of flow from upstream effluent water supply	Vessel overflow.	Monitor and control level with level control loop (LIC-201). Level alarm high (LAH-201) to alert operators to manually divert flow to discharge sewer.
Less of	Less flow (Stream 201)	Insufficient supply of effluent water form upstream processes.	Water storage tank can reach low levels or completely empty.	Level alarm low (LAL-201) to alert operators of deviation from normal operation. Low level switch (LSL-201) with interlock (I-201) to disable dosing water pumps (P-201A/B).
As well as	Solids in the treated effluent water	Inefficient solids filtering upstream	Solids build-up in tank. Blockage in pipeline.	Regular maintenance and cleaning.

Table 12: HAZOP meeting minutes for the Dosing Water Pumps (P-201A/B).

Plant: Wastewater Treatment Plant		**Area:** 200	**Process Unit:** P-201A/B	**Reference Drawing:** P&ID DWG-003
HAZOP Date: 03/10/2019		**HAZOP Members:** Matthee, L.H.; Möller, H.F.; Raga, V.V.; van Niekerk, M.; Verster, S.L.		
Guide Word	**Deviation**	**Cause**	**Consequence**	**Action**
No	No flow (Stream 201)	Blockage in pipeline	Pump runs dry resulting in cavitation.	Monitor flow downstream using flow indicator (FIT-201).
		Low level in TK-201		Low level switch (LSL-201) with interlock (I-201) to disable dosing water pumps (P-201A/B).
	No flow (Stream 202)	Blockage in pipeline	No flow to TK-202.	Monitor flowrate using flow indicator FIT-201.
		Pump failure (P-201A)		Switch to back-up pump system (P-201B).
More of	Higher discharge pressure	Blockage in pipeline (Stream 202)	Pump and pipe damage	Monitor pressure using pressure indicators (PI-201 and PI-202) on pump discharge lines.
	More flow (Stream 202)	Accidental start of back-up pump system (P-201B)	Pressure build-up in pipeline causing line rupture.	Program interlocks of pumps in MCC allowing only one pump to run at a time.
Less of	Lower discharge pressure	Internal wear of the pump resulting in pump inefficiency	Insufficient supply of dosing water to TK-202.	Switch to back-up pump system (P-201B).
	Less flow (Stream 202)	Malfunction of level control loop (LIC-202)	Insufficient water flow to TK-202.	Regular checks and maintenance on control loop.
Reverse	Reverse flow	Reverse pressure differential due to suction side pipe rupture.	Pump damage.	Check valves on the pump discharge lines CV-201 and CV-202.

Table 13: HAZOP meeting minutes for the Calcium Hydroxide Storage Hopper (V-201).

Plant: Wastewater Treatment Plant		**Area:** 200	**Process Unit:** V-201	**Reference Drawing:** P&ID DWG-003
HAZOP Date: 03/10/2019		**HAZOP Members:** Matthee, L.H.; Möller, H.F.; Raga, V.V.; van Niekerk, M.; Verster, S.L.		
Guide Word	**Deviation**	**Cause**	**Consequence**	**Action**
No	No calcium hydroxide discharge	Calcium hydroxide powder blockage in hopper	No calcium hydroxide to the mixing tank (TK-202).	Use vibrations on hopper to prevent build-up of powder.
Less of	Less calcium hydroxide discharge	Inconsistent calcium hydroxide discharge	Calcium hydroxide slurry will have incorrect concentration.	Use vibrations on hopper to ensure constant discharge rate.

Table 14: HAZOP meeting minutes for the Calcium Hydroxide Screw Conveyor (SC-201).

Plant: Wastewater Treatment Plant		**Area:** 200	**Process Unit:** SC-201	**Reference Drawing:** P&ID DWG-003
HAZOP Date: 03/10/2019		**HAZOP Members:** Matthee, L.H.; Möller, H.F.; Raga, V.V.; van Niekerk, M.; Verster, S.L.		
Guide Word	**Deviation**	**Cause**	**Consequence**	**Action**
No	No flow (Stream 203)	Power loss to SC-201 VSD	No calcium hydroxide will be transported to the mixing tank (TK-202).	Inspect and maintain electrical connections.
More of	More flow (Stream 203)	Current overload	VSD burnout Calcium hydroxide slurry will have incorrect concentration.	Thermal overload interlock (I-202) on SC-201 to prevent VSD burnout.
Less of	Less flow (Stream 203) general	Clumping of calcium hydroxide powder while being discharged from hopper (V-201)	Calcium hydroxide slurry will have incorrect concentration.	Use vibrations on hopper to ensure constant discharge rate.

Table 15: HAZOP meeting minutes for the Calcium Hydroxide Mixing Tank (TK-202).

Plant: Wastewater Treatment Plant		**Area:** 200	**Process Unit:** TK-202	**Reference Drawing:** P&ID DWG-003
HAZOP Date: 03/10/2019		**HAZOP Members:** Matthee, L.H.; Möller, H.F.; Raga, V.V.; van Niekerk, M.; Verster, S.L.		
Guide Word	**Deviation**	**Cause**	**Consequence**	**Action**
No	No flow (Stream 203)	Screw conveyor (SC-201) failure Hopper (V-201) blockage	No calcium hydroxide in mixing tank.	Hopper maintenance and vibrations to prevent blockages.
	No flow (Stream 202)	Pump failure (P-201A)	No water in mixing tank.	Switch to backup pump system (P-201B).
	No flow (Stream 204)	Blockage in pipeline	Increase in level may lead to overflowing or damage to tank. Pumps (P-202A/B) run dry.	Level alarm high (LAH-202) to alert operators of the deviation from normal operation. Manually switch off pumps (P-202A/B) if required.
	No agitation	Agitator (AG-201) motor burnout	Settling of calcium hydroxide solid in tank. Incorrect slurry concentration.	Thermal overload interlock (I-203) to prevent AG-201 motor burnout.
More of	More calcium hydroxide (Stream 203)	Malfunction of flow control loop FIC-201 and/or FIC-202	Increased calcium hydroxide concentration in slurry. Blockage in pipeline.	Regular checks and maintenance on control loops.
	More treated effluent water (Stream 202)	Malfunction of flow control loop (FIC-202)	Increased water concentration in slurry making it less effective in pH control of R-101.	Regular checks and maintenance on control loop.
	More calcium hydroxide slurry (Stream 204)	Malfunction of pH dosing control loop (ARC-101)	Low tank level.	Level alarm low (LAL-202) with interlock (I-204) to disable P-202A/B
Less of	Less calcium hydroxide (Stream 203)	Malfunction of flow control loop (FIC-201)	Decreased calcium hydroxide solid concentration in slurry.	pH alarm low (AAL-101) to alert operators of deviation from normal operation. Regular checks and maintenance on control loop.

<table>
<tr><td colspan="2">Plant: Wastewater Treatment Plant</td><td>Area: 200</td><td>Process Unit: TK-202</td><td>Reference Drawing: P&ID DWG-003</td></tr>
<tr><td colspan="2">HAZOP Date: 03/10/2019</td><td colspan="3">HAZOP Members: Matthee, L.H.; Möller, H.F.; Raga, V.V.; van Niekerk, M.; Verster, S.L.</td></tr>
<tr><th>Guide Word</th><th>Deviation</th><th>Cause</th><th>Consequence</th><th>Action</th></tr>
<tr><td rowspan="2">Less of</td><td>Less treated effluent water (Stream 202)</td><td>Malfunction of flow control loop (FIC-202)</td><td>Decreased water concentration in calcium hydroxide slurry.
More calcium hydroxide slurry dosed than required.</td><td>pH alarm high (AAH-101) with interlock (I-111) to disable pumps (P-202A/B).
Regular checks and maintenance on control loop.</td></tr>
<tr><td>Less calcium hydroxide slurry (Stream 204)</td><td>Malfunction of dosing loop (ARC-101)</td><td>Increase in level may lead to overflowing or damage to tank.</td><td>Level alarm high (LAH-202) to alert operators of deviation from normal operation.</td></tr>
</table>

Table 16: HAZOP meeting minutes for the Calcium Hydroxide Dosing Pumps (P-202A/B).

<table>
<tr><td colspan="2">Plant: Wastewater Treatment Plant</td><td>Area: 200</td><td>Process Unit: P-202A/B</td><td>Reference Drawing: P&ID DWG-003</td></tr>
<tr><td colspan="2">HAZOP Date: 03/10/2019</td><td colspan="3">HAZOP Members: Matthee, L.H.; Möller, H.F.; Raga, V.V.; van Niekerk, M.; Verster, S.L.</td></tr>
<tr><th>Guide Word</th><th>Deviation</th><th>Cause</th><th>Consequence</th><th>Action</th></tr>
<tr><td rowspan="5">No</td><td rowspan="2">No flow (Stream 204)</td><td>Blockage in pipeline</td><td rowspan="2">Pump runs dry (wasted energy).</td><td>Monitor pressure using pressure indicators (PI-203 and PI-204) on pump discharge lines.
Regular descaling of pipelines.</td></tr>
<tr><td>Low level in TK-202</td><td>Level alarm low (LAL-202) with interlock (I-204) to disable pump (P-202A/B).</td></tr>
<tr><td rowspan="2">No flow (Stream 205)</td><td>Pump failure (P-202A)</td><td rowspan="2">No calcium hydroxide dosing feed to R-101 resulting in micro-organism decay.</td><td>Switch to backup pump system (P-202B).</td></tr>
<tr><td>Blockage in pipeline</td><td>Manually stop feed pumps (P-102A/B) to the process.
Manually close temperature control valve TCV-101 to stop steam flowrate to E-102.</td></tr>
<tr></tr>
<tr><td>More of</td><td>Higher discharge pressure</td><td>Blockage in pipeline</td><td>Pump and pipe damage.</td><td>Monitor pressure using pressure indicators (PI-203 and PI-204) on pump discharge lines.</td></tr>
<tr><td>Less of</td><td>Lower discharge pressure</td><td>Internal wear of the pump resulting in pump inefficiency</td><td>Insufficient supply of calcium hydroxide slurry to R-101.</td><td>Switch to back-up pump system (P-202B).</td></tr>
<tr><td>As well as</td><td>Pump P-202 B start-up</td><td>Accidental start of back-up pump system (P-202B)</td><td>Pressure build-up in pipeline causing line rupture.</td><td>Program interlocks of pumps in MCC allowing only one pump to run at a time.</td></tr>
</table>

2.2 Summary of Changes to P&IDs

After performing the HAZOP studies on each process unit shown on the attached P&IDs in Appendix A, a number of changes were made in terms of the monitoring and control. These are listed in Table 17 and are reflected on the post-HAZOP P&IDs in Appendix B.

Table 17: Summary of changes to P&IDs.

Unit	Modification description and reason	P&ID location
S-105	Install strainer. A strainer would be installed on the feed line to remove large insoluble solids from the stream. This will minimise the risk of blockages in pipes feeding to and discharging from the buffer tank.	Stream 101
FI-105	Install flow indicator. It is critical that ferric chloride is dosed to TK-101 to prevent hydrogen sulphide formation. A flow indicator would be installed to enable monitoring of ferric chloride flow in the pipeline.	Stream 216
PI-109	Install pressure indicator. A pressure indicator after E-101 will ensure that the operator could identify if a blockage in the heat exchanger has occurred.	Stream 104
PI-110	Install pressure indicator. A pressure indicator after E-102 will ensure that the operator could identify if a blockage in the heat exchanger has occurred.	Stream 105
PI-111	Install pressure indicator. A pressure indicator after E-102 on the steam discharge line will enable the operator to identify a blockage within the heat exchanger. The pressure indicator will also indicate if plate cracking has occurred and the presence of unstable operation.	Stream 134
PRV-103	Install steam pressure relief valve. A safety pressure relief valve will be installed on the steam side of the heat exchanger. The valve will automatically open when the steam pressure increases above the maximum operating pressure.	E-102
LIT-102	Install level indicator and transmitter with a level high alarm. The level alarm will act as a warning system when the level in the AD (R-101) reaches an undesirable high level. This will prevent the flow of liquid from R-101 into the biogas lines.	R-101

Stream 128	Move stream exit to AD (R-101). Biogas will be returned to R-101 from the degassing tank (S-101). This will prevent the need to mix the biogas streams in a pipeline, which is undesirable.	S-101 & R-101
AIT-103	Install a gas analyser with a hydrogen sulphide detection alarm. The gas analyser will identify the presence of hydrogen sulphide in the biogas exiting R-101. If hydrogen sulphide is present, an alarm will notify the operator to inspect the ferric chloride dosing.	Stream 127
LIT-103	Install level indicator and transmitter with a level alarm high. The level alarm will act as a warning system when the level in the degassing unit (S-101) reaches an undesirable high level. This will prevent the flow of liquid from S-101 into the gas lines.	S-101
LSL-102	Install level switch low. The level switch low will activate the interlock 112 when the level within the clarifier reaches an undesirable low level.	S-102
I-112	Install safety interlock between clarifier and recycle pumps. When the level in the clarifier is critically low, the interlock will disable the sludge recycle pumps (P-105A/B). This will allow the clarifier level to recover to acceptable operating conditions. This will also minimise energy wasted from running the sludge recycle pumps (P-105A/B) dry.	S-102 & P105A/B
FI-103	Remove flow indicator from sludge recycle stream. Since FIT-106 is moved to this line, an additional flow indicator is unnecessary.	Stream 120
FI-104	Remove flow indicator from biogas stream. The flow indicator will be removed since the pressure indicator on R-101 will be sufficient to monitor and determine the presence of flow in the pipeline.	Stream 129
HV-164	Install sampling port on reactor outlet. An additional sampling port on the reactor outlet is installed. This will enable testing of TSS and TCOD concentrations, to monitor and determine if R-101 is functioning optimally.	Stream 107

3 BASIC PLANT LAYOUT

The objective of the plant layout design is to provide a layout which satisfies local by-laws, minimizes safety risks and ensures economic viability. The general approach to the designing of the plant layout is explained in detail below and a possible plant layout presented in Appendix C. In order to achieve this, the physical dimensions of the process units as well as the horizontal distances between these units are specified.

3.1 General Approach

The general approach to the plant layout was to ensure safe design, that all units could be easily accessed, and that trucks could safely navigate the roads without potential damage to equipment.

Majority of the equipment will be accessible via the main perimeter road (10 m wide, as per (Moran, 2016)) which will allow heavy duty vehicles, such as trucks and fire engines, to safely navigate around the plant. All roads will have a curve of radii 12 m or greater (East Sussex Government, 2017) to ensure easy and safe navigation. Furthermore, secondary roads (5 m wide in accordance with (Moran, 2016)) provide access for vehicles to process units otherwise unreachable. These roads are 'T'-shaped to facilitate easy manoeuvring of vehicles in and out of the area. All buildings are located 5 m from the road while fire hydrants are located 3 m from the road for easy access by emergency vehicles (CSIR, 2018). The distance between the units and the road enables maintenance vehicles to carry out activities while not impeding traffic. In the event of the road being inaccessible there is sufficient space for vehicles to bypass the affected area (outside of the perimeter road, not shown).

The main, one level, pipe rack present in the centre of the layout was sized by summing the outer diameters of all the pipes it will hold as well as a 20 mm clearance between them (Bausbacher & Hunt, 1993). The pipe rack is situated in the middle of the plant to assist process fluid transportation. This is especially useful for recycle streams that span large distances, such as the recycle stream from the drum filter (S-103) to the wastewater feed pre-heater (E-101). The pipe rack is given enough clearance to allow easy access for maintenance or expansion, therefore process units are located at a minimum distance of 3 m from the pipe rack (PIP, 2013).

Pump houses were placed with the aim of minimizing suction side head (Bausbacher & Hunt, 1993), thereby reducing pipe rack size and maximising accessibility. The pump houses can be accessed by trucks for easy removal via crane and replacement of pumps. Pumps were combined in pump houses to minimize space requirements and allow for easy grouping of electric cables and pipelines. The grouped location of multiple pumps also ensures that the valves closest to them are easily accessible

The influent subsystem (consisting of units TK-101; TK-102; P-101A/B, P-103A/B; P-102A/B, P-110A/B & P-111A/B; E-101, E-102 and TK-103) is grouped together due to their dependence and similar aim. This subsystem was placed near the highest traffic area due to its inherent safety (these tanks will not pose a significant danger to personnel). The tanks contain bunds which will prevent any major leakage to the environment. Pumps (P-101A/B and P-103A/B) are combined in a pump house due to the sequence of their process fluid flow. Similarly Pumps (P-102A/B, P-110A/B and P-111A/B) are also housed together.

The biogas subsystem (including units C-101, TK-104, V-101, E-103, R-101, P-109A/B and S-101) is defined to contain all units associated with flammable biogas. These units obey the spacing requirement standards for oil and chemical plants (GAPS, 2017). These units have a fire hydrant and water tank (either process water or an emergency water tank) in close proximity. The units were spaced assuming a south-easterly wind which will direct any fumes away from the plant and fan flames towards non-flammable areas of the plant. The flare is located 60 m from any equipment containing combustible materials including biogas and the polymer used for dosing (Moran, 2016). The fire hydrant closest to the flare has process water close by which can be used as an alternative emergency water supply should the underground source fail. The AD (R-101) is accessible on three sides as it is the largest unit. The increased accessibility was decided upon as multiple heavy duty vehicles will be required to assemble, disassemble and maintain this unit. The boiler (E-103) is located close to the AD feed heater (E-102) to prevent steam from condensing in the pipes during transport as well as to minimize energy losses.

The dewatering and recycle areas (consisting of units S-102; S-103; P-104A/B, P-105A/B & P-106A/B; S-104; TK-105; P-107 A/B and P-108 A/B) are located together as these units are responsible for the recycle and separation of process fluid between the units. The waste skip (TK-105) is near a secondary road to enable easy transfer of waste to the removal truck without blocking the main road. TK-105 is also accessible via the perimeter road if access via the secondary road is not possible. The drum filter (S-103) is located near the perimeter whereby the final treated effluent can easily flow from this position to the discharge point (located south-south-west). This area contains two pump houses whereby pumps are located due to the sequence of their process fluid flow.

The dosing section (which includes V-201; P-201A/B, P-203A/B; TK-203, V-202, TK-201, TK-202, TK-204; P-202A/B, P-204A/B, P-205A/B, P-206A/B and P-207A/B) includes the storage warehouse with a loading zone nearby. Tanks containing liquids (TK-203, TK-202 and TK-204) all have bunds around them to prevent environmental contamination. This section contains two pump houses with the pumps grouped according to the sequence of their process fluid flow.

The loading zone is positioned off the main perimeter road. This allows for easy offloading to the storage warehouse. It is located close to the dosing section which will require the most deliveries of consumables. Because the polymer is combustible, it was ensured that no ignition sources are nearby.

The control room is placed in the middle of the plant to ensure that the operator can quickly and easily travel to equipment if the need arises. The control room should ideally be a double story building, providing visibility of the entire plant to the operators. The location of the control room is within 35 m of equipment, minimizing the distance required for the operator to travel from the control room (Moran, 2016). Moreover, it is located far from the biogas handling section to ensure operator safety. The motor control centre is located near the control room to allow for easy access by the operator.

The substation is located next to the main road to ensure that it is easily accessible to maintenance personnel. It is also near to the influent area which will minimize the distance required for electrical cabling to travel.

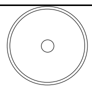
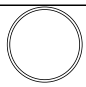
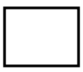
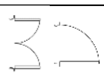
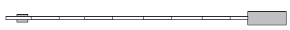
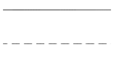
The utility buildings (such as the administration building, laboratory, medical station, maintenance and garage building and the break room) are located close to the entrance and exit to reduce congestion on the plant roads (in the event of maintenance). The buildings are located far from hazardous areas (i.e. far from large concentrations of biogas), but still within view of the plant so that any incidents are reported promptly. Additionally an emergency assembly point is located in a safe area away from potential dangers. The break room is provided for off-duty personnel allowing them to rest and eat without leaving the plant premises. A security booth and boom gate are present to ensure no unauthorized personnel enter the plant. The administration building assists visitors, relays messages and directs any deliveries to its correct location. The medical station includes enough supplies to treat or stabilise any injured personnel.

Future expansion area includes the area north-north-east and south-south-west of the plant (land not visible in diagram). Additionally, space is present in the section above the motor control centre. Provided the extra units added don’t have any risk of igniting due to their proximity to the flare.

3.2 Plant Layout Details

A layout key for the figures representing the top-down view of the process units is shown in Table 18. This should be used in conjunction with the plant layout found in Appendix C.

Table 18: Top-down view of process units in plant layout.

Top-Down View	Label
	Tank with agitator
	Tank without an agitator
	Screw Conveyor
	Pipe rack
	Building (could represent utility buildings or process units such as pump houses or the drum filter)
	Double/Single Door
	Security boom
	Zoned areas
	Main road
	Secondary road

Furthermore, the spacing between each process unit and the two units closest to it are specified in Table 19 below. These distances were determined as follows:

Tanks were located at a distance of at least half of their diameter away from the next unit (GAPS, 2017). Pump houses were located at a minimum of 10 m away from each other (PIP, 2013). An 8 m distance is maintained between the boiler (E-103) and the pump house containing P-109A/B and C-101 (PIP, 2013). All other heat exchangers are located, at a minimum distance of, 3 m away from the closest unit. The anaerobic digester (R-101) is located at a minimum distance of 15 m away from other separation units (PIP, 2013). Pump houses and storage tanks are spaced at a minimum of 5 m from the substation (PIP, 2013).

A minimum distance of 6 m was provided between utility buildings (administration, laboratory, maintenance and garage and the break room) (Moran, 2016). The control room was located centrally on the layout providing prompt access to equipment if required. A distance of 6 m was chosen between the control room and motor control centre (Moran, 2016).

Table 19: Process units of the wastewater treatment plant and the horizontal distance to the closest units.

Tag Number	Unit Description	Closest Units	Spacing (m)
Influent Subsystem			
P-101A/B	Wastewater Feed Pumps	Substation	5.0
		TK-102	4.0
TK-101	AD Feed Buffer Tank	TK-102	8.0
		TK-103	8.0
TK-102	Calamity Tank	P-101A/B & P-103A/B	4.0
		TK-101	8.0
P-102A/B	AD Feed Pump	E-101 & E-102	4.0
		TK-101	10.0
P-103A/B	Calamity Tank Discharge Pumps	Substation	5.0
		TK-102	4.0
E-101	Wastewater Feed Preheater	TK-103	2.8
		P-102 A/B, P-110A/B & P-111A/B	4.0
E-102	AD Feed Heater	TK-103	2.8
		P-102 A/B, P-110A/B & P-111A/B	4.0
P-110A/B	Treated Effluent Discharge Pump	E-101 & E-102	4.0
		TK-101	10.0
P-111A/B	Treated Effluent Pump to Dosing	E-101 & E-102	4.0
		TK-101	10
TK-103	Treated Effluent Buffer Tank	E-101 & E-102	2.8
		TK-101	8.0
Dewatering and Recycle Subsystem			
S-102	Clarifier	S-103	2.0
		S-104	3.5
S-103	Drum Filter	S-102	2.0
		P-104A/B, P-105A/B & P-106A/B	3.0

P-104A/B	Treated Effluent Pump to E-101	S-103	3.0
		S-102	5.9
P-105A/B	Sludge Recycle Pump	S-103	3.0
		S-102	5.9
P-106A/B	Centrifuge Feed Pump	S-103	3.0
		S-102	5.9
S-104	Centrifuge	S-102	3.5
		P-104A/B, P-105A/B & P-106A/B	8.0
P-107A/B	Centrate Pump to TK-101	Motor Control Centre	3.5
		TK-105	9.8
P-108A/B	Dewatered Sludge Pump	Motor Control Centre	3.5
		TK-105	9.8
TK-105	Dewatered Sludge Skip	P-107A/B & P-108A/B	9.8
		Motor Control Centre	16.3
Biogas Subsystem			
C-101	Air Compressor	S-101	3.0
		E-103	8.0
TK-104	Boiler Feed Water Buffer Tank	P-109A/B & C-101	13.5
		TK-103	17.0
S-101	Degassing Tank	P-109A/B	3.0
		E-103	3.0
R-101	Anaerobic Digester	P-104A/B, P-105A/B & P-106A/B	7.5
		E-103	13.5
P-109A/B	Boiler Feed Water Pump	S-101	3.0
		E-103	8.0
E-103	Biogas Boiler	S-101	3.5
		P-109A/B & C-101	8
V-101	Biogas Flare	Process Water Tank	14.5
		TK-105	15
Dosing Subsystem			
TK-201	Dosing Water Make-up Tank	P-201A/B & P-203A/B	3.8
		Substation	5.0
P-201A/B	Dosing Water Pump to TK-202	TK-201	3.8
		V-202 & SC-202	5.5
P-203A/B	Dosing Water Pump to TK-203	TK-201	3.8
		V-202 & SC-202	5.5
V-201 & SC-201	CH Storage Hopper with Screw Conveyor	TK-203	3.0
		TK-202	4.0
V-202 & SC-202	Polymer Storage Hopper with Screw Conveyor	P-202A/B, P-204A/B, P-205A/B, P-206A/B & P-207A/B	4.5
		TK-203	5.0
TK-202	CH Mixing Tank	TK-204	3.0
		V-201 & SC-201	4.0
P-202A/B	CH Slurry Dosing Pump	TK-203	4.5

		V-202 & SC-202	4.5
TK-203	Polymer Mixing Tank	V-201 & SC-201	3.0
		P-202A/B, P-204A/B, P-205A/B, P-206A/B & P-207A/B	4.5
P-204A/B	Polymer Dosing Pump to Clarifier	TK-203	4.5
		V-202 & SC-202	4.5
P-205A/B	Polymer Dosing Pump to Centrifuge	TK-203	4.5
		V-202 & SC-202	4.5
TK-204	Ferric Chloride Buffer Tank	TK-202	3.0
		V-201 & SC-201	3.0
P-206A/B	Ferric Chloride Dosing Pump to AD Buffer Tank	TK-203	4.5
		V-202 & SC-202	4.5
P-207A/B	Ferric Chloride Dosing Pump to Clarifier	TK-203	4.5
		V-202 & SC-202	4.5
Utilities			
SS	Substation	TK-201	5.0
		P-101A/B & P-103A/B	5.0
PW	Process Water Tank	Central Control Room	5.3
		V-101	14.5
CCR	Central Control Room	Process Water Tank	5.3
		Motor Control Centre	6.3
MCC	Motor Control Centre	P-107A/B & P-108A/B	3.5
		Central Control Room	6.3
SW	Storage Warehouse	V-201 & SC-201	3.5
		TK-204	6.5

4 REFERENCES

Anticorrosive Equipment Pvt Ltd. (n.d.). *NJRP Series: Standard Chemical Process Pumps.* Anticorrosive Equipment Pvt Ltd.

Bausbacher, E., & Hunt, R. (1993). *Process Plant Layout and Piping Design* (1 ed.). Prentice Hall.

Bosch. (2012). *Universal Steam Boiler.* Bosch.

Compressor World. (n.d.). *100 HP Rotary Screw Air Compressor offering 456 CFM with Sound Enclosure, 460 Volt 3 Phase | E100*. Retrieved October 3, 2019, from https://www.compressorworld.com/100-hp-rotary-screw-air-compressor-offering-456-cfm-with-sound-enclosure-460-volt-3-phase-e100.html

CSIR. (2018). *GUIDELINES FOR HUMAN SETTLEMENT PLANNING AND DESIGN.* CSIR.

East Sussex Government. (2017). *Design Standards for Industrial Roads.* Sussex.

Finn Biogas . (n.d.). *Equipment Catalogue: Industrial Biogas Plants.* Finn Biogas.

GAPS. (2017). *OIL AND CHEMICAL PLANT LAYOUT AND SPACING.* Global Asset Protection Services LLC.

Green, D. &. (2019). *Perry's Chemical Engineers' Handbook* (9 ed.). New York: McGraw-Hill Education.

JoJo. (n.d.). *Water Storage Solutions* . Retrieved October 3, 2019, from https://www.jojo.co.za/

Moran, S. (2016). *Process Plant Layout* (2 ed.). Butterworth-Heinemann.

Pioneer Pump. (n.d.). *Positive Displacement Pumping Solutions.* Pioneer Pump.

PIP. (2013). *Process Unit and Offsites Layout Guide.* Austin: Process Industry Practices (PIP).

PVS. (n.d.). *Drum Filter.* PVS.

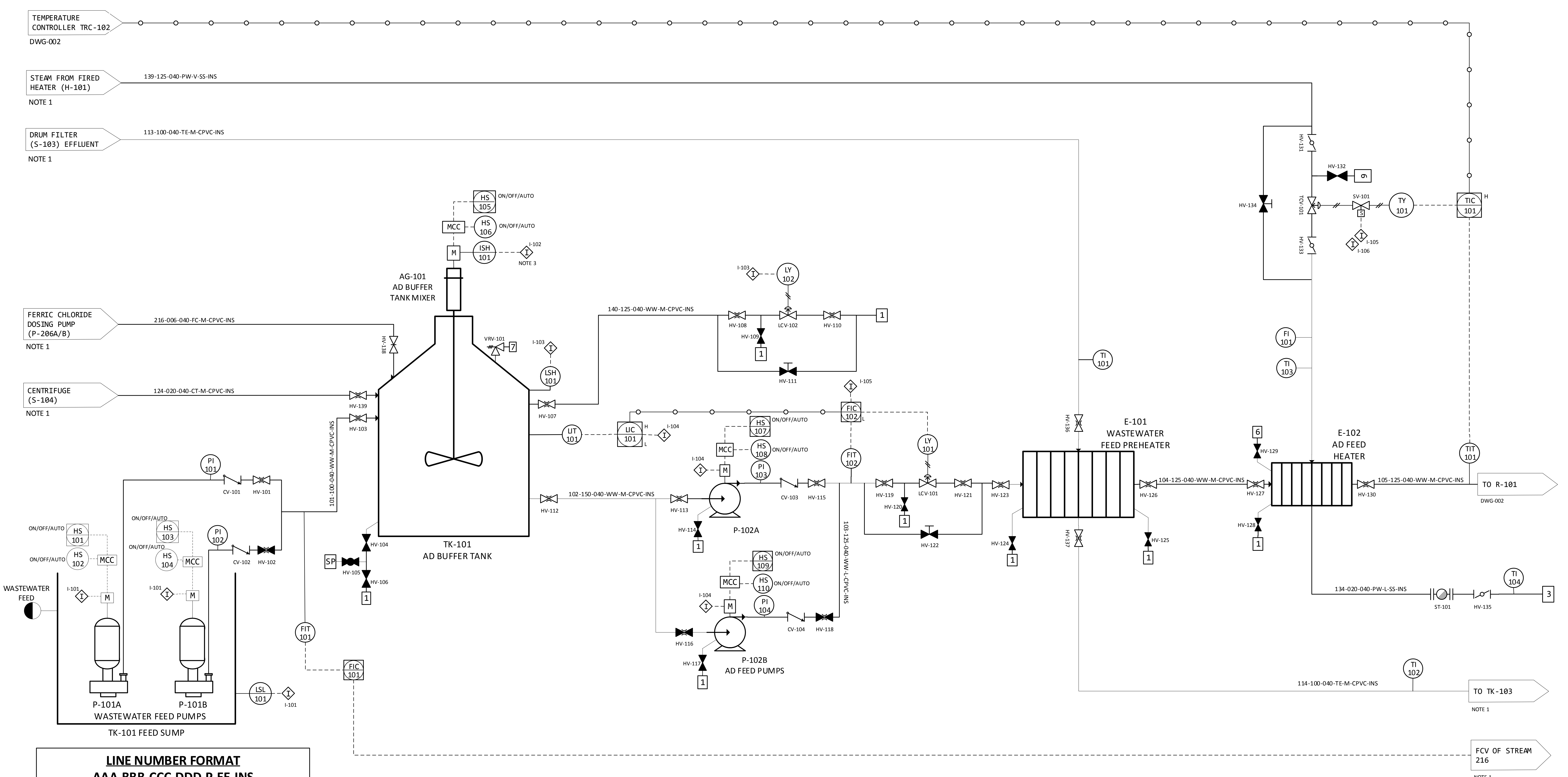
Qasim, S., & Zhu, G. (2018). *Wastewater Treatment and Reuse: Theory and Design Examples.* Taylor & Francis Group.

Sinnot, R. (2005). *Coulson & Richardson's Chemical Engineering Series: Chemical Engineering Design* (4 ed., Vol. 6). Elsevier.

Toghraei, M. (2013). *Rules of thumb on fixed roof atmospheric tanks.* Retrieved August 25, 2019, from http://engedu.ca/wp-content/uploads/Atmospheric-Tank-Rule-of-thumbs-1.pdf

Waste-Away. (n.d.). *Skip Bin Size*. Retrieved October 3, 2019, from http://www.w-away.co.za/bin-sizes-waste-away-skips.htm

APPENDIX A – P&IDS (PRE-HAZOP)



LINE NUMBER FORMAT

AAA-BBB-CCC-DDD-P-EE-INS

AAA	UNIQUE NUMBER LINE	
BBB	LINE NOMINAL SIZE	
CCC	PIPE SCHEDULE NUMBER	
DDD	TRANSPORTED FLUID	
	CT	CENTRATE
	FC	FERRIC CHLORIDE
	TE	TREATED EFFLUENT
	WW	WASTEWATER
P	PHASE	
	L	LIQUID
	M	MIXED
	S	SOLID
	V	VAPOUR
EE	MATERIAL OF CONSTRUCTION	
	CPVC	CHLORINATED POLYVINYL CHLORIDE
	SS	STAINLESS STEEL 304
INS	INSULATION	

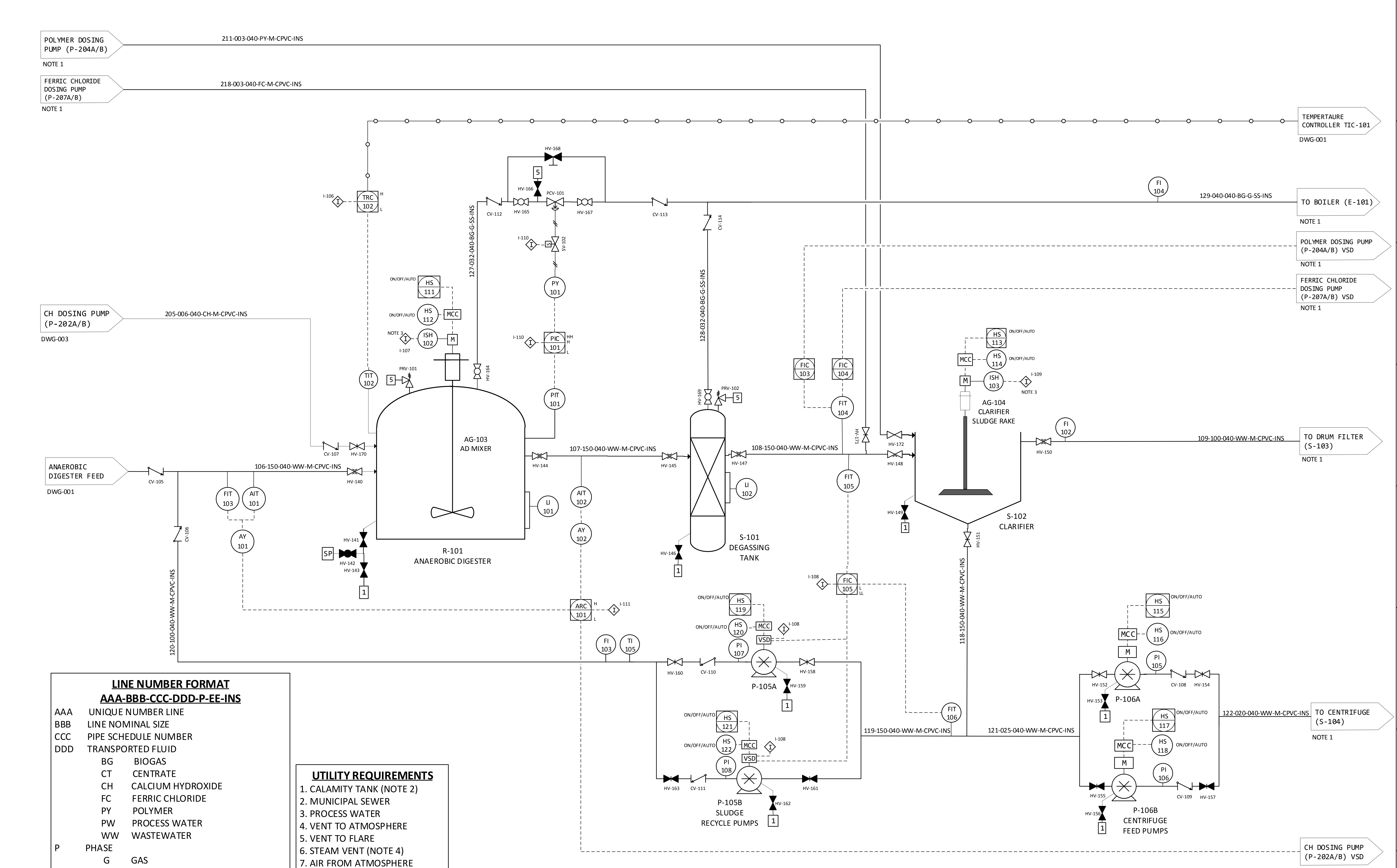
UTILITY REQUIREMENTS

1. CALAMITY TANK (NOTE 2)
2. MUNICIPAL SEWER
3. PROCESS WATER
4. VENT TO ATMOSPHERE
5. VENT TO FLARE
6. STEAM VENT (NOTE 4)
7. AIR FROM ATMOSPHERE
8. CHEMICAL SEWER

NOTES

1. STREAM ENTERS/EXITS TO A UNIT NOT SHOWN ON THESE THREE P&IDS
2. DRAIN TO A PIPELINE THAT FEEDS INTO THE CALAMITY TANK
3. TRIP THE AGITATOR MOTOR USING A CURRENT INTERLOCK
4. STEAM VENT/FLARE WILL BE REDIRECTED AWAY TO PREVENT INJURY TO PERSONNEL

Stellenbosch University Department of Process Engineering	Design 488 (2019)			
	P&ID for the feed sump, buffer tank, reactor feed pump and heat exchangers.			
Group Number: G-11	SECTION 4	DRAWING TYPE P&ID	DWG NO DWG-001	REV 2
Date: 2019-10-11	SCALE	1:1	SHEET	1 OF 3



LINE NUMBER FORMAT

AAA-BBB-CCC-DDD-P-EE-INS

AAA	UNIQUE NUMBER LINE		
BBB	LINE NOMINAL SIZE		
CCC	PIPE SCHEDULE NUMBER		
DDD	TRANSPORTED FLUID		
		BG	BIOGAS
		CT	CENTRATE
		CH	CALCIUM HYDROXIDE
		FC	FERRIC CHLORIDE
		PY	POLYMER
		PW	PROCESS WATER
		WW	WASTEWATER
P	PHASE		
		G	GAS
		L	LIQUID
		M	MIXED
		S	SOLID
		V	VAPOUR
EE	MATERIAL OF CONSTRUCTION		
		CPVC	CHLORINATED POLYVINYL CHLORIDE
		SS	STAINLESS STEEL 304
INS	INSULATION		

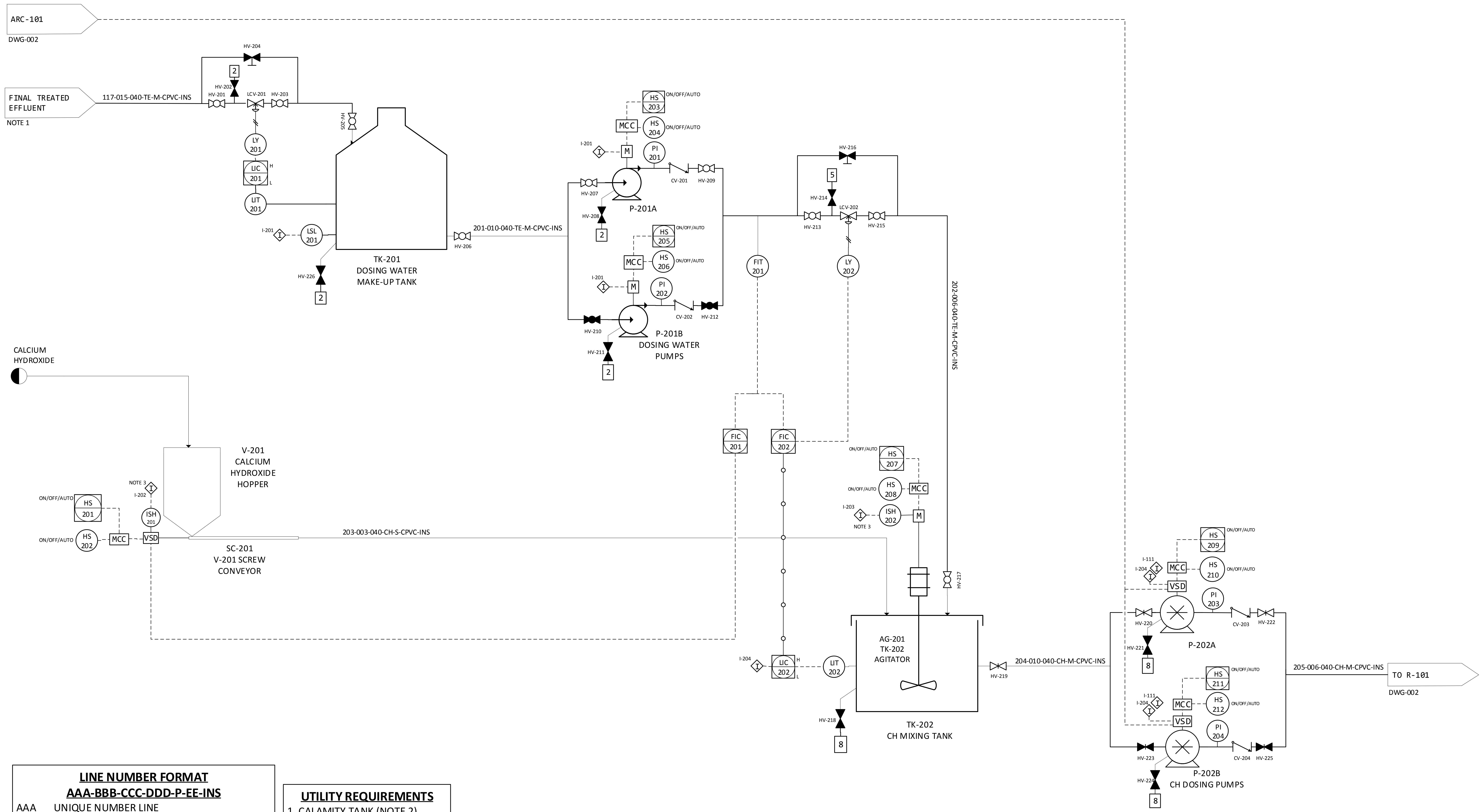
UTILITY REQUIREMENTS

1. CALAMITY TANK (NOTE 2)
2. MUNICIPAL SEWER
3. PROCESS WATER
4. VENT TO ATMOSPHERE
5. VENT TO FLARE
6. STEAM VENT (NOTE 4)
7. AIR FROM ATMOSPHERE
8. CHEMICAL SEWER

NOTES

1. STREAM ENTERS/EXITS TO A UNIT NOT SHOWN ON THESE THREE P&IDS
2. DRAIN TO A PIPELINE THAT FEEDS INTO THE CALAMITY TANK
3. TRIP THE AGITATOR MOTOR USING A CURRENT INTERLOCK
4. STEAM VENT/FLARE WILL BE REDIRECTED AWAY TO PREVENT INJURY TO PERSONNEL

Stellenbosch University Department of Process Engineering	Design 488 (2019)				
	P&ID for the anaerobic digester and degassing tank, clarifier and sludge return				
Group Number: G-11	SECTION 4	DRAWING TYPE P&ID	DWG NO DWG-002		REV 2
Date: 2019-10-11	SCALE	1:1		SHEET	2 OF 3



LINE NUMBER FORMAT
AAA-BBB-CCC-DDD-P-EE-INS

AAA	UNIQUE NUMBER LINE	
BBB	LINE NOMINAL SIZE	
CCC	PIPE SCHEDULE NUMBER	
DDD	TRANSPORTED FLUID	
	CH	CALCIUM HYDROXIDE
	PW	PROCESS WATER
	TE	TREATED EFFLUENT
P	PHASE	
	L	LIQUID
	M	MIXED
	S	SOLID
EE	MATERIAL OF CONSTRUCTION	
	CPVC	CHLORINATED POLYVINYL CHLORIDE
	SS	STAINLESS STEEL 304
INS	INSULATION	

UTILITY REQUIREMENTS

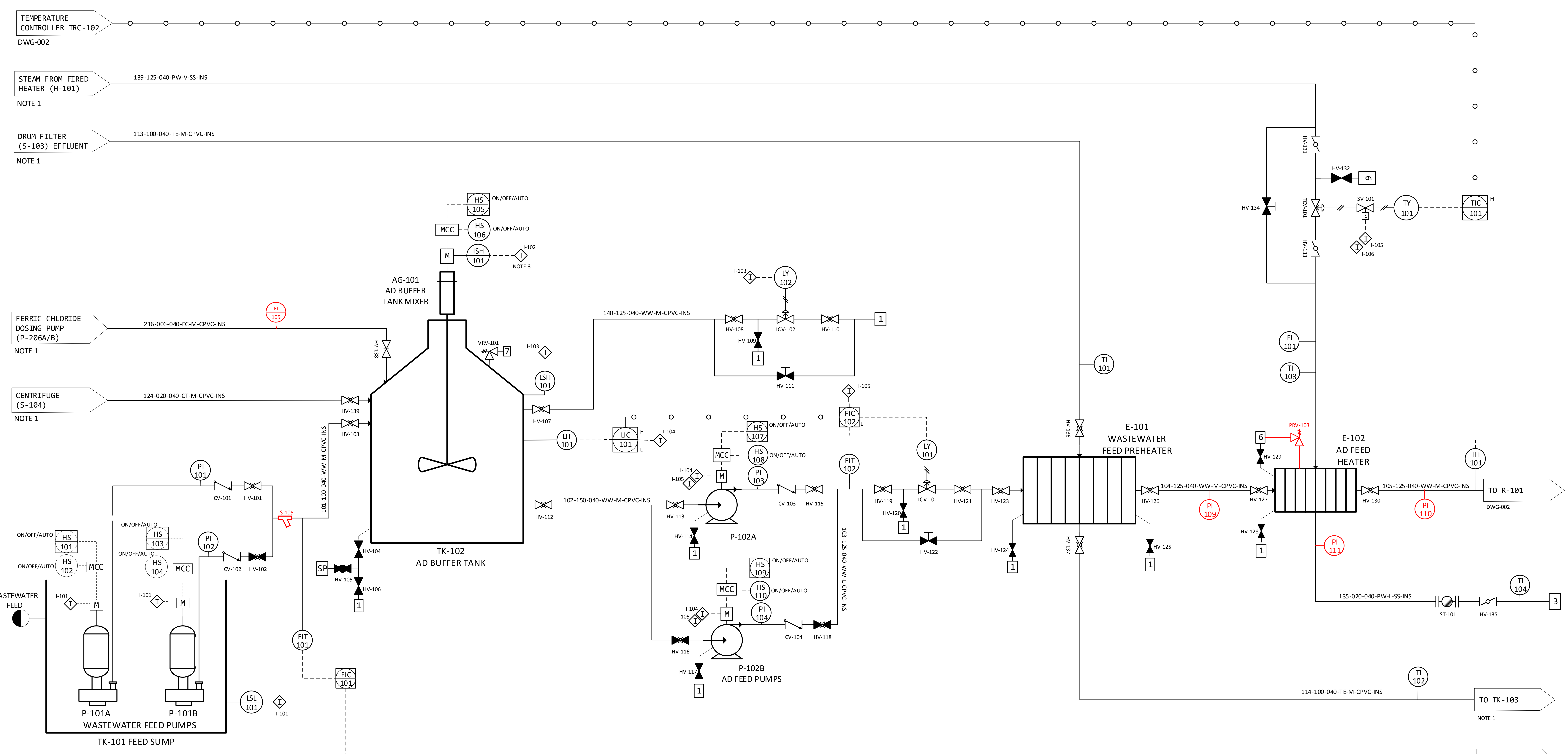
1. CALAMITY TANK (NOTE 2)
2. MUNICIPAL SEWER
3. PROCESS WATER
4. VENT TO ATMOSPHERE
5. VENT TO FLARE
6. STEAM VENT (NOTE 4)
7. AIR FROM ATMOSPHERE
8. CHEMICAL SEWER

NOTES

1. STREAM ENTERS/EXITS TO A UNIT NOT SHOWN ON THESE THREE P&IDS
2. DRAIN TO A PIPELINE THAT FEEDS INTO THE CALAMITY TANK
3. TRIP THE AGITATOR MOTOR USING A CURRENT INTERLOCK
4. STEAM VENT/FLARE WILL BE REDIRECTED AWAY TO PREVENT INJURY TO PERSONNEL

Stellenbosch University Department of Process Engineering	Design 488 (2019)			
	P&ID for the pH dosing station.			
Group Number: G-11	SECTION 4	DRAWING TYPE P&ID	DWG NO DWG-003	REV 2
Date: 2019-10-11	SCALE 1:1		SHEET 3 OF 3	

APPENDIX B – P&IDS (POST-HAZOP)



LINE NUMBER FORMAT

AAA-BBB-CCC-DDD-P-EE-INS

AAA	UNIQUE NUMBER LINE	
BBB	LINE NOMINAL SIZE	
CCC	PIPE SCHEDULE NUMBER	
DDD	TRANSPORTED FLUID	
	CT	CENTRATE
	FC	FERRIC CHLORIDE
	TE	TREATED EFFLUENT
	WW	WASTEWATER
P	PHASE	
	L	LIQUID
	M	MIXED
	S	SOLID
	V	VAPOUR
EE	MATERIAL OF CONSTRUCTION	
	CPVC	CHLORINATED POLYVINYL CHLORIDE
	SS	STAINLESS STEEL 304
INS	INSULATION	

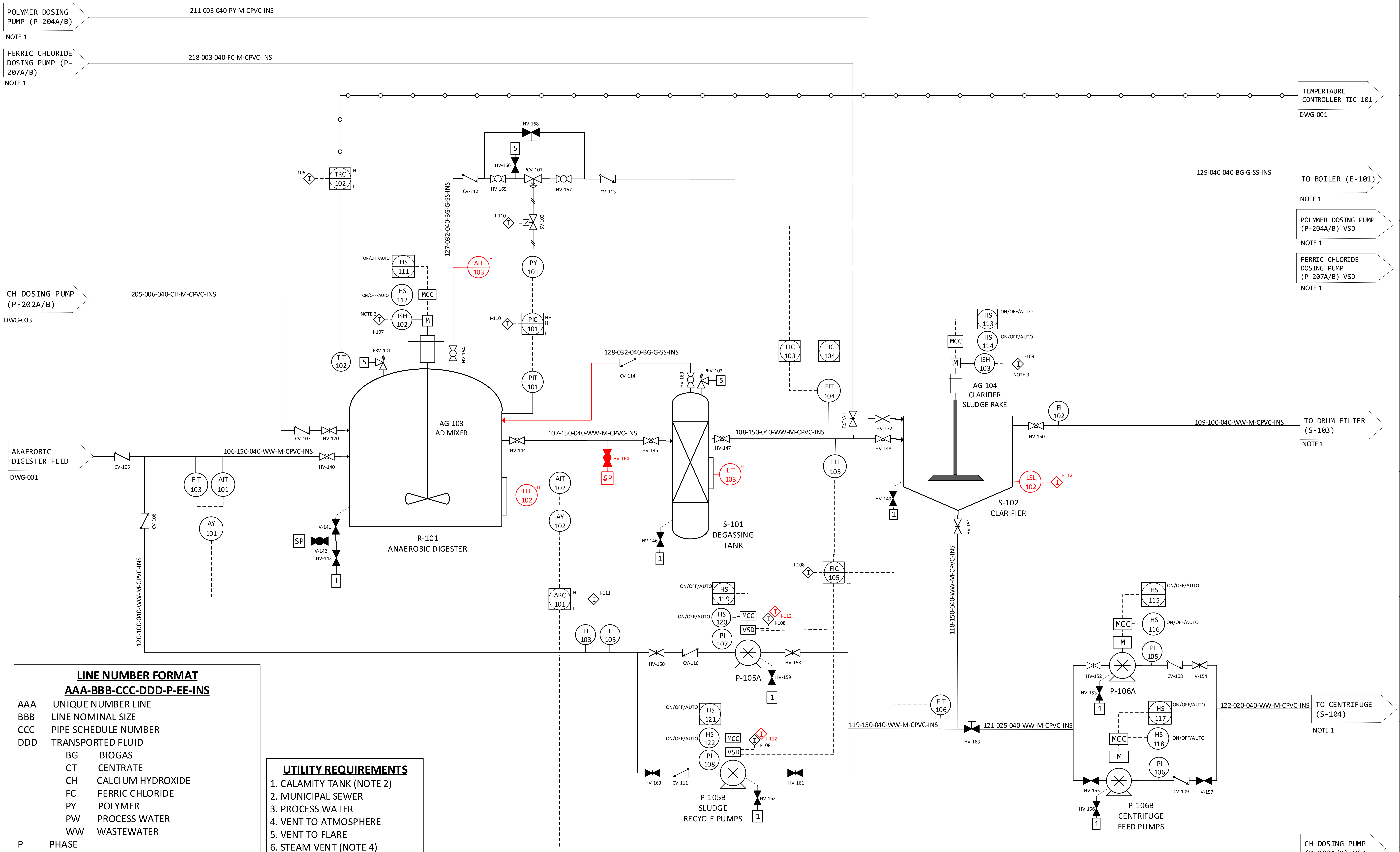
UTILITY REQUIREMENTS

1. CALAMITY TANK (NOTE 2)
2. MUNICIPAL SEWER
3. PROCESS WATER
4. VENT TO ATMOSPHERE
5. VENT TO FLARE
6. STEAM VENT (NOTE 4)
7. AIR FROM ATMOSPHERE
8. CHEMICAL SEWER

NOTES

1. STREAM ENTERS/EXITS TO A UNIT NOT SHOWN ON THESE THREE P&IDS
2. DRAIN TO A PIPELINE THAT FEEDS INTO THE CALAMITY TANK
3. TRIP THE AGITATOR MOTOR USING A CURRENT INTERLOCK
4. STEAM VENT/FLARE WILL BE REDIRECTED AWAY TO PREVENT INJURY TO PERSONNEL

Stellenbosch University Department of Process Engineering	Design 488 (2019)			
	P&ID for the feed sump, buffer tank, reactor feed pump and heat exchangers.			
Group Number: G-11	SECTION 4	DRAWING TYPE P&ID	DWG NO DWG-001	REV 2
Date: 2019-10-11	SCALE 1:1		SHEET 1 OF 3	



LINE NUMBER FORMAT

AAA-BBB-CCC-DDD-P-EE-INS

AAA	UNIQUE NUMBER LINE	
BBB	LINE NOMINAL SIZE	
CCC	PIPE SCHEDULE NUMBER	
DDD	TRANSPORTED FLUID	
	BG	BIOGAS
	CT	CENTRATE
	CH	CALCIUM HYDROXIDE
	FC	FERRIC CHLORIDE
	PY	POLYMER
	PW	PROCESS WATER
	WW	WASTEWATER
P	PHASE	
	G	GAS
	L	LIQUID
	M	MIXED
	S	SOLID
	V	VAPOUR
EE	MATERIAL OF CONSTRUCTION	
	CPVC	CHLORINATED POLYVINYL CHLORIDE
	SS	STAINLESS STEEL 304
INS	INSULATION	

UTILITY REQUIREMENTS

1. CALAMITY TANK (NOTE 2)
2. MUNICIPAL SEWER
3. PROCESS WATER
4. VENT TO ATMOSPHERE
5. VENT TO FLARE
6. STEAM VENT (NOTE 4)
7. AIR FROM ATMOSPHERE
8. CHEMICAL SEWER

NOTES

1. STREAM ENTERS/EXITS TO A UNIT NOT SHOWN ON THESE THREE P&IDS
2. DRAIN TO A PIPELINE THAT FEEDS INTO THE CALAMITY TANK
3. TRIP THE AGITATOR MOTOR USING A CURRENT INTERLOCK
4. STEAM VENT/FLARE WILL BE REDIRECTED AWAY TO PREVENT INJURY TO PERSONNEL

Stellenbosch University
Department of Process Engineering

Design 488 (2019)

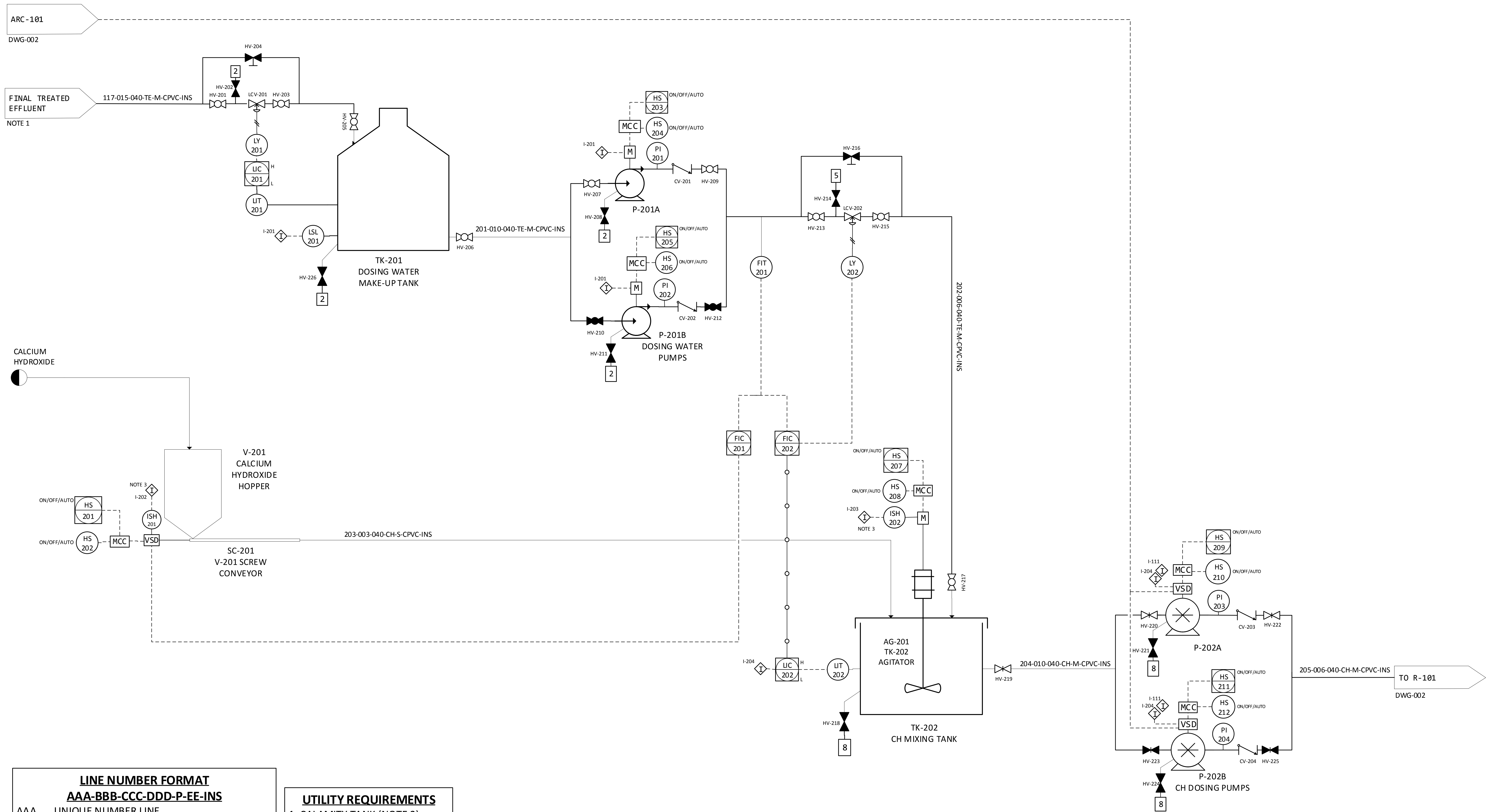
P&ID for the anaerobic digester and degassing tank, clarifier and sludge return

SECTION	DRAWING TYPE	DWG NO	REV
4	P&ID	DWG-002	2

Group Number: G-11

Date: 2019-10-11

SCALE 1:1 SHEET 2 OF 3



LINE NUMBER FORMAT
AAA-BBB-CCC-DDD-P-EE-INS

AAA	UNIQUE NUMBER LINE	
BBB	LINE NOMINAL SIZE	
CCC	PIPE SCHEDULE NUMBER	
DDD	TRANSPORTED FLUID	
	CH	CALCIUM HYDROXIDE
	PW	PROCESS WATER
	TE	TREATED EFFLUENT
P	PHASE	
	L	LIQUID
	M	MIXED
	S	SOLID
EE	MATERIAL OF CONSTRUCTION	
	CPVC	CHLORINATED POLYVINYL CHLORIDE
	SS	STAINLESS STEEL 304
INS	INSULATION	

UTILITY REQUIREMENTS

1. CALAMITY TANK (NOTE 2)
2. MUNICIPAL SEWER
3. PROCESS WATER
4. VENT TO ATMOSPHERE
5. VENT TO FLARE
6. STEAM VENT (NOTE 4)
7. AIR FROM ATMOSPHERE
8. CHEMICAL SEWER

NOTES

1. STREAM ENTERS/EXITS TO A UNIT NOT SHOWN ON THESE THREE P&IDS
2. DRAIN TO A PIPELINE THAT FEEDS INTO THE CALAMITY TANK
3. TRIP THE AGITATOR MOTOR USING A CURRENT INTERLOCK
4. STEAM VENT/FLARE WILL BE REDIRECTED AWAY TO PREVENT INJURY TO PERSONNEL

Stellenbosch University
Department of Process Engineering

Design 488 (2019)

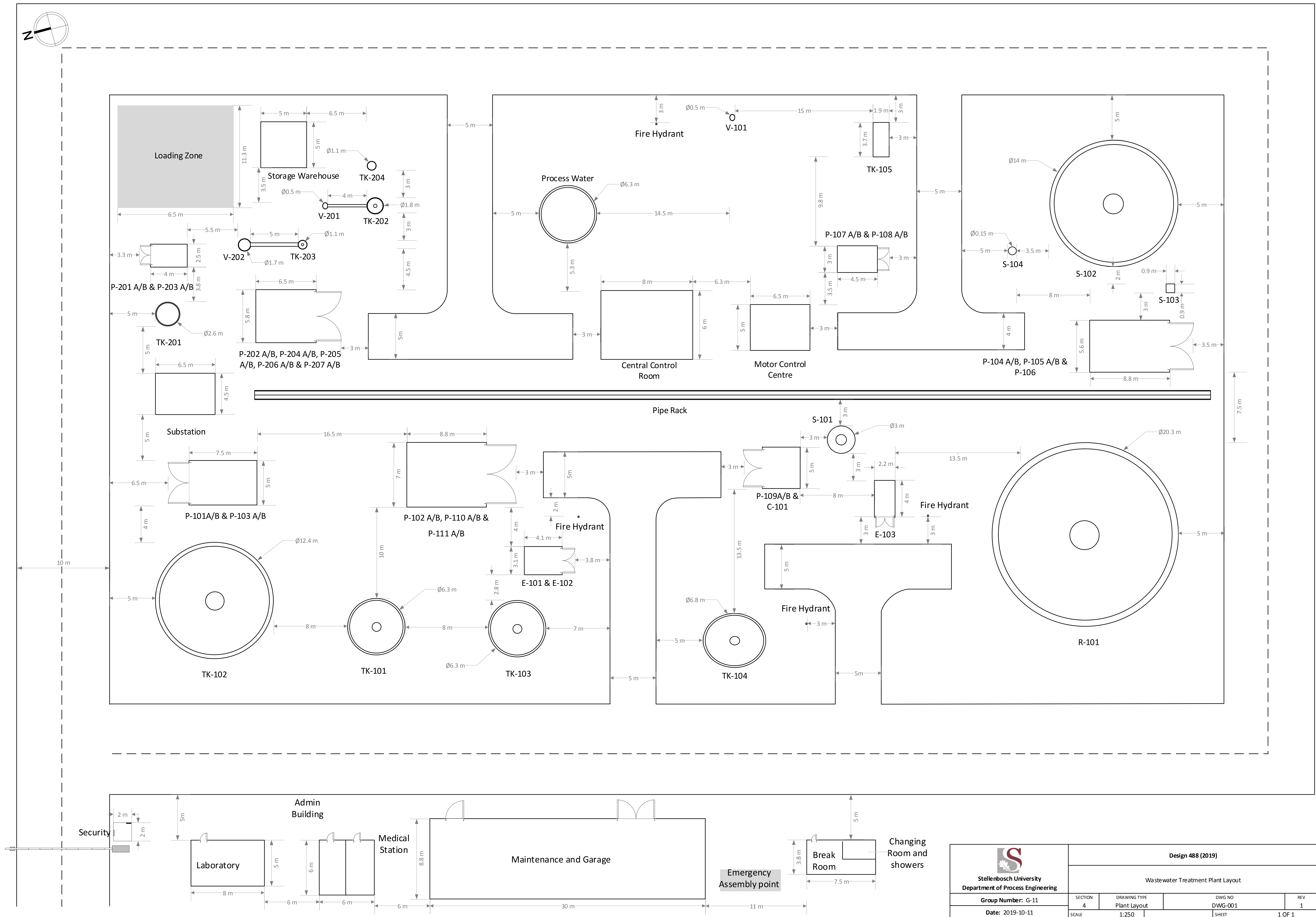
P&ID for the pH dosing station.

Group Number: G-11

Date: 2019-10-11

SECTION	DRAWING TYPE	DWG NO	REV
4	P&ID	DWG-003	2
SCALE	1:1	SHEET	3 OF 3

APPENDIX C – PLANT LAYOUT DIAGRAM


Loading Zone
Storage Warehouse
TK-204
V-201
TK-202
V-202
TK-203
P-201 A/B & P-203 A/B
TK-201
P-202 A/B, P-204 A/B, P-205 A/B, P-206 A/B & P-207 A/B
Substation
P-101A/B & P-103 A/B
TK-102
TK-101
P-102 A/B, P-110 A/B & P-111 A/B
TK-103
Fire Hydrant
E-101 & E-102
Fire Hydrant
V-101
Process Water
Central Control Room
Motor Control Centre
TK-105
P-107 A/B & P-108 A/B
S-104
S-102
S-103
P-104 A/B, P-105 A/B & P-106
Pipe Rack
S-101
P-109A/B & C-101
E-103
Fire Hydrant
Fire Hydrant
TK-104
R-101
Security
Admin Building
Laboratory
Medical Station
Maintenance and Garage
Emergency Assembly point
Break Room
Changing Room and showers
Stellenbosch University
Department of Process Engineering
Group Number: G-11
Date: 2019-10-11
Design 488 (2019)
Wastewater Treatment Plant Layout
SECTION 4
DRAWING TYPE Plant Layout
DWG NO DWG-001
REV 1
SCALE 1:250
SHEET 1 OF 1

APPENDIX D – SIZING OF PROCESS UNITS

TANKS

The tanks mentioned below were sized by determining an appropriate residence time and therefore volume required. Thereafter the diameter was calculated using Equation 1 and the height using Equation 2. Furthermore the height to diameter ratio was taken to be 1:1 for tanks between 100 m^3 and 10 000 m^3 (Toghraei, 2013).

$$D = \left(2^{\frac{2}{3}} \cdot V^{\frac{1}{3}}\right) \Big/ \left(\pi^{\frac{1}{3}} \cdot \left(H/D\right)_{ratio}^{\frac{1}{3}}\right) \qquad [\,1\,]$$

$$H = D \cdot \left(\frac{H}{D}\right)_{ratio} \qquad [\,2\,]$$

- TK-101 AD Feed Buffer Tank
- TK-102 Calamity Tank
- TK-103 Treated Effluent Buffer Tank
- TK-104 Boiler Water Buffer Tank

The dewatered sludge skip (TK-105) dimensions were determined using a waste management service company catalogue (Waste-Away, n.d.).

The dosing section tanks were sized based on the volume required. The dimensions of pre-built tanks that could hold that volume were then obtained from a supplier catalogue (JoJo, n.d.). This is not necessarily to say these tanks would be used, only to get an approximation of the physical area these tanks would occupy. The ferric chloride buffer tank (TK-204) was sized according to chemical storage tank dimensions, whereas the other three mentioned below were sized using water storage tank dimensions.

- TK-201 Dosing Water Make-up Tank
- TK-202 CH Mixing Tank
- TK-203 Polymer Mixing Tank

The height to diameter ratio was taken to be 3 for tanks smaller than 100 m^3, 1 for tanks between 100 m^3 and 10000 m^3 and 0.2 for tanks larger than 10000 m^3 (Toghraei, 2013). The diameter and height were calculated using Equations 1 and 2, respectively.

HEAT EXCHANGERS

The wastewater feed pre-heater (E-101) and AD feed heater (E-102) were sized using a method found in literature (Sinnot, 2005). Using the number of plates required, the thickness of the plates, the channel width between the plates and the width of the plates the physical area occupied by the heat exchangers could be determined.

The biogas boiler (E-103) was sized using a supplier catalogue (Bosch, 2012) based on the flowrate of steam required. The type of boiler selected was a Universal Steam Boiler U-HD 3200.

SEPARATION UNITS

The degassing tank (S-101) diameter was sized based on literature (Sinnot, 2005), as was the clarifier (S-102) diameter (Qasim & Zhu, 2018) and the centrifuge (S-104) bowl diameter (Green, 2019). Lastly, the drum filter sizing was based on the flowrate required and determined to be Type 801 from a supplier catalogue (PVS).

PUMPS

The pumps were sized based on the flowrates and using supplier catalogues. The ANTICO NRJP Series ISO Standard Pump Catalogue was used to select the centrifugal pumps (Anticorrosive Equipment Pvt Ltd) and Pioneer Pump Product Catalogue was used to select the positive displacement pumps (Pioneer Pump).

OTHER PROCESS UNITS

The anaerobic digester (R-101) was sized based on the volume required and a height to diameter ratio of 1:2 found in literature (source?).

The air compressor (C-101) was sized based on the volumetric flowrate of air required using a company catalogue. The type chosen was 100 HP Rotary Screw Air Compressor (Compressor World, n.d.).

The biogas flare (V-101) was sized based on the biogas volumetric flowrate using a company catalogue. The type selected was a NOXmatic 100 (Finn Biogas).

The calcium hydroxide storage hopper (V-201) and polymer storage hopper (V-202) were sized based on the respective powder volume to be stored as shown in literature (Sinnot, 2005).

APPENDIX E – UPDATED PROCESS DESCRIPTION

Referring to PFD DWG-001: Wastewater feed from the plant sump is available at an average temperature of 17.5 °C and atmospheric pressure. The wastewater feed stream (Stream 101) enters the process at a mass flowrate of 1 452 t/day into the AD Buffer Tank (TK-101). In the event of a power failure, pump failure or a break in the pipeline the wastewater can be diverted to the calamity tank (TK-102) temporarily, as Stream 140. Once the condition has stabilised, the wastewater stream (Stream 141) exiting TK-102 can be pumped via the calamity tank discharge pump (P-103A/B) to TK-101.

Dosing is performed in TK-101 to ensure optimal feed conditions. TK-101 is dosed with 11.2 kg/h of ferric chloride (Stream 216, PFD DWG-003) to control the hydrogen sulphide formation in the Anaerobic Digester (AD). The centrate (Stream 124, PFD DWG-002) from the centrifuge (S-104, PFD DWG-002) is recycled back to TK-101 as the stream does not meet the required effluent specifications and therefore cannot be discharged directly.

From TK-101 the wastewater stream is pumped via P-102A/B to the Wastewater Feed Preheater (E-101). The wastewater stream (Stream 103) enters E-101 at 17.5 °C and is preheated to 23.2 °C by Stream 113 (PFD DWG-002). The preheated wastewater stream (Stream 104) enters the AD Feed Heater (E-102). Steam at 147 °C (Stream 139) originating from the Boiler (E-103) is used to heat Stream 104 further. This heated stream exits E-102 as Stream 105 at a temperature set by the temperature controller TRC-102 (from P&ID DWG-002). As a result, Stream 139 is subsequently condensed and cooled to 140 °C and exits E-102 as Stream 135, recycle process water.

Ferric chloride consumes alkalinity and therefore 2.05 t/h of calcium hydroxide solid in a slurry stream (Stream 205) is dosed in R-101 to ensure sufficient alkalinity and to increase the pH from 6.0 to 7.0. This ensures optimal conditions for the micro-organisms. Additionally, the recycle sludge stream (Stream 120) from the clarifier (S-102, PFD DWG-002) underflow enters R-101. In R-101 the micro-organisms break down the biodegradable material, producing biogas consisting of 65 vol.% methane and 35 vol.% carbon dioxide. A portion of the produced biogas is entrained in the liquid whilst the remainder collects in the AD headspace. The biogas collected in the headspace is removed as Stream 127, regulating the pressure of R-101. The reactor effluent, Stream 107 leaves R-101 at 35 °C as an overflow stream. Stream 107 flows into the Degassing Tank (S-101). All entrained gas leaves S-101 as Stream 128 and is combined with Stream 127 to form Stream 129. Subsequently, the reactor effluent is free from entrained biogas and exits S-101 as Stream 108 at a temperature of 35 °C.

Stream 129, the combined biogas stream is sent to the boiler (E-103). In the event that a portion of the biogas needs to be flared, Stream 129 will split so that Stream 130 is directed to the flare (V-101) while Stream 132 to E-103. The biogas will be combusted in the flare and the resulting flue gas will exit V-101 as Stream 131.

The recycled process water returning from E-102 (Stream 135) is supplemented with fresh process water (Stream 134) when required. The resultant stream (Stream 136) is sent to the boiler feed water buffer tank (TK- 104). The boiler feed water from TK-104 (Stream 137) is pumped via the boiler feed water pump (P-109 A/B) to the boiler (E-103). In the boiler the biogas (Stream 132) is combusted to vaporize and heat the water (Stream 137) to 147 °C. Air is required in E-103 for the combustion of the biogas. Air enters the compressor (C-101) as Stream 138, where it is compressed to a pressure of 1.8 bar (g) before being sent to the boiler (E-103). The steam exits the boiler at 147 °C as Stream 139 and the flue gas exits E-103 at a temperature and pressure of 205 °C and 1.8 bar (g), respectively, in Stream 133.

As previously mentioned, Stream 113 at 30.0 °C is used to preheat the wastewater feed stream (entering the plant at 17.5 °C) via the wastewater feed preheater (E-101). The cooled stream exiting E-101 (Stream 114) is at 24.0 °C when entering the treated effluent buffer tank (TK-103). A portion of the treated effluent is used as dosing water to make up the required dosing solutions. This is pumped from TK-103 via P-111A/B as Stream 117 to the dosing water make-up tank (TK-201).

The remaining treated effluent leaving TK- 103 (Stream 115) is transported via the treated effluent discharge pump (P-110A/B) and exits with a mass flowrate of 1 446 t/day and a discharge pressure of 0.8 bar (g). The final treated effluent water (Stream 110) has TCOD and TSS concentrations of 667 mg/L and 133 mg/L respectively. These concentrations are below the allowable discharge limits of 1 000 mg/L TCOD and 200 mg/L TSS.

Referring to PFD DWG-002: The clarifier feed stream, Stream 108 (from PFD DWG-001), is to be dosed with coagulant ferric chloride (Stream 218, PFD DWG-003) at a flowrate of 2.0 kg/h. The coagulant is dosed in the pipeline prior to entering the clarifier (S-102) because it requires rapid mixing which is achieved by the turbulent flow. Once Stream 108 has been dosed with the coagulant it enters the clarifier. The polymer flocculant solution (Stream 211, PFD DWG-003) is added to the feed weir of S-102 at a flowrate of 65.4 kg/h. The thickened sludge leaves from the bottom of S-102 as Stream 118. Assuming negligible heat losses due to the short detention time, both the underflow (Stream 118) and overflow stream (Stream 109) leave the clarifier at a temperature of 34.5 °C.

Stream 109 leaves the clarifier as an overflow stream and enters the drum filter (S-103). The drum filter is the final treatment stage before discharge where TSS is further reduced. A portion of the treated drum filter effluent, Stream 110, is split and used as backwash (Stream 111) for S-103, removing the solids collected on the drum filter cloth. The remaining drum filter effluent is pumped via the treated effluent pumps P-104A/B to the Wastewater Feed Preheater (E-101). The solids removed from the drum filter cloth exit S-103 with the backwash water as Stream 112. This stream (Stream 112) is sent to the centrifuge (S-104) for sludge dewatering.

Stream 119, a split of Stream 118, is sent back to the AD (R-101) via the sludge recycle pump (P-105A/B) as the recycle sludge stream. A portion of Stream 118 is periodically not recycled (Stream 120) and pumped via the centrifuge feed pump (P-106A/B) to the centrifuge (S-104) for dewatering.

The centrifuge (S-104) is used for dewatering aided by a polymer flocculant solution (Stream 213, PFD DWG-003) dosed at a flowrate of 388.4 kg/h when in operation. The wastewater liquid is separated from the solids so that Stream 125 (dewatered sludge) exiting the centrifuge has a high solids concentration. Stream 125 is transported via the dewatered sludge pump (P-108A/B) to the dewatered sludge skip (TK-105) for storage. Stream 126 leaves the skip with a mass flowrate of 5.8 t/day when in operation. Stream 123, the centrate exiting the S-104, is recycled via P-107A/B when in operation to the AD buffer tank (TK-101) as previously mentioned.

Referring to PFD DWG-003: The treated effluent stream (Stream 117, PFD DWG-001) is sent to the dosing water make-up tank (TK-201). This treated effluent water will be used to prepare the calcium hydroxide and polymer dosing solutions. The ferric chloride is readily available in a diluted solution.

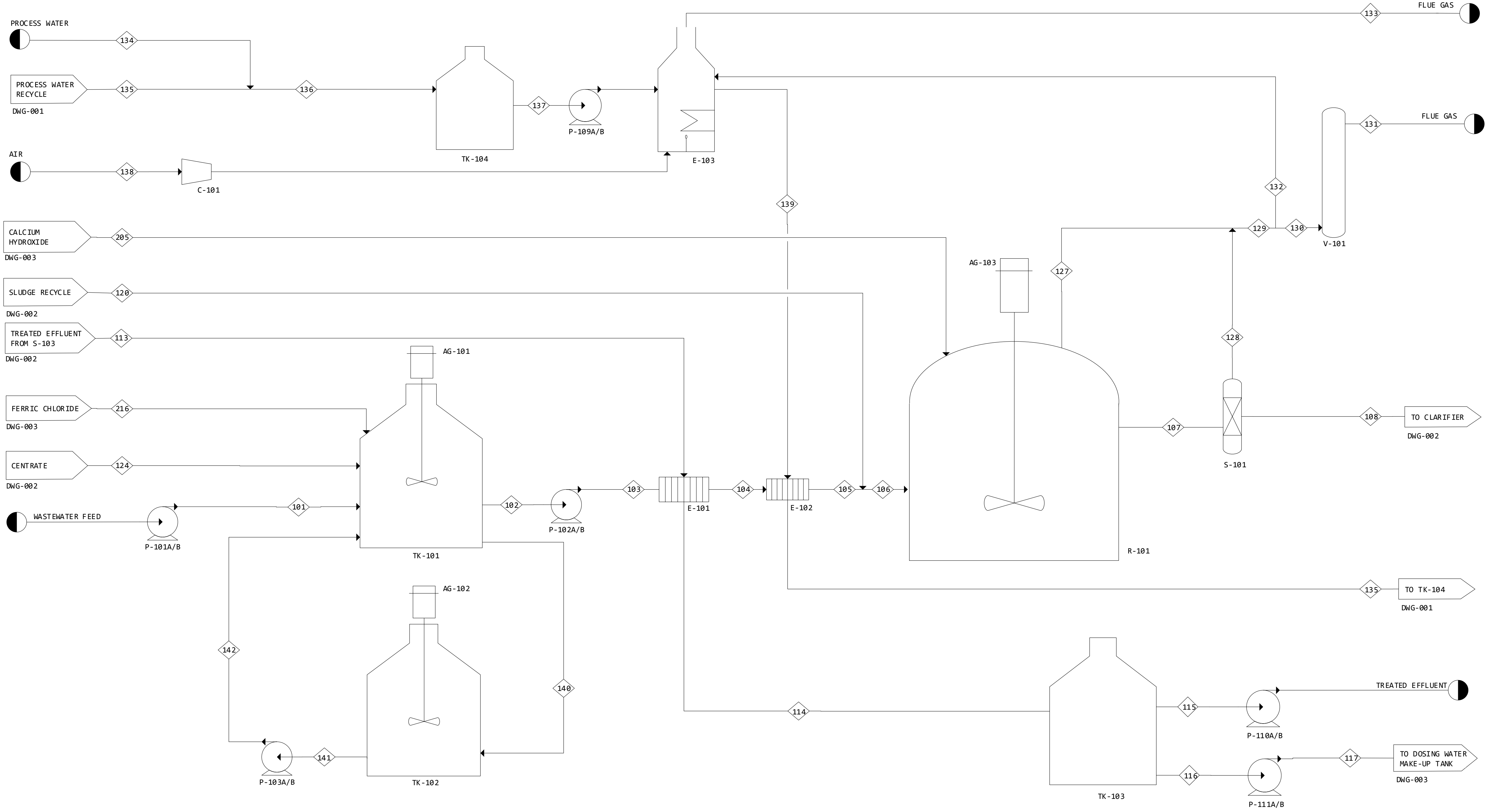
The calcium hydroxide is transported from the storage hopper (V-201) via the screw conveyor (SC-201) as Stream 203. Treated effluent dosing water (Stream 202) is pumped to the calcium hydroxide mixing tank (TK-202) via the dosing water pump P-201A/B. The calcium hydroxide slurry is transported to R-101 (PFD DWG-001) via the calcium hydroxide dosing pump (P-202A/B).

The polymer flocculant is stored in the polymer storage hopper (V-202). It is transported from V-202 via the screw conveyor (SC-202) as Stream 208 to the polymer mixing tank (TK-203). Treated effluent dosing water (Stream 207) enters TK-203 to prepare the polymer solution. The prepared polymer solution is pumped from TK-203 to the clarifier (S-102, PFD DWG-002) via P-204A/B and to the centrifuge (S-104, PFD DWG-002) via P-205A/B.

Ferric chloride is stored in the ferric chloride buffer tank (TK-204). From TK-204 the ferric chloride leaving as Stream 214 is split and a portion of the stream is sent for dosing to the AD buffer tank (TK- 101, PFD DWG-001) via P-206A/B as Stream 216. The remaining portion is transported to the clarifier feed stream (Stream 108, PFD DWG-002) via P-207A/B as Stream 218.

APPENDIX F – PROCESS FLOW DIAGRAMS

P-101A/B	TK-101	AG-101	TK-102	AG-102	P-102A/B	P-103A/B	E-101	E-102	R-101	AG-103	S-101	V-101	TK-103	P-110A/B	P-111A/B	C-101	TK-104	P-109A/B	E-103
SUMP PUMP	AD BUFFER TANK	AD BUFFER TANK MIXER	CALAMITY TANK	TK-102 AGITATOR	AD FEED PUMP	CALAMITY TANK DISCHARGE PUMP	WASTEWATER FEED PREHEATER	AD FEED HEATER	ANAEROBIC DIGESTER (AD)	AD MIXER	DEGASSING TANK	BIOGAS FLARE	TREATED EFFLUENT BUFFER TANK	TREATED EFFLUENT DISHCARGE PUMP	TREATED EFFLUENT PUMP TO DOSING	AIR COMPRESSOR	BOIELR FEED WATER BUFFER TANK	BOILER FEED WATER PUMP	BOILER



Stellenbosch University
Department of Process Engineering

Design 488 (2019)

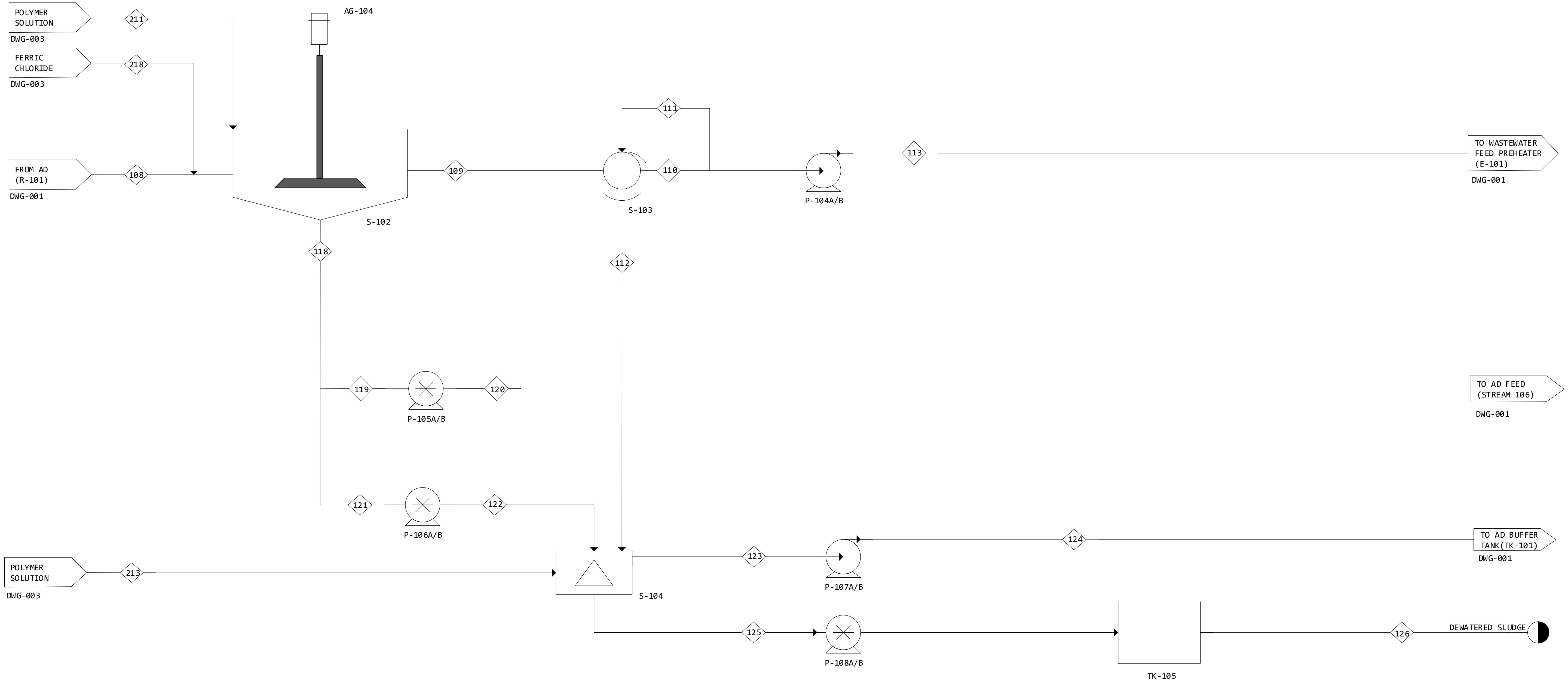
Wastewater treatment plant utilizing anaerobic digestion.

Group Number: G-11

Date: 2019-10-11

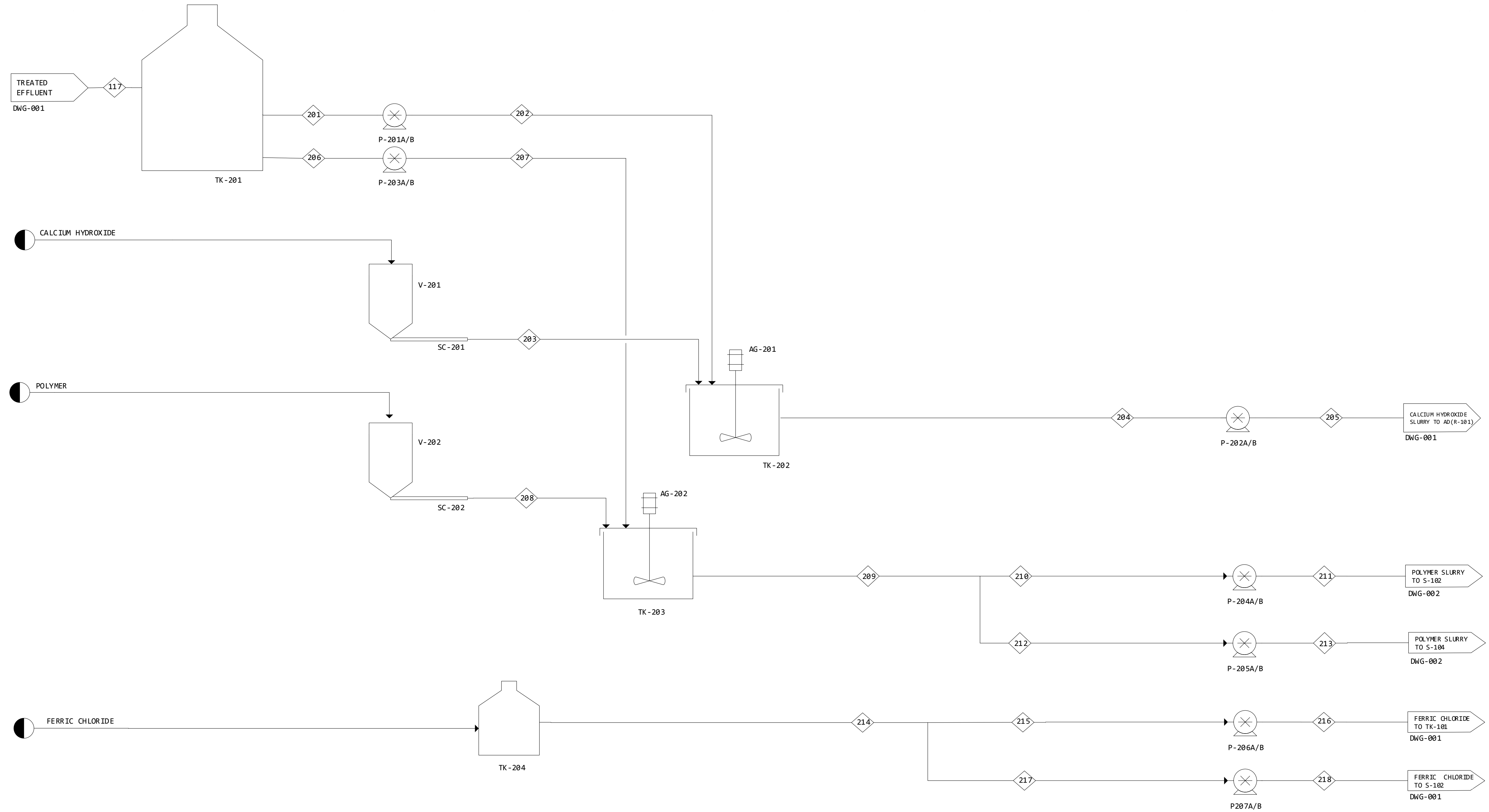
SECTION	DRAWING TYPE	DWG NO	REV
4	PFD	DWG-001	3
SCALE 1:1		SHEET 1 OF 3	

S-102	AG-104	P-104A/B	P-105A/B	P-106A/B	S-104	P-107A/B	P-108A/B	TK-105	S-103
CLARIFIER	CLARIFIER SLUDGE RAKE	TREATED EFFLUENT PUMP TO E-101	SLUDGE RECYCLE PUMP	CENTRIFUGE FEED PUMP	CENTRIFUGE	CENTRATE PUMP TO TK-101	DEWATERED SLUDGE PUMP	DEWATERED SLUDGE SKIP	DRUM FILTER



Stellenbosch University Department of Process Engineering	**Design 488 (2019)**			
	Wastewater treatment plant utilizing anaerobic digestion.			
Group Number: G-11	SECTION 4	DRAWING TYPE PFD	DWG NO DWG-002	REV 3
Date: 2019-10-11	SCALE	1:1	SHEET	2 OF 3

TK-201	P-201A/B	P-203A/B	V-201	SC-201	TK-202	AG-201	P-202A/B	V-202	SC-202	TK-203	AG-202	P-204A/B	P-205A/B	TK-204	P-206A/B	P-207A/B
DOSING WATER MAKE-UP TANK	DOSING WATER PUMP TO TK-202	DOSING WATER PUMP TO TK-203	CALCIUM HYDROXIDE STORAGE HOPPER	V-201 SCREW CONVEYOR	CALCIUM HYDROXIDE MIXING TANK	TK-202 AGITATOR	CALCIUM HYDROXIDE DOSING PUMP	POLYMER STORAGE HOPPER	V-202 SCREW CONVEYOR	POLYMER MIXING TANK	TK-203 AGITATOR	CLARIFIER POLYMER DOSING PUMP TO S-102	POLYMER DOSING PUMP TO S-104	FERRICCHLORIDE BUFFER TANK	FERRIC CHLORIDE DOSING PUMP TO TK-101	FERRIC CHLORIDE DOSING PUMP TO S-102



Stellenbosch University Department of Process Engineering	Design 488 (2019)			
	Wastewater treatment plant utilizing anaerobic digestion.			
Group Number: G-11	SECTION 4	DRAWING TYPE PFD	DWG NO DWG-003	REV 3
Date: 2019-10-11	SCALE	1:1	SHEET	3 OF 3