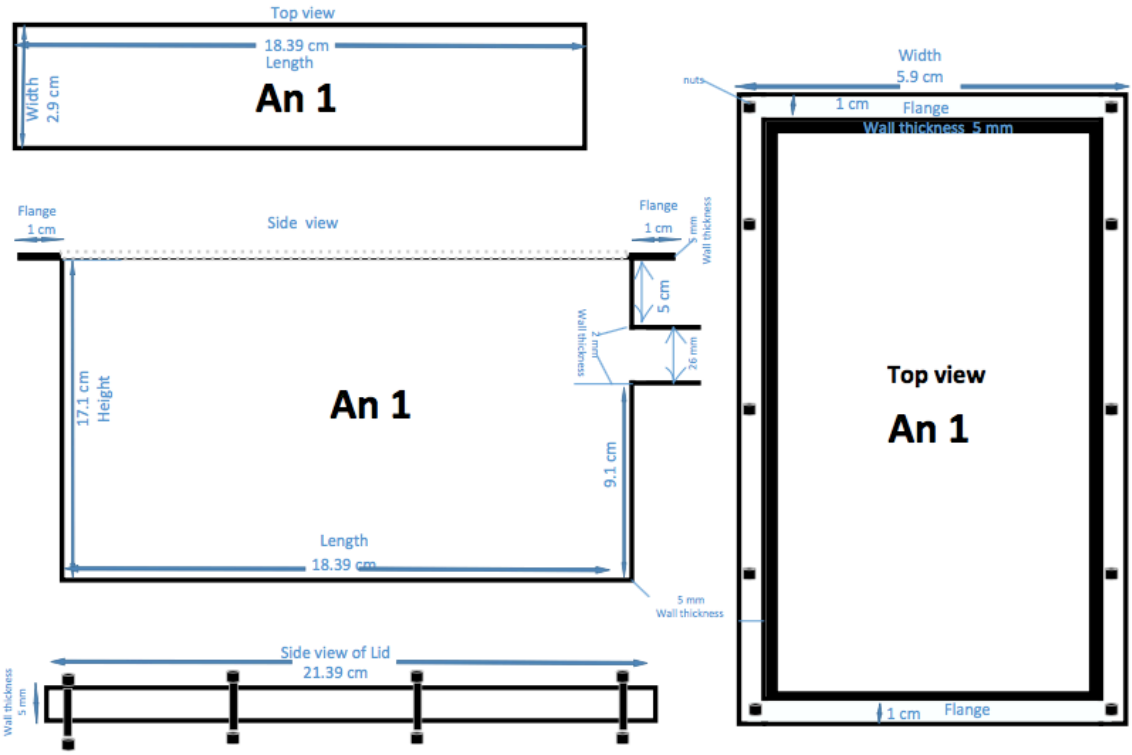
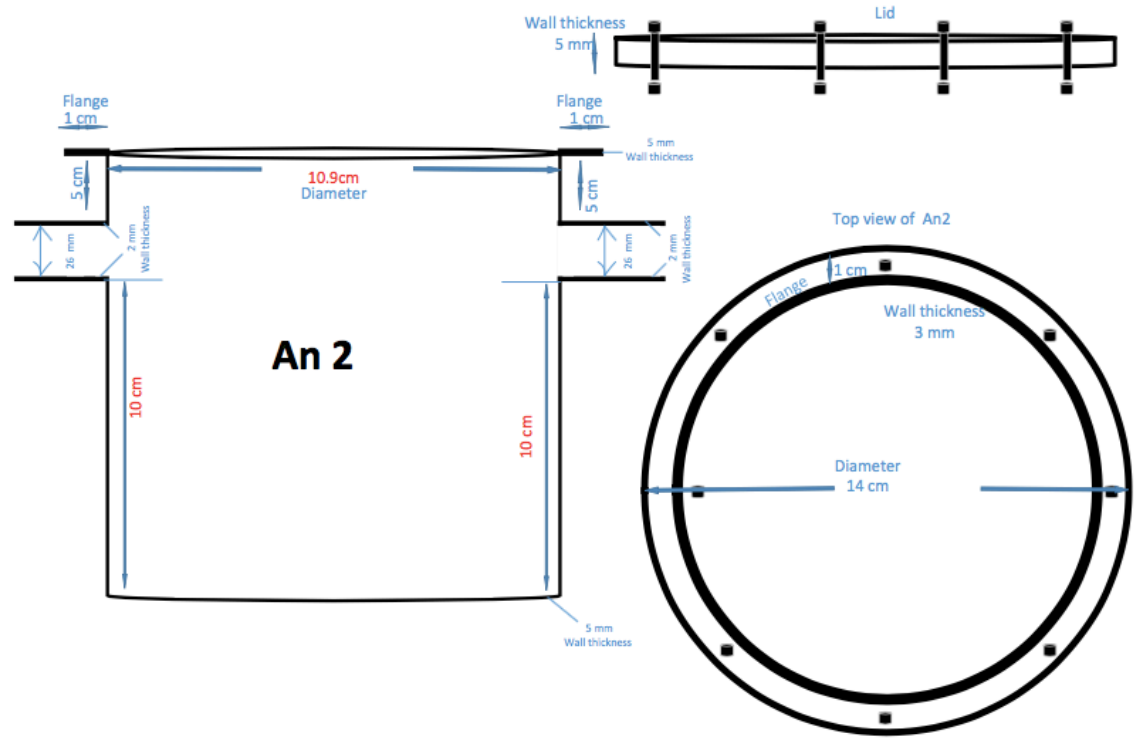
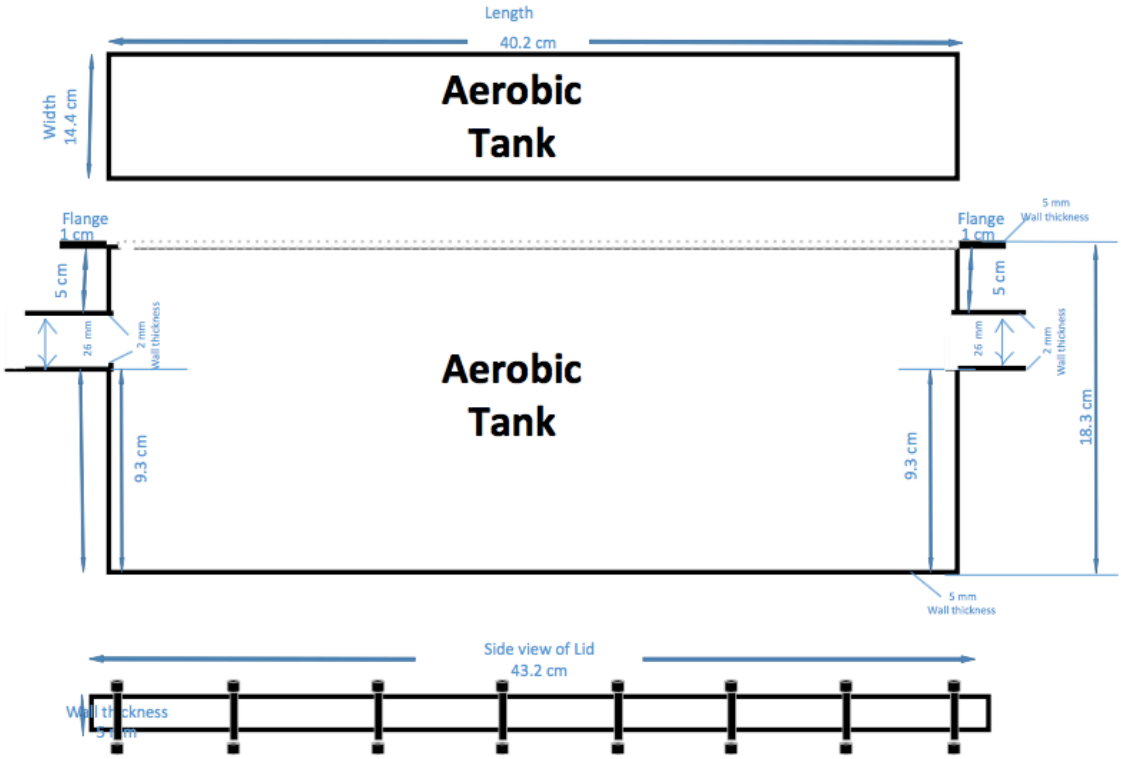
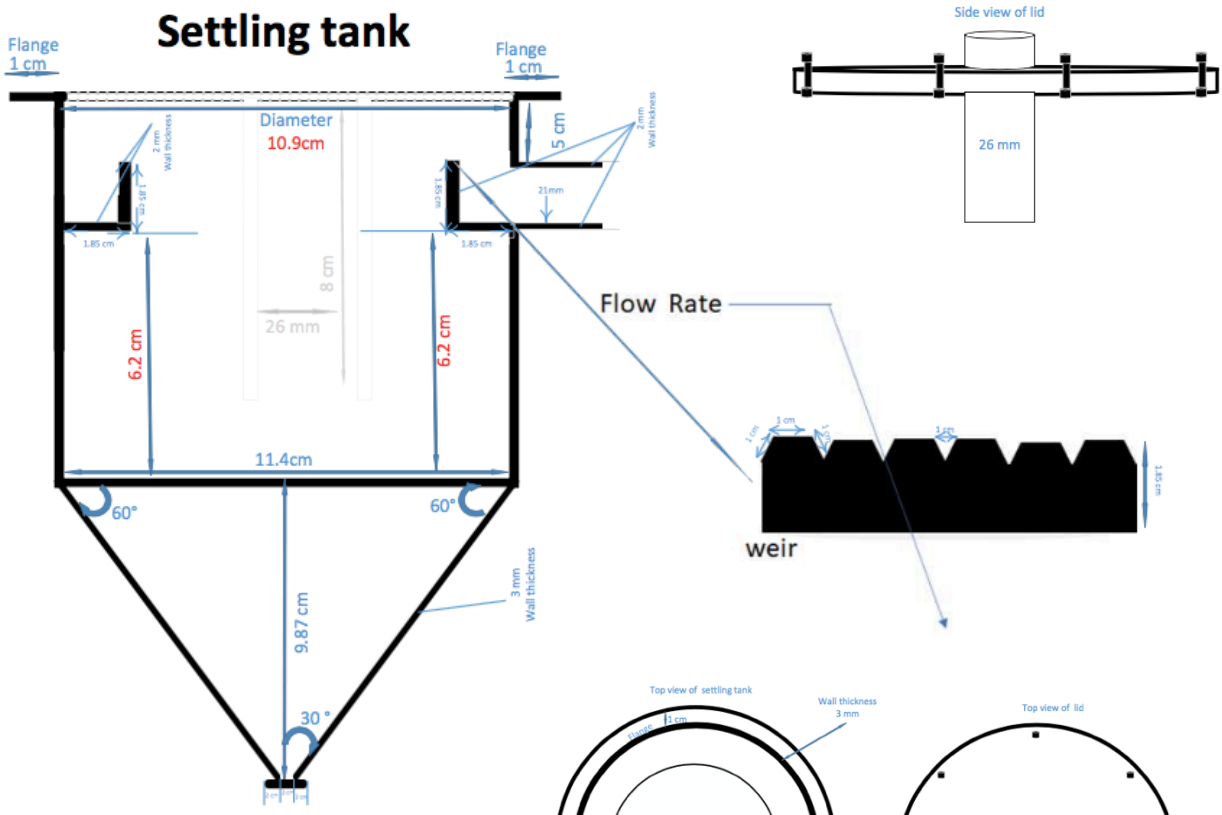
# Appendix

## Table of content


Top view
18.39 cm
Length
Width
2.9 cm
An 1
Side view
Flange
1 cm
Flange
1 cm
5 mm
Wall thickness
5 cm
2 mm
Wall thickness
26 mm
17.1 cm
Height
An 1
9.1 cm
Length
18.39 cm
5 mm
Wall thickness
Side view of Lid
21.39 cm
Wall thickness
5 mm
Width
5.9 cm
nuts
1 cm
Flange
Wall thickness 5 mm
Top view
An 1
1 cm
Flange


Wall thickness
5 mm
Lid
Flange
1 cm
Flange
1 cm
5 mm
Wall thickness
5 cm
10.9cm
Diameter
5 cm
26 mm
2 mm
Wall thickness
26 mm
2 mm
Wall thickness
An 2
10 cm
10 cm
5 mm
Wall thickness
Top view of An2
Flange
1 cm
Wall thickness
3 mm
Diameter
14 cm


Length
40.2 cm
Width
14.4 cm
Aerobic
Tank
Flange
1 cm
5 cm
26 mm
2 mm
Wall thickness
9.3 cm
Aerobic
Tank
Flange
1 cm
5 mm
Wall thickness
5 cm
26 mm
2 mm
Wall thickness
9.3 cm
18.3 cm
5 mm
Wall thickness
Side view of Lid
43.2 cm
Wall thickness
5 mm


Settling tank
Flange
1 cm
Flange
1 cm
Diameter
10.9cm
5 cm
2 mm
Wall thickness
1.85 cm
21mm
8 cm
26 mm
6.2 cm
6.2 cm
11.4cm
60°
60°
9.87 cm
30 °
3 mm
Wall thickness
Side view of lid
26 mm
Flow Rate
weir
Top view of settling tank
Wall thickness
3 mm
1.85 cm
Weir
Diameter
14 cm
Top view of lid
26 mm
Diameter
14 cm

# Datasheet

## Stock No. 102-6127

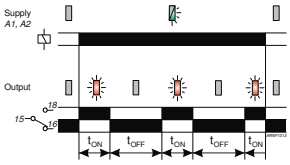
### Asymmetrical Recycling, Multi-voltage Timer

ENGLISH

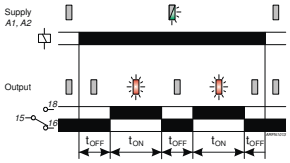
- ***NEW*** **17.5mm DIN rail housing**
- **Switch Initiated Delay Off (Delay On Release) re-triggerable timing function**
- **7 Selectable time ranges (0.1 seconds – 100 hours)**
- **Fine adjustment of selected time range**
- **Multi-voltage input (12 – 230V AC/DC)**
- **External trigger input can be from Voltage Free Contact or Solid State**
- **Timer will still function with load connected to trigger (B1) input**
- **1 x SPDT relay output 8A**
- **Green LED indication for supply / timing status**
- **Red LED indication for relay status**
- **Conforms to IEC 61812**

## FUNCTION DIAGRAMS

Asymmetrical Recycling On / Off **(AN)**




Asymmetrical Recycling Off / On **(AF)**
(terminals A1 and B1 linked)




## INSTALLATION AND SETTING

Installation work must be carried out by qualified personnel.

- BEFORE INSTALLATION, ISOLATE THE SUPPLY.
- Connect the unit as required.
- If Asymmetrical Recycling "Off / On" is required, placed a link between terminals A1 and B1.

*Setting the unit.*

- Set the "$t_{OFF}$" ❹ and "$t_{ON}$" ❺ "Range" selectors to the required position (depending on whether seconds, minutes or hours are required).
- Set the "Set %" adjustment for the "$t_{OFF}$" ❸ and "$t_{ON}$" ❻ as required. The "Set %" is a % of the selected range, so 60% of the 1 – 10 hour range will give 6 hours.

*Applying power.*

- Apply power and the green LED ❶ will start flashing to indicate timing is in progress.
- The red relay LED ❷ will illuminate to indicate the relay is the energised state when the "$t_{ON}$" delay is running.
- When the "$t_{OFF}$" delay is running and relay is de-energised, the red LED will remain extinguished.

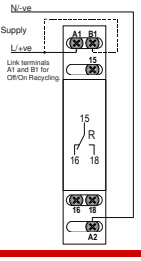
*Note:*

[1] *In accordance with IEC 61812, the green LED is permitted to extinguish during a voltage dip or momentary interruption of the power supply providing the state of the output relay does not change. The dip / interruption duration and levels are defined in the product standard.*

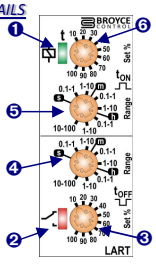
## TECHNICAL SPECIFICATION

| | | | | |
|---|---|---|---|---|
| Supply voltage U **(A1, A2)**: | 12 – 230V AC/DC | | | |
| Frequency range: | 48 - 63Hz (AC supplies) | | | |
| Supply variation: | +/ - 15% | | | |
| Overvoltage category: | III (IEC 60664) | | | |
| Rated impulse withstand voltage: | 4kV (1.2/50µS) IEC 60664 | | | |
| Power consumption (max.): | 12V | 24V | 110V | 230V |
| AC: | 0.3VA | 0.4VA | 1.3VA | 3.4VA |
| DC: | 0.26W | 0.24W | 0.47W | 0.95W |
| Timing functions (2): | | | | |
| | Asymmetrical Recycling "On / Off" (AN) | | | |
| | Asymmetrical Recycling "Off / On" (AF) *(A1 > B1 linked)* | | | |
| Timing ranges (7): | Seconds: | Minutes: | Hours: | |
| (applies to "$t_{ON}$" and "$t_{OFF}$") | 0.1 – 1 | 0.1 – 1 | 0.1 – 1 | |
| | 1 – 10 | 1 – 10 | 1 – 10 | |
| | | | 10 - 100 | |
| Reset time: | 100mS | | | |
| Accuracy: | ± 1% of maximum full scale | | | |
| Adjustment accuracy: | < 5% of maximum full scale | | | |
| Repeat accuracy: | ± 0.5% at constant conditions (IEC 61812) | | | |
| Drift with temperature: | ± 0.05% / °C | | | |
| Drift with voltage: | ± 0.2% / V | | | |
| Power on indication / Timing[1]: | Green LED | | | |
| Relay status | Red LED | | | |
| Ambient temp: | -20 to +60°C | | | |
| Relative humidity: | +95% | | | |
| Output **(15, 16, 18)**: | SPDT relay | | | |
| Output rating: | AC1 | | 250V 8A (2000VA) | |
| | AC15 | | 250V 5A (no), 3A (nc) | |
| | DC1 | | 25V 8A (200W) | |
| Electrical life: | ≥ 150,000 ops at rated load | | | |
| Dielectric voltage: | 2kV AC (rms) IEC 60947-1 | | | |
| Rated impulse withstand voltage: | 4kV (1.2/50µS) IEC 60664 | | | |
| Housing: | Orange flame retardant UL94 V0 | | | |
| Weight: | ≈ 60g | | | |
| Mounting option: | On to 35mm symmetric DIN rail to BS EN 60715 or direct surface mounting via 2 x M3.5 or 4BA screws using the black clips provided on the rear of the unit. | | | |
| Terminal conductor size | ≤ 2 x 2.5mm² solid or stranded | | | |
| Approvals: | Conforms to IEC 61812. | | | |
| | c UL us LISTED IND. CONT. EQ. E111187 | | | |
| | CE and RoHS Compliant. | | | |
| | EMC: Immunity: EN 61000-6-2 (EN 61000-4-3 10V/m 80MHz - 2.7GHz) | | | |
| | Emissions: EN 61000-6-4 | | | |

## CONNECTION DIAGRAM

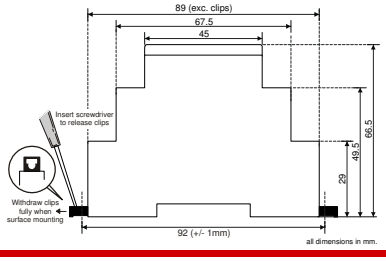



## SETTING DETAILS




1. Power supply status / Timing (Green) LED
2. Relay output status (Red) LED
3. "$t_{OFF}$" delay "Set %" adjustment
4. "$t_{OFF}$" delay "Range" selector
5. "$t_{ON}$" delay "Set %" adjustment
6. "$t_{ON}$" delay "Range" selector

## DIMENSIONS



# PART LIST

RS Components | Electronic and Electrical Components (rs-online.com)

Asymmetrical Recycling Time Relay
RS Stock No.102-6127

https://docs.rs-online.com/6d54/0900766b81717add.pdf

Panel Mount Peristaltic Dc Pump 60 rpm
RS Stock No.705-6665

https://docs.rs-online.com/9510/0900766b80e09dd0.pdf

Bi Directional Speed Regulator
RS Stock No.752-2009

https://docs.rs-online.com/e5d6/A700000007082393.pdf

Din Rail Power Supply, 120W, 12V Output
RS Stock No.136-8317
https://no.rs-online.com/web/p/din-rail-power-supplies/1368317?sra=pstk

VERDERFLEX®
OEM

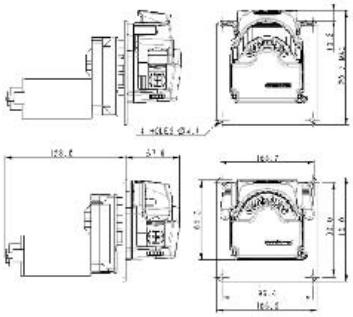
## EASY TUBE LOADING PUMP

MODEL: AU EZ d.c. PUMP
FIXED/VARIABLE SPEED

Easy tube loading peristaltic pump with 3-roller rotor as standard, stainless steel mounting plate and 12 vdc gear motor. Integral pump head drive shaft with ball dual ball race bearings.
Three available drive options combined with five tube sizes giving wide range of flow rates. Connection to a speed control circuit will give variable flow capability.

The quick and simple tube change only takes seconds.

For stackable options see **MODEL AU ES.**



| | | |
|---|---|---|
| Pump head | : | Polyamide, Acetal and Stainless Steel. |
| Gear motor | : | Permanent magnet |
| Power supply | : | 12 vdc 17W |
| Tube materials | : | Verderprene & Silicone |
| Weight | : | 1.3Kg |

| Easy tube loading pump d.c. | | | | | |
|---|---|---|---|---|---|
| Nominal flow rate ml/min | | | | | |
| Tube | 0.8mm | 1.6mm | 3.2mm | 4.8mm | 6.3mm |
| 60 rpm | 4.6 | 16 | 64 | 140 | 225 |
| 100 rpm | 7.7 | 28 | 108 | 235 | 375 |
| 150 rpm | 12 | 42 | 162 | 352.5 | 562.5 |

**Verder Ltd**
Unit 7 Carnival Park, Carnival Close, Basildon, SS14 3WN
Tel: +44 (0) 1268 662 450, Fax: +44 (0) 1268 662 459
Email: Basildon@verderflex.com

VERDER

www.verderflex.com

# Calculating WAS volume based on preferred sludge age

$$SRT = \frac{V * X}{Q_w * X_r + Q_i * X_i}$$

V: volume of reactor

X: TS in aeration tank

$Q_w$ = Waste sludge flow rate from return line

$X_r$: TS of sludge in return line

$Q_i$: EF rate from secondary clarifier

$X_i$: TS in EF (preferable = 0)

Want to find $Q_w$:

$$Q_w = \frac{V * X}{SRT * X_r}$$

Assumed values:

V = 0,95 + 0,95 + 5,5 = 7,4 L

X ≈ 2 000 mg/L

Xr ≈ 10 000 mg/L

SRT ≈ 3,3 days

Calculated $Q_w$:

$$Q_w = \frac{7{,}4\ L * 2\ 000 \frac{mg}{L}}{10\ 000 \frac{mg}{L} * 3{,}3\ d} = 446\ ml/d$$

# The volume of sludge if WAS is taken out every third hour:

Every third hour = 8 intervals per day.

$$V_{interval} = \frac{446\ ml/d}{8\ intervals/d} = 56\ ml/interval$$

# HRT Pilot

The HRT for the reactor is found by using the following formula:

$$HRT = \frac{V}{Q}\ [min]$$

HRT = hydraulic retention time
V = volume of reactor
Q = Flow

## Anaerobic HRT

$V_{An2} = V_{An3} = 0.9$ L
$Q = Q_{inf} = 34$ L/d

$$HRT_{An2} = HRT_{An3} = \frac{0.9\ L}{34\ L/d} = 0.63\ h \approx 38\ min$$

$$HRT_{Anaerobic} = 38\ \text{min} * 2 = 1h\ 16\ min$$

## Aerobic HRT

$V_{Ae} = 5.5$ L
$Q = Q_{inf} = 34$L/d

$$HRT_{Ae} = \frac{5.5\ L}{34\ L/d} = 3.38\ h \approx 3\ h\ 52\ min$$

## Fermentation HRT

$V_{An1} = 0{,}5$ L
$Q = Q_{RAS} = 6$ ml/min

$$HRT_{An1} = \frac{0{,}5L}{0{,}006\ L/min} = 83\ \text{min} = 1h\ 23\ min$$

# Raw Influent Wastewater Characteristics

07.03.2022

| Parameter | | Unit |
|---|---|---|
| **PO4-P** | 3.92 | mg P/L |
| **Tot P** | 4.65 | mg P/L |
| **NO2-N** | 0.075 | mg N/L |
| **NO3-N** | 0.075 | mg N/L |
| **NH4-N** | 13.5 | mg N/L |
| **sCOD** | 106 | mg/L |
| **totCOD** | 214 | mg/L |
| **Conductivity** | 0.442 | μS/L |
| **pH** | 7.47 | |
| **DO** | 8.5 | mg/L |
| **TS** | 450 | mg/L |
| **TSS** | 116 | mg/L |
| **VS** | 159 | mg/L |
| **VSS** | 81 | mg/L |

# Dilution of raw influent wastewater

08.03.2022

Diluted in accordance with the sCOD concentration.

$$c_1 * V_1 = c_2 * V_2$$

The influent container
$V_1$ = 1000 L

Average sCOD concentration at IVAR:
$c_1$ = 80 mg/L

sCOD concentration in the raw ww at the lab:
$c_2$ = 106 mg/L

Find the amount of raw wastewater for the container:

$$V_{2,ww} = \frac{80\frac{mg}{L} * 1000\ L}{106\frac{mg}{L}} = 754.7\ L$$

The amount of tap water:

$$V_{tap} = 1000\ L - 754.7\ L = 245.3\ L$$

The wastewater at IVAR have infiltration of seawater, and to archive a similar conductivity 60 L of seawater is added to the container. This is equal to 6% of the total volume. The new volume of wastewater is:

$$V_{ww} = 754.7\ L - (754{,}7\ L * 0.06)\ \approx 710\ L$$

The tap water volume with 6% seawater:

$$V_{tap} = 245.7\ L - (245{,}7\ L * 0.06) \approx 230\ L$$

# Sludge from IVAR Characteristics

10.03.2022

| Parameter | | Unit |
|---|---|---|
| **$PO_4$-P** | 3.77 | mg P/L |
| **tot P** | 20.1 | mg P/L |
| **$NO_2$-N** | 0 | mg N/L |
| **$NO_3$-N** | 0.145 | mg N/L |
| **$NH_4$-N** | 22.8 | mg N/L |
| **tot N** | 188 | mg N/L |
| **sCOD** | 34.2 | mg/L |
| **totCOD** | 1314 | mg/L |
| **Conductivity** | 1393 | µS/cm |
| **pH** | 7.66 | |
| **DO** | 7.05 | mg/L |
| **Temp.** | 15 | °C |

## Solids

| | TS [mg/L] | TSS [mg/L] | VS [mg/L] | VSS [mg/L] |
|---|---|---|---|---|
| **Settled** | 8584 | | 6264 | |
| **Mixed** | 3600 | 2608 | 2172 | 2016 |

# Calculation of amount of TS needed in each reactor at inoculation

08.03.22

The wanted TS for each reactor:

An1 = 10 000 mg TS/L

An2 = 2 000 mg TS/L

An3 = 2 000 mg TS/L

Aerobic = 2 000 mg TS/L

Settler = 10 000 mg TS/L

The volume of each reactor:

An1 = 0.5 L

An2 = An3 = 0.95 L

Aerobic = 5.5 L

Settler = 0.4 L

The amount of TS needed for each reactor:

$$An1 = 10\,000\,mg\frac{TS}{L} * 0.5\,L = 5\,000\,mg\,TS$$

$$An2 = An3 = 2\,000\frac{mg\,TS}{L} * 0.95\,L = 1\,900\,mg\,TS$$

$$Aerobic = 2\,000\frac{mgTS}{L} * 5.5\,L = \ 11\,000\,mg\,TS$$

$$Settler = 10\,000\frac{mg\,TS}{L} * 0.4\,L = 4\,000\,mg\,TS$$

The amount of TS needed:

$$(5\,000 + 2 * 1900 + 11\,000 + 4\,000)mg\,TS = 23\,800\,mg\,TS$$

# Acetate for batch experiment

05.05.2022

136,08 g/mol $CH_3COONa * 3H_2O$

59 g/mol $CH_3COO$

1 g acetate = 1.08 g COD

Want a concentration equal to 100 mg COD/L in batch:

100 mg COD = 0.1 g COD

$$\frac{0.1\ g\ COD}{1.08 \frac{g\ COD}{g\ CH_3COO}} = 0.092\ g\ CH_3COO$$

1 g CH3COO -> 0,61 g $CH_3COONa * 3H_2O$

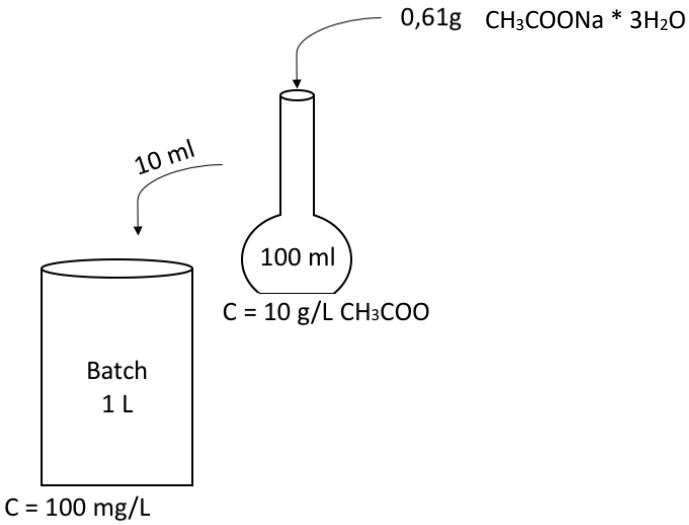
Add 0,61 g $CH_3COONa * 3H_2O$ to a 100 ml volumetric flask to get a 10g/L concentration.

Volume from volumetric flask that needs to be added to the batch:

$$V_1 * c_1 = V_2 * c_2$$

V1 = 1 L = 1 000 ml
C1 = 100 mg/L
C2 = 10 000 mg/L

$$V_2 = \frac{1000\ ml * 100\ mg/L}{10\ 000\ mg/L} = 10\ ml$$



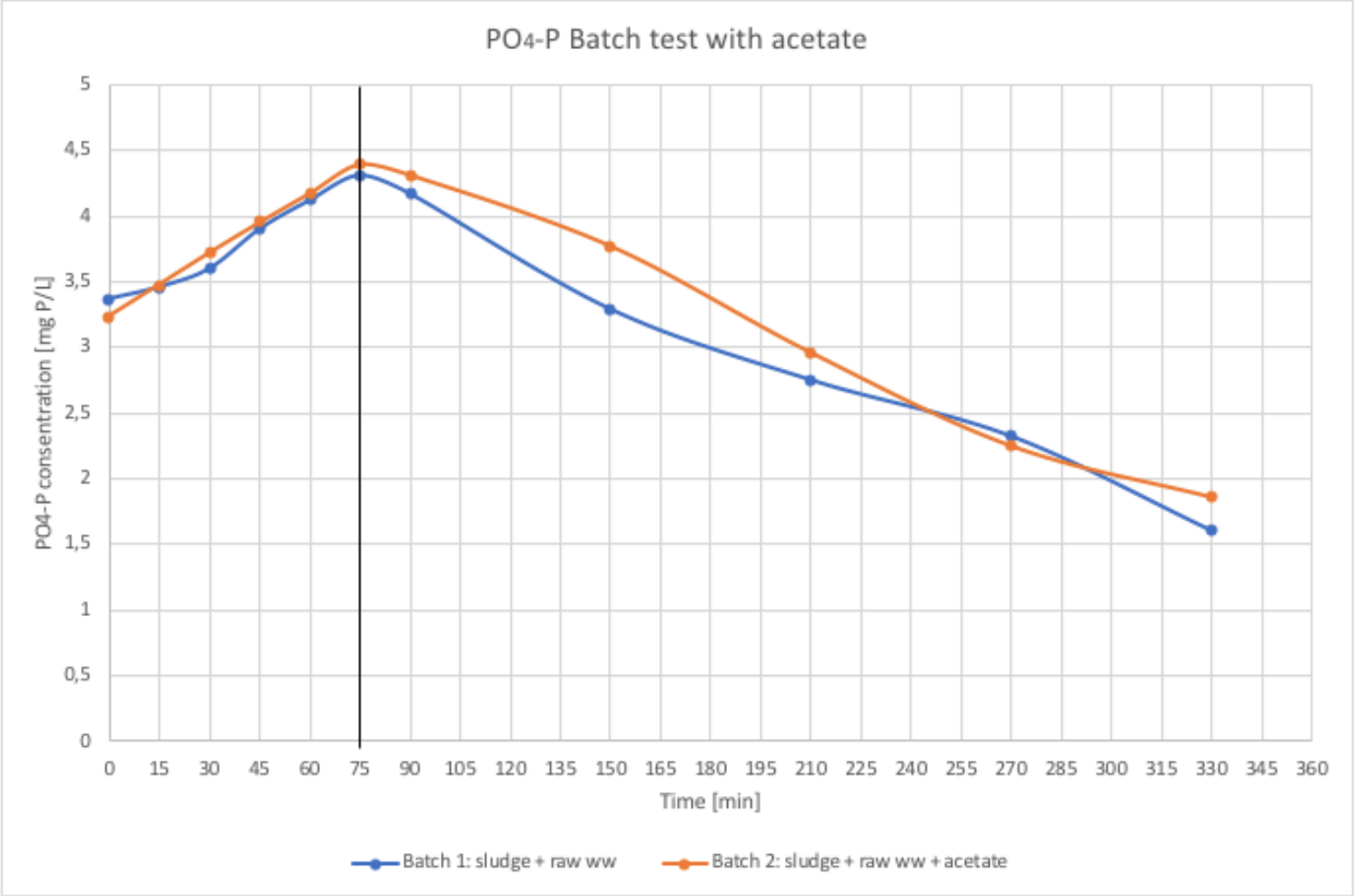
# 05.04.22: Batch test with acetate

| | | Batch test 1: sludge + wastewater | | | | | | Batch test 2: sludge + ww + acetate (10 mg/L) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| time [min] | time [h:min] | PO4-P [mgP/L] | sCOD [mg/L] | DO [mgP/L] | pH | T[°C] | Conductivity [µS/cm] | PO4-P [mgP/L] | sCOD [mg/L] | DO [mg/L] | pH | T[°C] | Conductivity [µS/cm] |
| 0 | 00:00 | 3,37 | 86,7 | 0,75 | 7,40 | 14,5 | | 3,24 | 115 | 0 | 7,56 | | 553 |
| 15 | 00:15 | 3,46 | 69,6 | 0 | 7,98 | 15,0 | | 3,48 | 115 | 0 | 8,05 | 16,0 | 1130 |
| 30 | 00:30 | 3,60 | 70,8 | 0 | 8,32 | 15,4 | | 3,72 | 88,4 | 0 | 8,55 | 16,1 | 1132 |
| 45 | 00:45 | 3,90 | 73,3 | 0 | 8,4 | 15,8 | | 3,95 | 89,2 | 0 | 8,72 | 16,4 | 1129 |
| 60 | 01:00 | 4,12 | 67,4 | 0 | 8,5 | 16,2 | | 4,17 | 105 | 0 | 8,78 | 16,6 | 1128 |
| 75 | 01:15 | 4,31 | 69,6 | 0 | 8,57 | 16,6 | | 4,39 | | 0 | 8,84 | 16,9 | 1120 |
| 90 | 01:30 | 4,17 | 60,9 | 8,04 | 8,53 | 17,0 | | 4,31 | 86,9 | | 8,79 | 17,3 | 858 |
| 150 | 02:30 | 3,29 | 49,1 | 8,44 | 8,30 | 17,8 | | 3,77 | 52,7 | | 8,79 | 17,3 | 858 |
| 210 | 03:30 | 2,75 | 46,6 | 8,28 | 8,29 | 18,4 | | 2,96 | 52,7 | | 8,27 | 19,3 | 621 |
| 270 | 04:30 | 2,32 | 48,8 | 7,68 | 8,28 | 19,0 | | 2,25 | 51 | | 8,23 | 20,0 | 354 |
| 330 | 05:30 | 1,60 | 45,9 | 6,7 | 8,26 | 19,2 | 1084 | 1,86 | 43,3 | | 8,21 | 20,3 | 241 |
| P-removed | | 1,77 | | | | | | 1,38 | | | | | |
| % removed | | 52,52 | | | | | | 42,59 | | | | | |

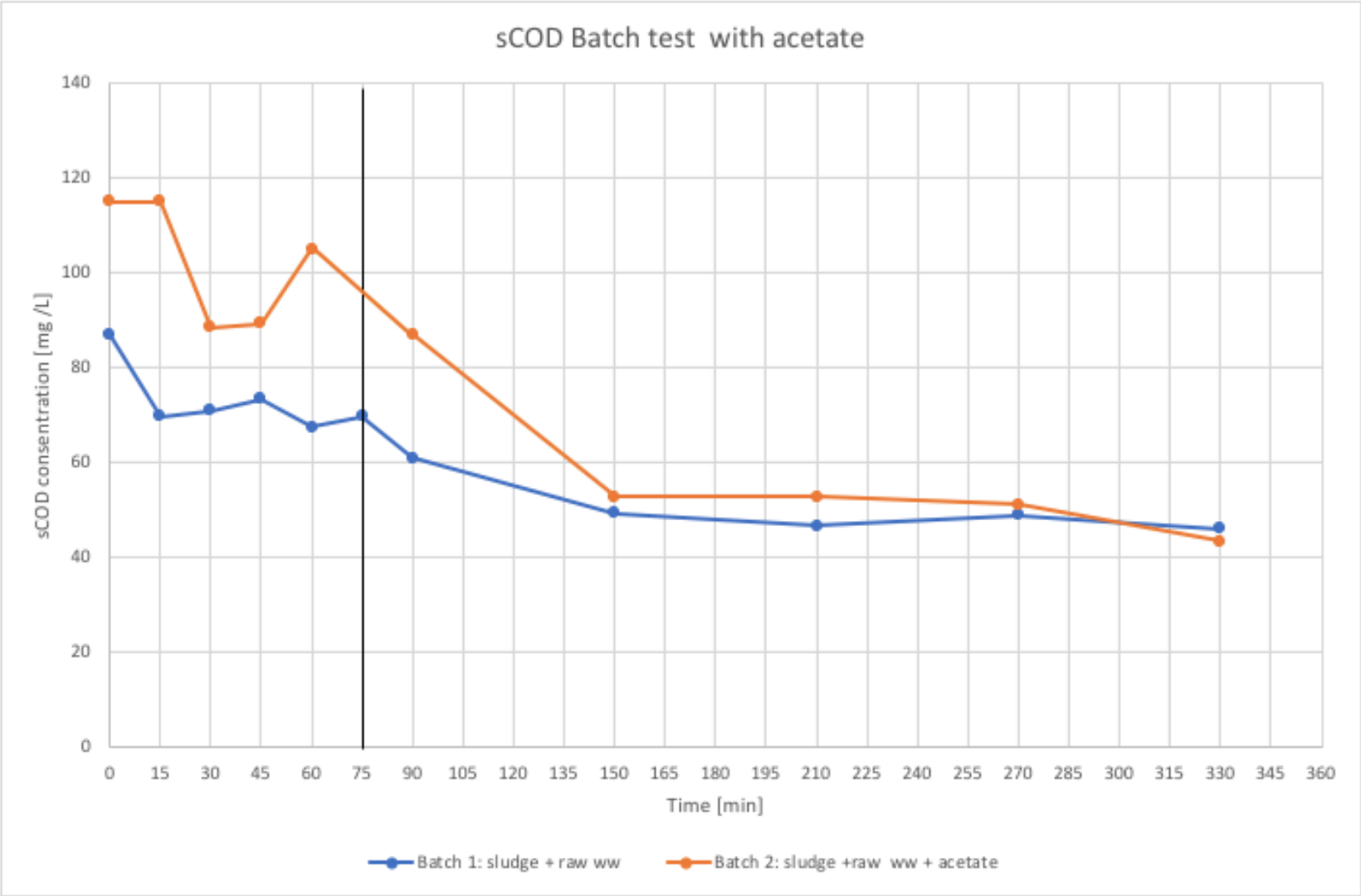
| initial water | PO4-P | sCOD |
|---|---|---|
| ww | 3,08 | 116 |

ww from tank A

# 05.04.22: Batch test with acetate



# 05.04.22: Batch test with acetate



# 21.04.22: Fermentation 1h 23min

| | | Batch test 1: sludge + wastewater | | | | | | Batch test 2: sludge fermented 1h 23 min + ww | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| time [min] | time [h:min] | $PO_4$-P [mgP/L] | sCOD [mg/L] | DO [mg/L] | pH | T[°C] | Conductivity | $PO_4$-P [mgP/L] | sCOD [mg/L] | DO | pH | T[°C] | Conductivity [µS/cm] |
| 0 | 00:00 | 1.41 | 75.5 | 0 | 7.75 | 20.2 | | 0.833 | 99.5 | | 8.08 | 20.5 | 562 |
| 15 | 00:15 | 1.49 | 61.3 | 0 | 8.45 | 19.2 | | 0.902 | 57.6 | | 8.66 | 19 | 549 |
| 30 | 00:30 | 1.33 | 55.6 | 0 | 8.63 | 18.3 | | 0.842 | 61.2 | | 8.85 | 17.9 | 682 |
| 45 | 00:45 | 1.62 | 59.5 | 0 | 8.73 | 17.7 | | 0.888 | 57.8 | | 8.96 | 16.7 | 290 |
| 60 | 01:00 | 1.22 | 69.2 | 0 | 8.8 | 17.3 | | 1.13 | 70.6 | | 9.02 | 16.7 | 171 |
| 75 | 01:15 | 1.39 | 63.3 | 0 | 8.8 | 17.7 | | 1.62 | 71.6 | | 9.02 | 16.7 | 3.81 |
| 90 | 01:30 | 0.962 | 72.7 | 8.56 | 8.57 | 18.1 | | 0.916 | | | 8.75 | 17.9 | 12 |
| 150 | 02:30 | 0.627 | 54.7 | 8.29 | 8.05 | 19 | | 0.782 | 50.7 | | 7.87 | 19.8 | 9,8 |
| 210 | 03:30 | 0.727 | | 8.64 | 8.14 | 20.3 | | 0.299 | | | 8.19 | 20.6 | 3.81 mS/cm |
| 270 | 04:30 | 0.325 | 33 | 8.71 | 8.29 | 21 | | 0.253 | 51.4 | | 8.23 | 21 | |
| P-removed | | 1.085 | | | | | | 0.58 | | | | | |
| % removed | | 76.95 | | | | | | 69.63 | | | | | |

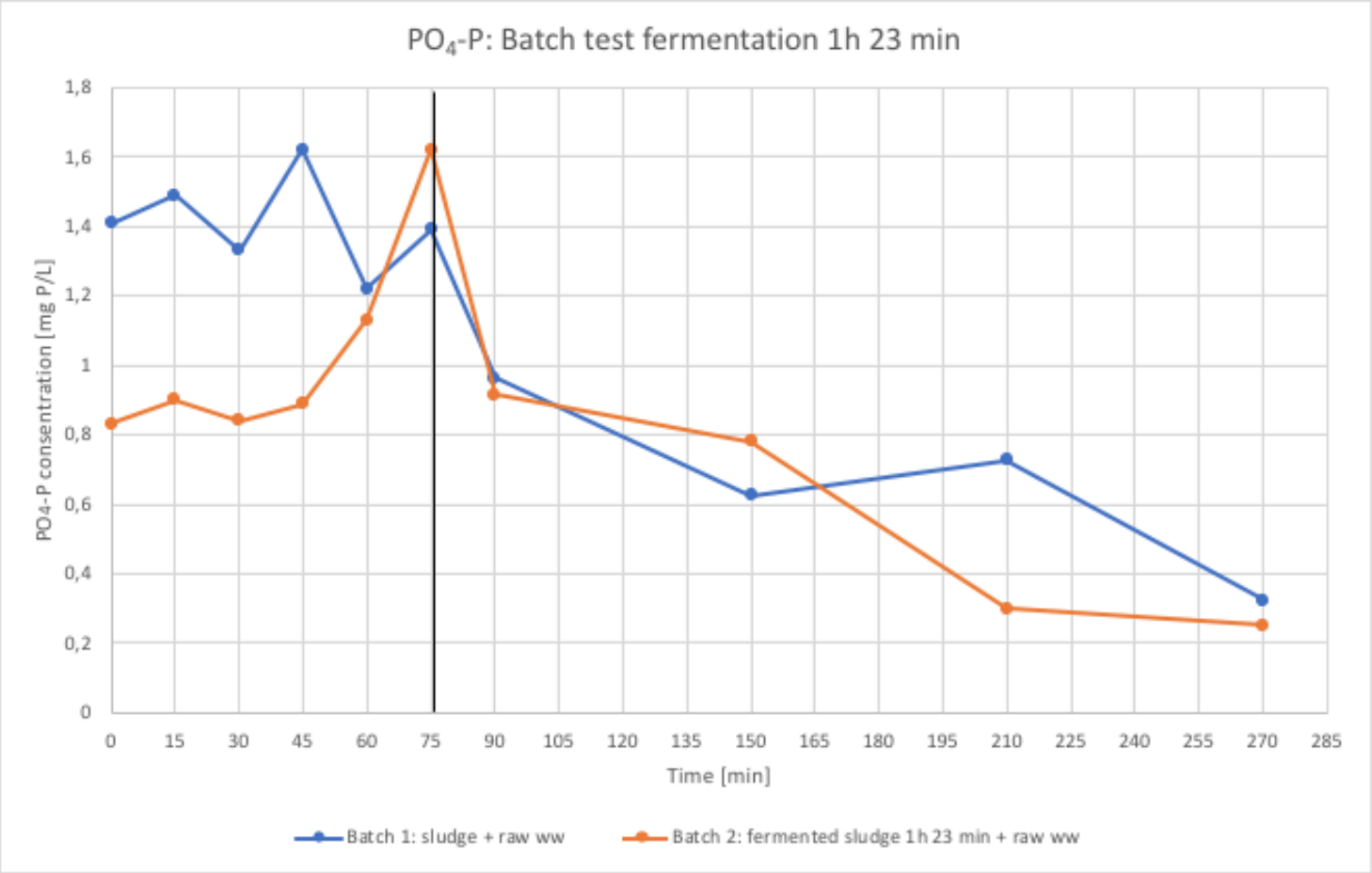
| initial water | $PO_4$-P | sCOD |
|---|---|---|
| ww | 1.64 | 49.4 |
| ferment | 0.34 | 54.8 |

ww is raw influent wastewater

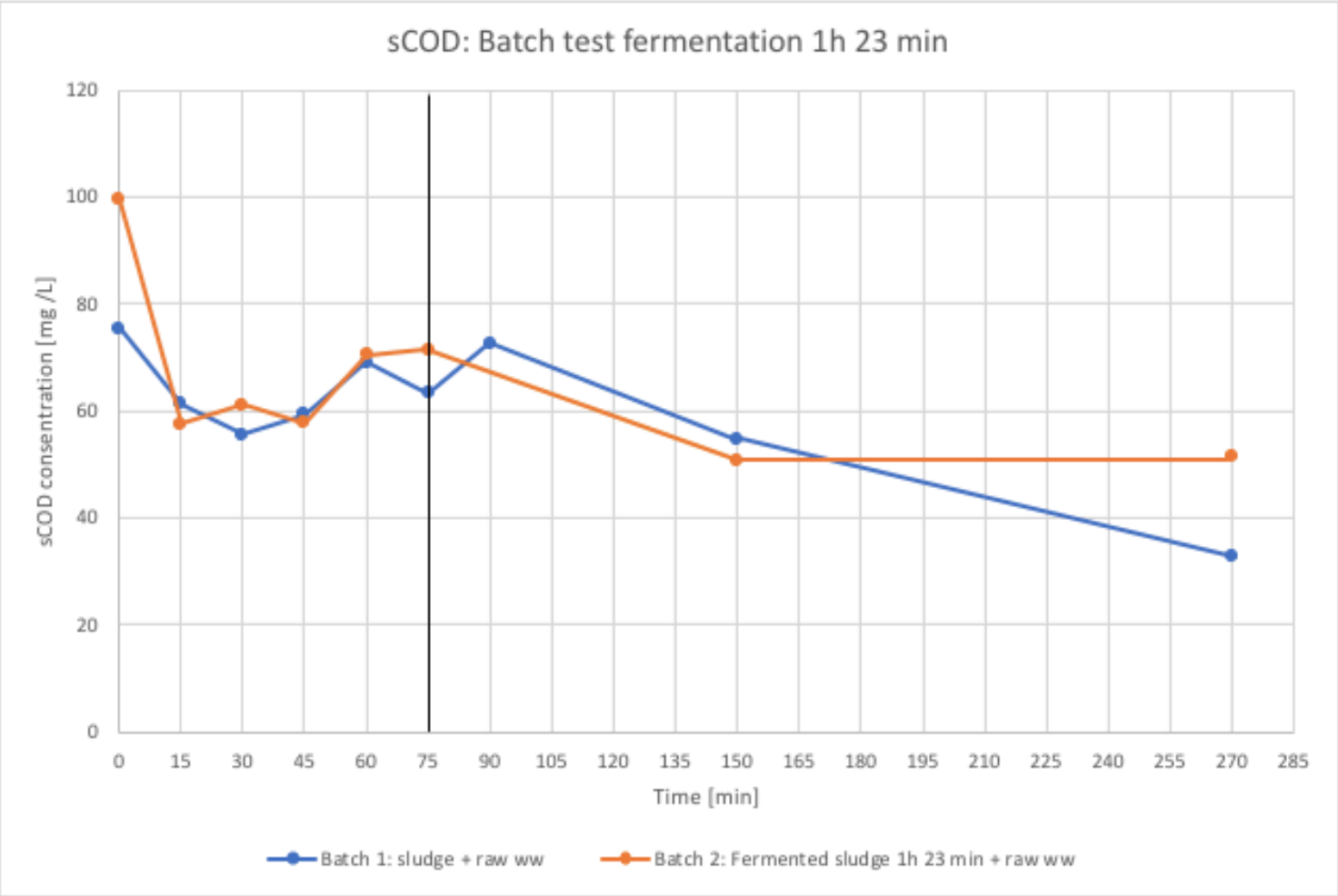
EF pilot: 1.08

| TS at time 04:30 for ferment + ww: | 3372 *mg TS/L* |
|---|---|

# 21.04.22: Fermentation 1h 23min



# 21.04.22: Fermentation 1h 23min



## 26.04.22: Batch test with fermentation 1h 23 min

| | | Batch test 1: sludge + wastewater | | | | | | Batch test 2: sludge + ww + fermentation 1h 23 min | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| time [min] | time [h:min] | $PO_4$-P [mgP/L] | sCOD [mg/L] | DO | pH | T[°C] | Conductivity [µS/cm] | $PO_4$-P [mgP/L] | sCOD [mg/L] | DO [mg/L] | pH | T[°C] | conductivity |
| 0 | 00:00 | 2.4 | 76.1 | 0 | 8.15 | 19 | 2,9 mS/cm | 3.14 | 99.1 | 0 | 7.92 | 20 | |
| 15 | 00:15 | 3.16 | 80.7 | 0 | 7.97 | | 2,28 mS/cm | 3.64 | 83.4 | 0 | 8.23 | 19.2 | |
| 30 | 00:30 | 3.84 | 71.6 | 0 | 8.48 | 20.6 | 1780 | | 85.2 | 0 | 8.3 | 19.3 | |
| 45 | 00:45 | 4.43 | 67.3 | 0 | 8.48 | 20.6 | 1708 | 4.98 | 92.3 | 0 | | | |
| 60 | 01:00 | 4.99 | 65.3 | 0 | 8.69 | 20.6 | 968 | 5.58 | 78 | 0 | 8.4 | 19.8 | |
| 75 | 01:15 | 5.19 | 64 | 0 | 8.69 | 20.6 | 196 | 6.87 | 76 | 0 | 8.5 | 20.1 | |
| 90 | 01:30 | | 73.8 | | 8.69 | 20.6 | 196 | | 79 | 0 | 8.5 | 20.2 | |
| 105 | 01:45 | 4.97 | 70.7 | | 8.6 | 20.7 | 3 mS/cm | 6.09 | 84.8 | 8.2 | 8.4 | 20.3 | |
| 150 | 02:30 | 3.93 | 65 | | 7.96 | 20.9 | 3 mS/cm | 4.11 | 89.2 | 8.04 | 8.19 | 20.5 | |
| 210 | 03:30 | 3.01 | 70.1 | | 8.04 | 21.1 | 1655 | 3.33 | 72.3 | 8.14 | 8.13 | 20.8 | |
| 270 | 04:30 | 1.75 | | | 7.94 | 21.3 | 1762 | 1.71 | 66.3 | 8.11 | 8.04 | 21 | |
| 330 | 05:30 | 1.46 | 79.6 | | 7.89 | 21.4 | 1448 | 1.21 | 51.6 | 8 | 7.9 | 21.1 | |
| P-removed | | 0.94 | | | | | | 1.93 | | | | | |
| % removed | | 39.17 | | | | | | 61.46 | | | | | |

Point in batch 2 removed due to deviating result

Forgot to turn off N-gas and turn on air

Batch left in aeration during fermentation

Batch first left for 30 min for SVI before fermentation for 1h 23 min

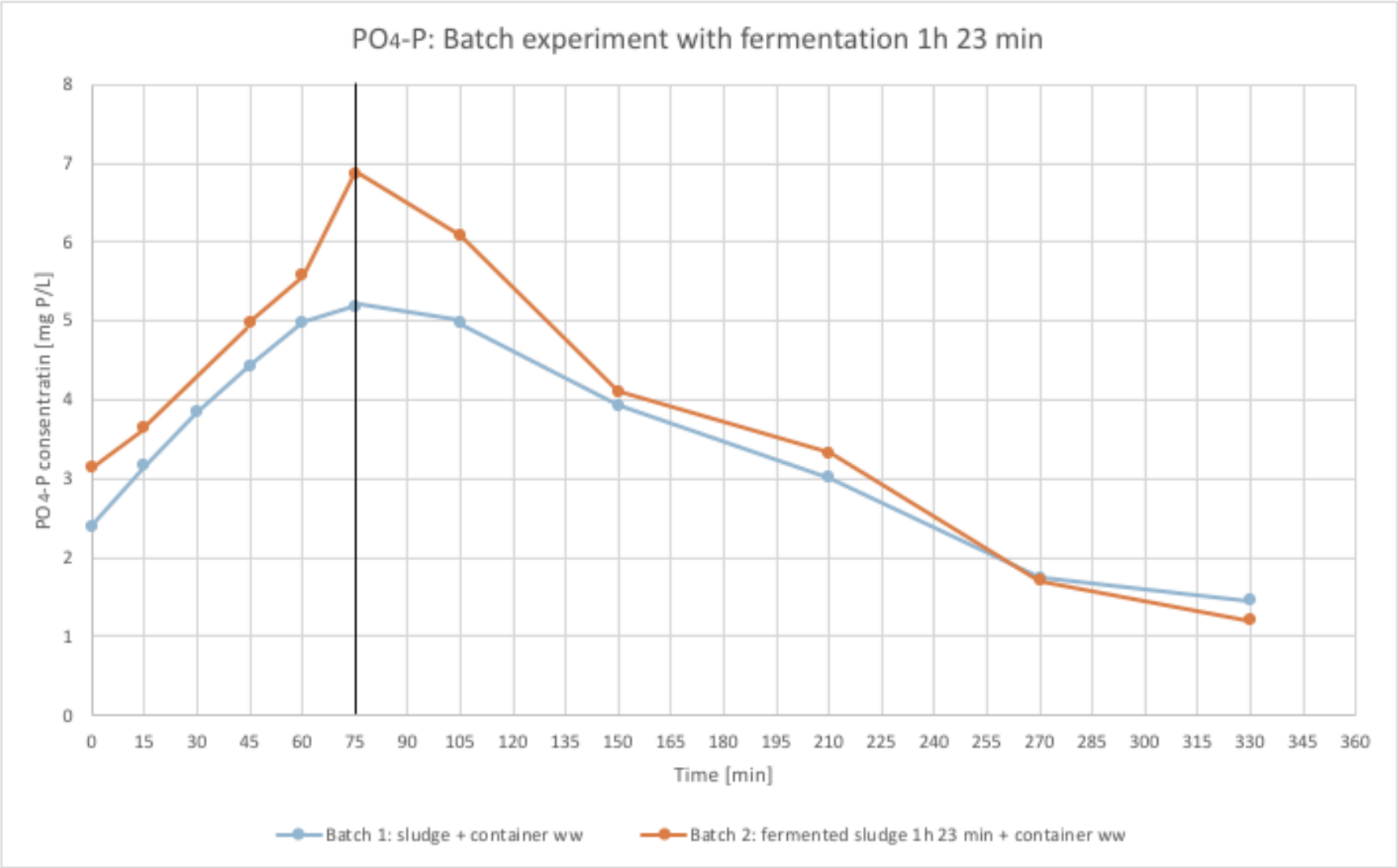
| Initial | $PO_4$-P | sCOD | tot P |
|---|---|---|---|
| ww | 3.97 | 111 | |
| Fermented | 1.29 | 7.2 | 46.4 |
| ww from container | | | |
| EF pilot that | 2.27 | | |

**Sludge from aerobic tank:**

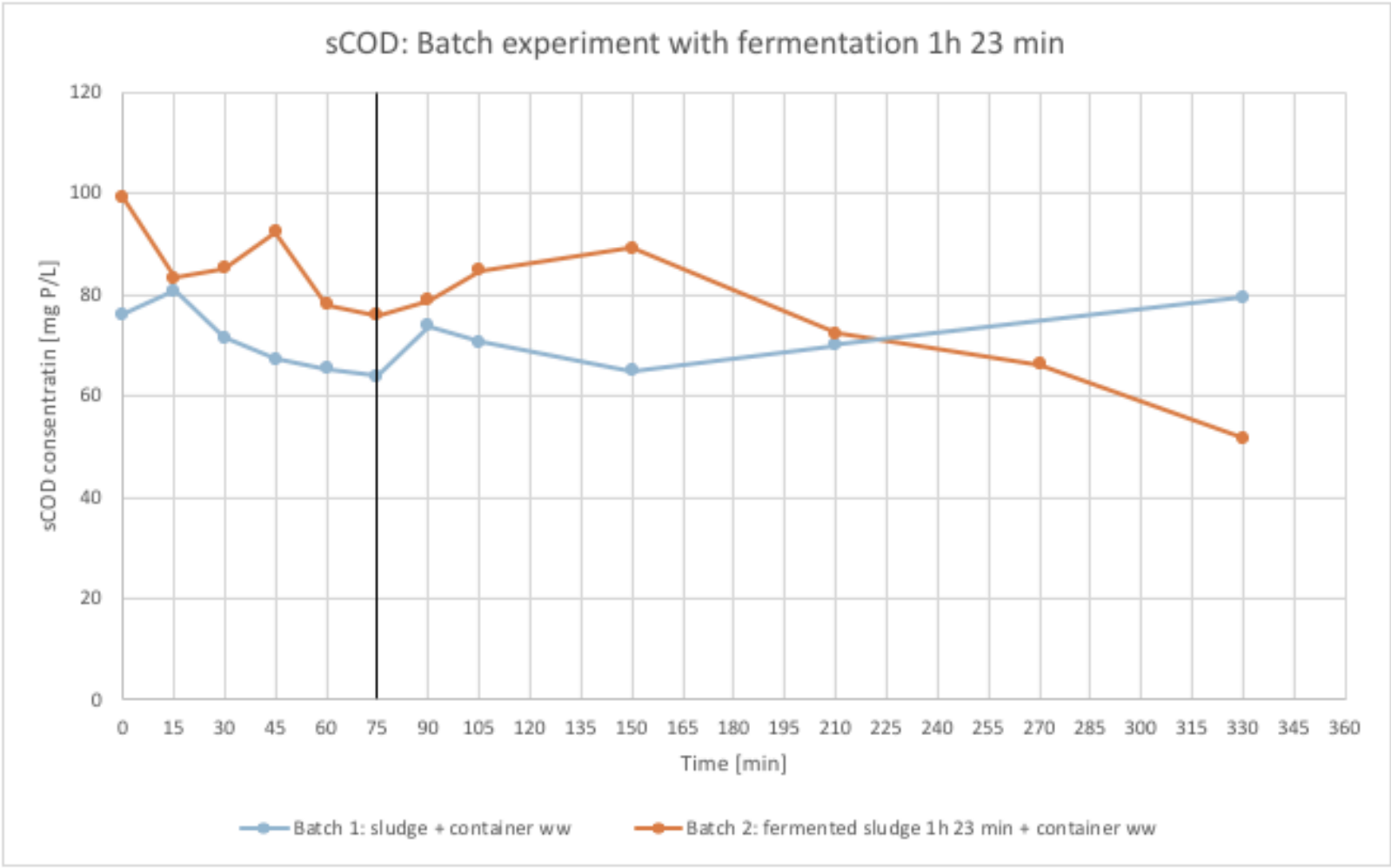
| | | |
|---|---|---|
| tot P | 56.6 | mg P/L |
| $PO_4$-P | 2.42 | mg P/L |
| TS | 3732 | mg TS/L |
| VS | 1424 | mg/L |

XX

## 26.04.22: Batch test with fermentation 1h 23 min



# 26.04.22: Batch test with fermentation 1h 23 min



# 27.04.22: Fermentation 1h 23min + acetate

| | | Batch test 1: sludge fermented 1h 23 min + ww | | | | | | Batch test 2: Sludge + ww + acetate | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| time [min] | time [h:min] | PO4-P [mgP/L] | sCOD [mg/L] | DO [mg/L] | pH | T[°C] | Conductivity | PO4-P [mgP/L] | sCOD [mg/L] | DO | pH | T[°C] | Conductivity [mS/cm] |
| 0 | 00:00 | 3.2 | 99.1 | 0 | 8.17 | 19.7 | | 2.62 | 98.1 | 0 | 7.67 | 20.1 | 2.98 |
| 15 | 00:15 | | 94.1 | 0 | 8.47 | 19.3 | | 3.27 | 121 | 0 | 8.49 | 20.3 | 3 |
| 30 | 00:30 | 3.76 | 96.6 | 0 | 8.6 | 19 | | 3.63 | 106 | 0 | 8.7 | 19.7 | 3 |
| 45 | 00:45 | 4.45 | 79.4 | 0 | 8.7 | 18.6 | | 4.49 | 104 | 0 | 8.9 | 19.2 | 2.99 |
| 60 | 01:00 | 4.49 | 80.4 | 0 | 8.8 | 18.3 | | 4.91 | 107 | 0 | 9 | 18.9 | 2.99 |
| 75 | 01:15 | 4.98 | 74.9 | 0 | 8.86 | 18.1 | | 5.11 | 103 | 0 | 9.05 | 18.6 | 2.9 |
| 90 | 01:30 | 5.38 | 75.9 | 8.86 | 8.7 | 18.3 | | 5.44 | 103 | | 9.05 | 18.7 | 2.98 |
| 150 | 02:30 | 4.84 | 77.7 | 8.73 | 8.4 | 19.2 | | 5.37 | 105 | | 8.49 | 19.5 | 3.01 |
| 210 | 03:30 | 4.39 | 77.9 | 8.6 | 8.3 | 19.9 | | 4.42 | 89.9 | | 8.13 | 20.3 | 3 |
| 270 | 04:30 | 3.95 | 62.1 | 8.5 | 8.25 | 20.3 | | 3.47 | | | 8.07 | 20.7 | 2.99 |
| 315 | 05:15 | 3.19 | | 8.49 | 8.21 | 20.5 | | 2.49 | | | 8.03 | 20.9 | 2.99 |
| P-removed | | 0.01 | | | | | | 0.13 | | | | | |
| % removed | | 0.00 | | | | | | 4.96 | | | | | |

Point in batch 1 removed due to deviating result

Batch left in aeration during fermentation

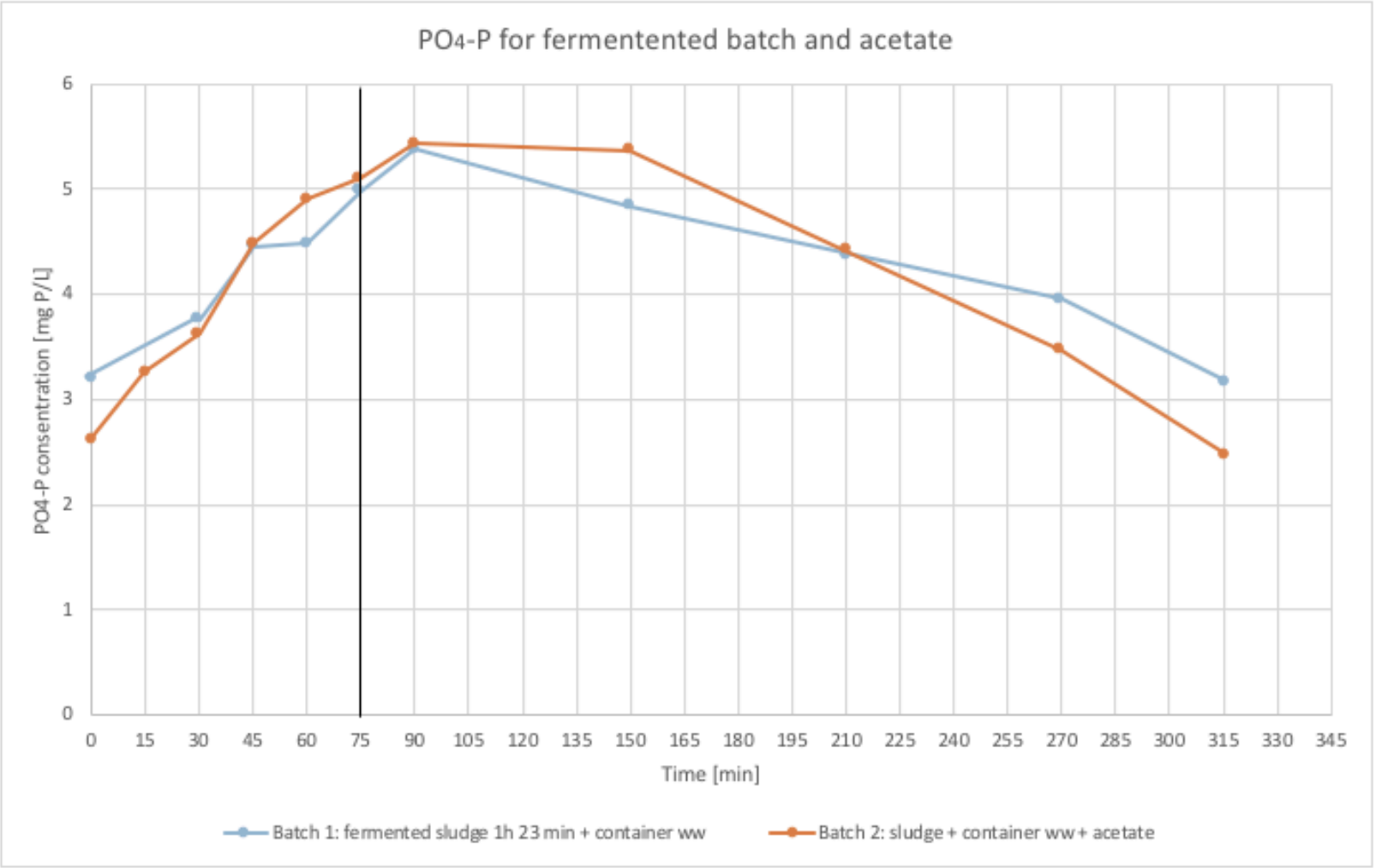
| Initial water | PO4-P | sCOD |
|---|---|---|
| ww | 4.02 | 93 |
| Fermented | 1.88 | 69.2 |

ww same as in pilot

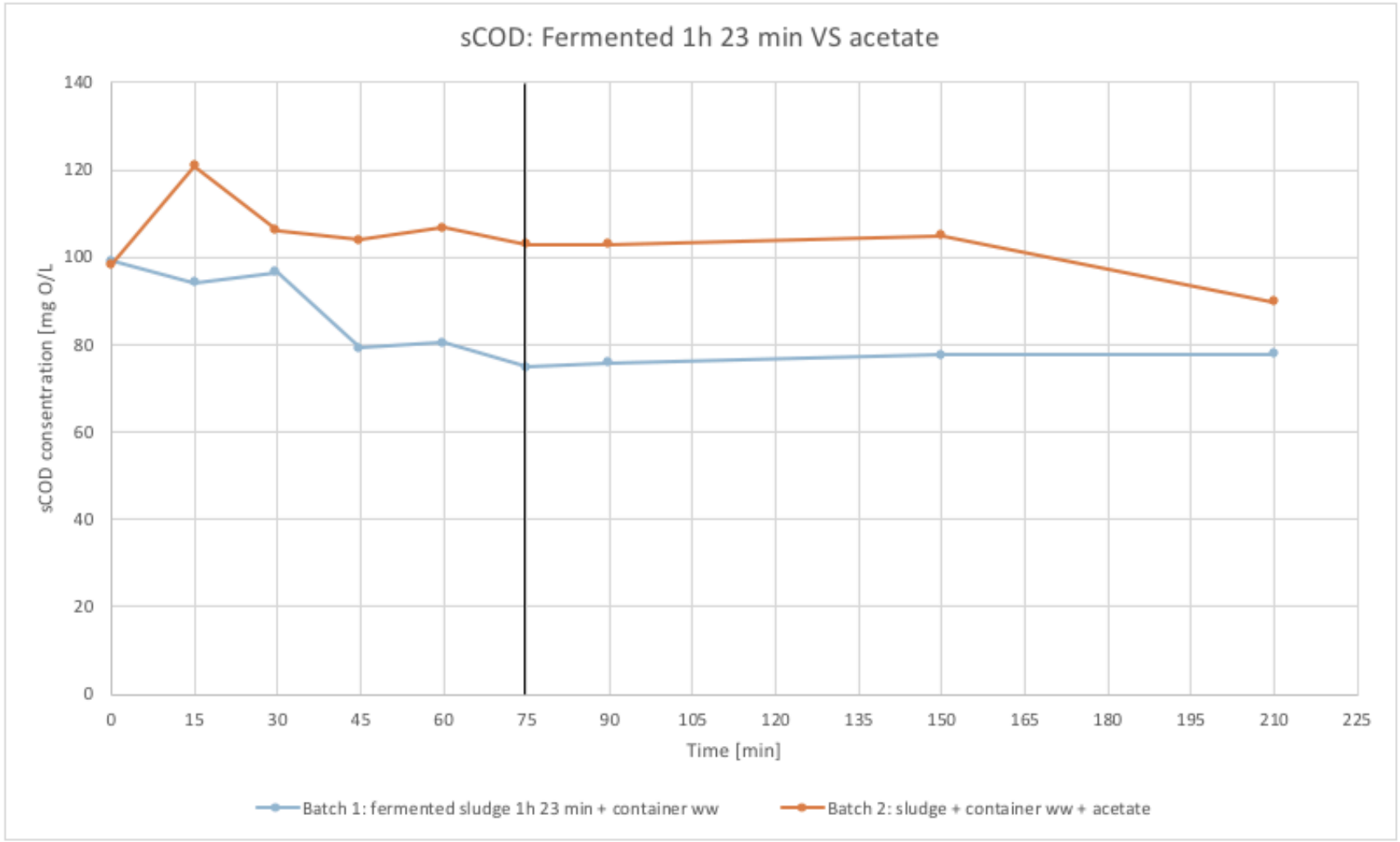
EF pilot: 3.96

| | PO4-P | tot P | sCOD | *pH* | TS | VS | DO |
|---|---|---|---|---|---|---|---|
| Aerobic | 3.02 | 33.5 | 47.1 | 4.4 | 3164 | | 5.62 |
| EF | 3.96 | | 42.4 | | 2516 | | |

# 27.04.22: Fermentation 1h 23min + acetate



# 27.04.22: Fermentation 1h 23min + acetate



# Acetate to influent container

10.05.2022

Amount of sCOD for PAOs:

1 mg $P_{inf}$ → 7 mg sCOD (Janssen , Meinema og Van Der Roest 2002)

$PO_4$-P concentration in influent wastewater: 1.25 mg P/L

$$1.25\ \frac{mg\ P}{L} * 7 \frac{mg\ COD}{mg\ P} = 8{,}75\ mg\ COD/L$$

Amount of sCOD for denitrifiers:

1 mg $NO_3$-N → 3 mg sCOD (Ødegaard 2014).

$NO_3$-N concentration effluent: 22.8 mg N/L

$$22.8 \frac{mg\ N}{L} * 3 \frac{mg\ COD}{mg\ N} = 68.4\ mg\ COD/L$$

Want to add 20 mg as surplus. The amount of COD needed:

| | | |
|---|---|---|
| | *For PAOs* | *8.75 mg/L* |
| + | *For denitrifiers* | *68.40 mg/L* |
| + | *Surplus* | *20.00 mg/L* |
| = | *Amount needed* | *97.15 mg/L* |

Acetate:
136.8 g/mol $CH_3COONa * 3\ H_2O$
59 g/mol $CH_3COD$

The volume in the container at 10.05.22 is 650 L.
The solution will be diluted in a 2L volumetric flask.

$$c_1 * V_1 = c_2 * V_2$$

$$\frac{0.097 \frac{g}{L} * 650\ L}{2\ L} = 31.5 \frac{g}{L}\ CH_3COD$$

The amount of acetate salt to be diluted in the 2 L volumetric flask:

$$\frac{31.5 \frac{g}{L} * 136\ g/mol}{59\ g/mol} = 74.61\ g$$

# Acetate to influent container

13.05.2022

Amount of sCOD for PAOs:

1 mg $P_{inf} \rightarrow$ 7 mg sCOD (Janssen , Meinema og Van Der Roest 2002)

$PO_4$-P concentration in influent wastewater: 5.38 mg P/L

$$5.38\ \frac{mg\ P}{L} * 7 \frac{mg\ COD}{mg\ P} = 37.66\ mg\ COD/L$$

Amount of sCOD for denitrifiers:

1 mg $NO_3$-N $\rightarrow$ 3 mg sCOD (Ødegaard 2014).

$NO_3$-N concentration effluent: 10.6 mg N/L

$$10.6 \frac{mg\ N}{L} * 3 \frac{mg\ COD}{mg\ N} = 31.8\ mg\ COD/L$$

Want to add surplus such that the total amount is 200 g acetate.

Acetate:
136.8 g/mol $CH_3COONa$ * 3 $H_2O$
59 g/mol $CH_3COD$

The volume in the container is 1000 L.
The solution will be diluted in a 2 L volumetric flask.

$$c_1 * V_1 = c_2 * V_2$$

$$\frac{0.200 \frac{g}{L} * 1000\ L}{2\ L} = 100 \frac{g}{L}\ CH_3COD$$

The amount of acetate salt to be diluted in the 2 L volumetric flask:

$$\frac{100 \frac{g}{L} * 136\ g/mol}{59\ g/mol} = 230.5\ g$$

# Minimum SRT for Nitrification at 20°C

$$SRT_m = \frac{1}{\mu_{AmT} - b_{AT}}$$

$SRT_m$ = minimum sludge age for nitrification

$\mu_{AmT} = \mu_{Am20}$ = maximum specific growth rate at 20°C

$b_{AT} = b_{A20}$= 0.04

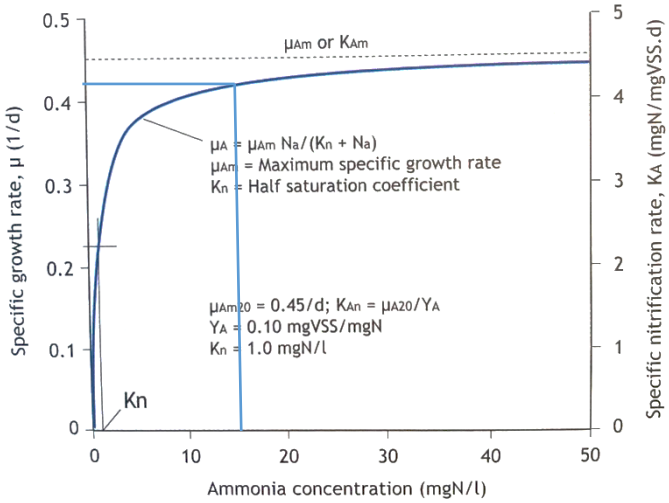



**Figure 5.1** The Monod specific growth rate equation for nitrification at 20°C

Using the $NH_4$-$N_{EF}$ = 14.2 mg N/L and we can read from Figure 5.1 that $\mu_{Am20} \approx 0.42$ (Henze, et al. 2008).

This gives an SRT:

$$SRT_m = \frac{1}{0.42 - 0.04} = 2.6\ days$$

This could also be read directly from Figure 5.2.

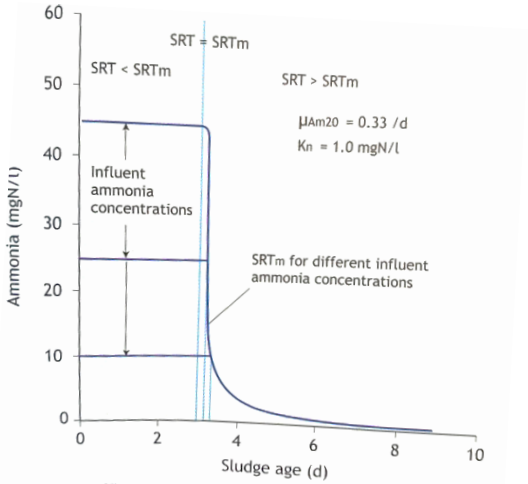
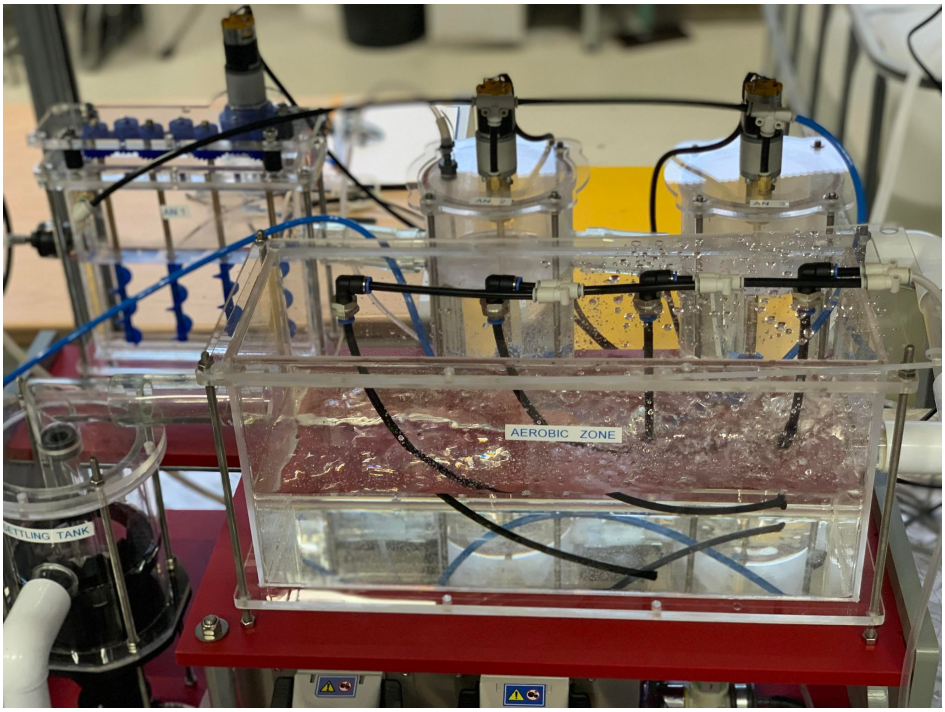



**Figure 5.2** Effluent ammonia concentration versus sludge age for the steady state nitrification model




# LAB-SCALED PILOT FOR OPTIMIZATION OF EBPR

Preparation for optimization of EBPR process at IVAR SNJ

VIKTORIA RØVIG

Specialization project

Supervisors:
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## Abstract

IVAR SNJ is the wastewater treatment plant in the region of Nord-Jæren in Norway. The treatment plant use activated sludge to treat the wastewater from the 400 000 person equivalents connected to the plant. IVARs goal is to use the wastewater as a resource and create biogas and phosphorus as fertilizer. In order to extract the phosphorus from the wastewater Enhanced Biological Phosphorus Removal (EBPR) is used. But IVAR experience some challenges with this process. In order to optimize the EBPR process at IVAR a 1:100 lab-scaled pilot of the treatment plant has been built. This paper gives a description of IVAR SNJ as well as the lab-scaled pilot. The aim is to identify how the lab-scaled pilot can be used to optimize the EBPR process at IVAR by starting at its challenges. It is well documented that the main challenge at IVAR is to be found in the settling tank. Together with the settling tank several other operational issues as dissolved oxygen in the anaerobic reactor and possible improvement of fermentation in the side-stream reactor has been found. The lab-scaled pilot is developed with a different settling tank to accommodate the settling challenges. The reactors are design with different height levels to avoid back mixing. The lab-scaled pilot can be used to see how good settling properties and no back mixing will affect the EBPR process when drifted with the same operational parameters as IVAR use today. If needed the operational parameters need to be adjusted to accommodate the good settling.

# Abbreviation

BOD – Biological Oxygen Demand

COD - Chemical Oxygen Demand

EBPR – Enhanced Biological Phosphorus Removal

GAOs – Glycogen Accumulating Organisms

HRT – Hydraulic Retention Time

OHOs – Ordinary Heterotroph Organisms

ORP – Oxidation-Reduction Potential

P – Phosphorus

PAOs – Polyphosphate-Accumulating Organisms

PE – Person Equivalents

PHA - Poly-β-Hydroxyalkanoate

RAS – Return Activated Sludge

rbCOD – Readily Biodegradable COD

SRT – Sludge Retention Time

SVI – Sludge Settling Index

VFA – Volatile Fatty Acids

VSS – Volatile suspended solids

# Table of content

# 1 Introduction

The wastewater treatment plant in Nord-Jæren is called IVAR SNJ. IVAR treats the wastewater from Nord-Jæren with the aim to recover resources such as biogas, phosphorus and water itself (IVAR, 2018). However, IVAR have problems when it comes to the phosphorus recover process. Lab experiments has shown great potential for phosphorus removal from the wastewater at IVAR, but the same results are not to be found in the effluent water from the treatment plant (Lilleland , 2019).

This paper is a preparation for the project work that will be done on a lab-scaled pilot of IVAR treatment plant. The lab-scaled pilot is a 1:100 version of the IVAR treatment plant, but with a different designed settling tank. The aim of the project is to optimize the treatment process at IVAR. This paper will discuss how the lab-scaled pilot can be used to optimize the treatment process at IVAR. It will start with a description of the theory behind EBPR and some of the important parameters. Then it will include a description of the IVAR treatment plant, identify its challenges, as well as a description of the lab-scaled pilot. A discussion on how the lab-scaled pilot can be used to investigate some of the challenges that has been fund at IVAR will follow.

# 2 Theory

## 2.1 Norwegian wastewater characteristics

Norwegian wastewater is known to be highly diluted, cold and low in nutrients (Ødegaard, 2014). The characteristic does often change from one place to another. Typical values for Norwegian wastewater are given in Table 1. How much it varies depend on the local industry and the composition of public buildings. Seasonal variations are often common. The wastewater during the spring is often colder than the rest of the year due to infiltration of melted snow. Average wastewater temperature during winter can be 5°C and even colder during the spring. The characteristics do also change daily and hourly. The coastal areas are often more diluted due to combined sewage system and heavier rainfall events. The typical pH in the wastewater is around 7 – 8 and has low alkalinity (Ødegaard, 2014, p. 421).

Table 1: Concentrations in [g/m$^3$] for Norwegian wastewater in different situations *(Ødegaard, 2014)*.

| PARAMETERS | DRY WEATHER | | WET WEATHER | |
|---|---|---|---|---|
| | **Good condition[1)]** | **Bad condition[2)]** | **Good condition[3)]** | **Bad condition[4)]** |
| $BOD_5$ | 200 | 120 | 150 | 60 |
| COD | 400 | 240 | 300 | 120 |
| SS | 233 | 140 | 175 | 70 |
| TOT P | 6.0 | 3.6 | 4.5 | 1.5 |
| TOT N | 40 | 25 | 30 | 12 |

1) 100 L/pe*d infiltration
2) 300 L/pe*d infiltration
3) 100 L/pe*d infiltration + stormwater = 100 L/pe*d
4) 300 L/pe*d infiltration + stormwater = 700 L/pe*d

The sources of wastewater in Stavanger are domestic wastewater, industrial wastewater, infiltration/inflow and stormwater (Danielsen, 2018). Domestic wastewater includes water from public facilities and households. The infiltrated water includes seawater, which means a percentage of salt can be found in the wastewater.

## 2.2 Treatment Requirements

IVAR is required to have secondary treatment and has an outlet to the sea. The treatment goals for secondary treatment are found in Table 2.

Table 2: The EU's requirements for wastewater treatment in densely populated areas. (> 10.000 PE to sea) *(Ødegaard, 2014, pp. 431, 557)*.

| TREATMENT PROCESS | MAX CONCENTRATION | MINIMUM % REDUCTION |
|---|---|---|
| PRIMARY TREATMENT | BOD: 40 mg/L | 20 % |
| | SS: 60 mg/L | 50 % |
| SECONDARY TREATMENT | $BOF_5$: 25 mg/l | 70 % |
| | COD: 125 mg/l | 75 % |

## 2.3 Phosphorus

Phosphorus (P) in wastewater is often found as organically bound phosphorus or inorganic phosphorus. The inorganic phosphorus is often found as orthophosphate ($[PO_4]^{3-}$) or as polyphosphate ($[P_2O_7]^{4-}$ and $[P_3O_{10}]^{5-}$). The amount of organically bound P is usually small while orthophosphate is the dominant one and can make up 80 – 90% of the total P–content (Ødegaard, 2014, p. 419). The usual reason for removing phosphorus from wastewater is to prevent eutrophication in the receiving waterbody. Freshwater is especially sensitive to high P concentrations, while seawater is more sensitive to nitrogen (Ødegaard, 2014).

## 2.4 Chemical P-removal

Removal of phosphorus can be done through chemical removal which include coagulation, flocculation and separation. A coagulant is added to the water and the flocculation makes the particles collide. Because of the coagulant the particles are able to bound together and make bigger flocs that are easier to separate from the water by sedimentation, flotation or filtering. Typical coagulants are aluminum or iron salts. These salts will therefore be found in the sludge when chemical removal is used (Ødegaard, 2014, p. 441). The process is considered robust and is highly dependent on the right coagulant dosage. It can achieve > 90% removal of phosphorus (Ødegaard, 2014, p. 456).

## 2.5 Activated sludge

Activated sludge is a type of biological wastewater treatment. Suspended microorganisms float freely in the reactor and remove substrates from the wastewater. The microorganism uses organic matter in the wastewater as a carbon and energy source for cell growth. The microorganisms convert the easy biodegradable substrate first, then the slowly biodegradable organic material such as proteins. They can also convert particulate organic matter if it goes through hydrolysis (Ødegaard, 2014, p. 460).

The microorganism's floc together in aggregates. The flocs have a size between 50 – 200 mm, which makes them easy to remove in settling tanks. Sludge Volume Index (SVI) is used to evaluate the sludge settling properties in activated sludge process. An SVI < 80 mL/g indicates that the sludge is dense and has rapid settling characteristics. Typical values for an activated sludge plant are between 100 – 200 mL/g. The process produces a clear, high-quality effluent. The sludge settles slower and trap more particulate matter in a uniform blanket before it settles. If the SVI is > 250 mL/g the sludge is settling slower and is less compact (Rumbaugh, 2019).

The activated sludge process is dependent on Return Activated Sludge (RAS) from the separation tank to be returned to the bioreactor in order to keep up a suitable concentration of microorganisms in the activated sludge system (Ødegaard, 2014, p. 468).

Activated sludge processes can be used for removal of organic carbon, nitrification and denitrification and Enhanced Biological Phosphorus Removal (EBPR). This paper will focus on activated sludge as EBPR.

## 2.6 Enhanced Biological Phosphorus Removal

EBPR is a well–established technology for phosphorus removal from wastewater and can be used in combination with activated sludge to remove P without the use of chemicals. The process is known to have low operating costs, small reagent–consumption and low sludge production levels (Deng, et al., 2016). It utilizes Polyphosphate–Accumulating Organisms (PAOs) in the biomass which are responsible for the removal of P from the liquid phase through cellular growth. It is recurred that the PAOs are altered between anaerobic and aerobic conditions. A good EBPR process can reach a concentration down 0.1 mg/L (Barnard & Scruggs, 2003). After the process the phosphorus is removed through the biomass by means of separation. Sometimes EBPR is combined with denitrification. Since IVAR does not have nitrogen removal this is considered out of scope. The effect of nitrogen will therefore be mentioned but not be further explained in this paper.

### 2.6.1 Anaerobic zone

In the anaerobic reactor the PAOs use already stored polyphosphate to assimilate Volatile Fatty Acids (VFA) to produce intracellular Poly-β-Hydroxyalkanoate (PHA). At the same time the PAOs release soluble orthophosphate. The PHA content in the PAO increase while the amount of orthophosphate decrease. This leads to an increasing P concentration in this reactor (Barnard & Scruggs, 2003). A figure of the principle is shown in Figure 1.

The fraction of COD found in the reactor is of importance, since the microorganisms will remove the easy biodegradable COD first. PAOs in conventional EBPR plant could take up acetic and propionic acid in the presence of nitrates, but other substrates need to be fermented ( Wang, et al., 2019). The anaerobic zone has favorable conditions for fermentation and hydrolysis of COD, which breaks it down and makes it easier for the microorganisms to store. The RAS is mixed with the wastewater and organic substrates are fermented to ethanol, VFA, and succinate, which can all serve as carbon sources for PAOs.

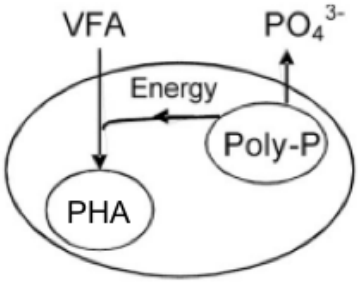



Figure 1: The figure shows the principle of the process in the PAOs in anaerobic conditions.

### 2.6.2 Aerobic zone

In the aerobic reactor the PHA is metabolized and oxidized which provides energy for cell growth. The PAOs use energy to form bonds of orthophosphate which is stored within the cells. This leads to a decrease in soluble orthophosphate in the reactor. The principle is shown in Figure 2. The cell growth leads to an increase in biomass with high phosphate storage. The uptake of phosphate in the aerated reactor is large than the release in the anaerobic reactor. This can be seen in Figure 3. Bernard & Scrugges (2003) suggest a storing potential of 125% (Barnard & Scruggs, 2003). The concentration of soluble COD is also decreasing, which gives a removal of organic matter in the aerobic tank. This is called aerobic degradation and is mostly done by the Ordinary Heterotroph Organisms (OHOs) which are also found in EBPR processes (Danielsen, 2018).

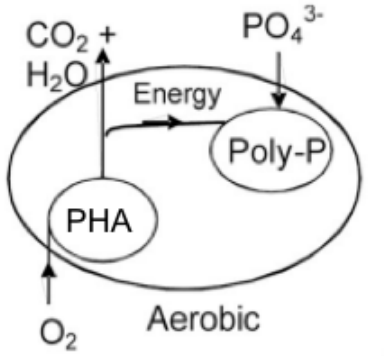



Figure 2: The figure shows the process happening in the PAOs at aerobic conditions.

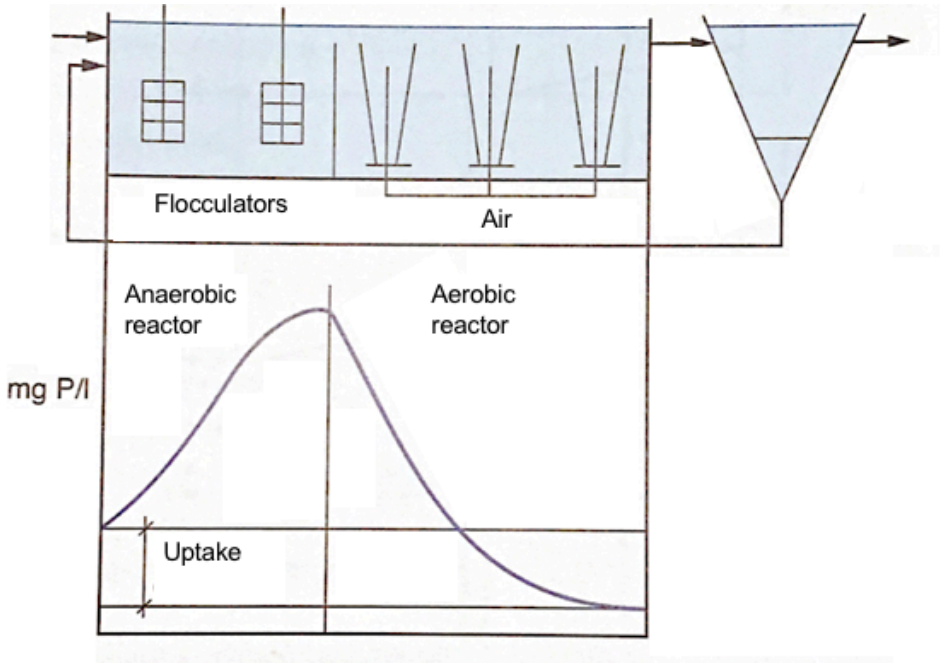



Figure 3: The graph in the figure shows how the P-concentration in the anaerobic reactor increase, while the uptake of P in the aerobic reactor is greater than the release.

### 2.6.3 Organisms found in EBPR

#### PAOs

Phosphorus accumulating organisms (PAOs) are used to remove the P from the wastewater by exposure to alternating anaerobic and aerobic environments. PAOs are obligate aerobes, meaning they need oxygen to grow. They have the ability to store approximately 0.38 g P/g

VSS (Danielsen, 2018, p. 20). PAOs exists in different forms with different abilities. Two groups of PAOs that are often found in EBPR are *Tetrasphaera* and *Accumulibacter*. Much research has been focusing on Candidatus Accumulibacter as the main PAO for removing P in the EBPR process, and the EBPR process has therefore been adjusted for growing these. Now research points out the possibility that with more prolonged and deeper anaerobic conditions, growth of other PAOs may be favored and their behavior may differ from that of the much-researched Accumulibacter species (Barnard, et al., 2017).

Tetrasphaera is a broad class of bacteria that has still to be well characterized and is considered a type of PAO (Barnard, et al., 2017). The bacteria have the advantage that they can ferment complex organic molecules such as carbohydrates and amino acids (including glucose, glutamate, aspartate) and produce stored carbon in the process. Some Tetrasphaera takes up VFA, but it is not their preferable source of carbon. When taking up VFA no poly–P is removed. They can also produce VFA under anaerobic conditions, which can be utilizing by other PAOs. Tetrasphaera do also seem to have the ability to do nitrification and be able to take up phosphorus in anoxic conditions. Bernard, et al. (2017) conclude that the net impact of Tetrasphaera on EBPR could be significant and a fermentation process that brings out Tetrasphaera could be favorable since significantly more of the available carbon could be used for phosphate removal (Barnard, et al., 2017).

**GAOs**

Glycogen Accumulating Organisms (GAOs) are undesired in EBPR since it competes with the PAOs by taking up VFAs without any phosphorus uptake. GAOs use glycogen as their primary energy source. Under certain conditions GAOs can dominate the process and the P–removal will be poorly (Barnard & Scruggs, 2003).

Factors that affect the PAO/ GAO competition (Ødegaard, 2014):

- Type of C–source
- Influent P/COD–ratio
- pH and temperature
- SRT

Bernard, et al. (2017) do also suggest that the presence of Tetrasphaera can contribute to a low GAO count in the process (Barnard, et al., 2017).

**OHOs**

Ordinary Heterotroph Organisms (OHOs) contain about 0.015 g P/g VSS and are able to remove 10 – 20 % of the phosphorus in the reactor if they are the main organism (Danielsen, 2018). OHOs do not consume VFAs in the anaerobic reactor since it needs oxygen or nitrate as an electron acceptor for the consumption of organic carbon.

The removal of organic material through aerobic degradation is mainly caused by the OHOs. In this process organic material is degraded to the end products Carbon Dioxide ($CO_2$) and water ($H_2O$). The OHOs gets energy and carbon needed for production of new biomass.

### 2.6.4 Side–stream configuration

A configuration that can be used in EBPR is the side–stream configuration. In this configuration the influent water is not lead to the first anaerobic reactor but to the second reactor in the series. The RAS, however, is lead to the first reactor which allows the microorganisms to be fermented in this reactor without the influence of the influent water. The main purpose of the fermentation reactor is to is to hydrolysis slowly and particulate biodegradable organic material to soluble organic compounds as VFAs. Raw Norwegian wastewater is diluted and therefore has a low fraction of readily biodegradable organic matter. The access to enough carbon is considered a limiting factor in EBPR, and the fermentation tank can help with that (Danielsen, 2018).

A study comparing side–stream to conventional operation showed that the side–stream configuration could improve the P–removal performance ( Wang, et al., 2019). The study showed three times higher aerobic P–uptake. This could be caused by involvement by other types of PAOs, such as Tetrasphaera. The study also showed a higher resistance and faster recovery after a flush–out storm event in the side–stream reactor. As the fermentation happens in a different tank it allows for different retention time for the RAS and the influent water.

This configuration has shown to be more effective and stable than conventional EBPR removal, especially if mixers in the sides–stream anaerobic reactors were operated intermittently. It did also have a relatively higher PAO activity, as well as glycolysis activity. Adequate anaerobic retention time with condition that allows continues supply of complex VFAs via RAS fermentation will potentially provide completive advantages to PAOs over GAOs ( Wang, et al., 2019).

The side–stream configuration can also remove nitrate through denitrification. Denitrification involves the reduction of nitrate ($NO_3$) to nitrogen gas ($N_2$). OHOs can help with this process by using nitrate as an electron acceptor to be able to consume the organic material present in the reactor (Danielsen, 2018). Reducing the amount of nitrate will help the EBPR process so that denitrification do not consume rbCOD in the aerobic reactor that could be consumed by the PAOs. Nitrate can also have a negative effect PAOs metabolism which can cause problems with storing polyphosphate (Ødegaard, 2014, p. 484).

### 2.6.5 Settling tank

The main function of a settling tank is to remove particles, generated as flocs in the biological reactor or other suspended solids before the treated water is discharged into the recipient. The settling tank provides stagnant conditions where the gravity helps the flocs to settle. The surface of a sedimentation tank can be circular, rectangular or square, and have both considered horizontal or vertical flow direction. Horizontal flow is traditionally used the most. The sedimentation basin is an important step in an activated sludge process. The basing helps to produce a clear effluent as well as sufficient thickening of the sludge. Thickening of the sludge is important to reach a high concentration for the return sludge. The sludge scrapers scrape the sludge into a sludge pocket where it is pumped away, either as RAS or as waste for sludge treatment (Ødegaard, 2014, p. 436).

## 2.7 Factors effecting EBPR

### 2.7.1 Temperature

Growth rate of microorganism depend on the temperature. Low temperatures usually result in low grow rate, while too high temperatures may cause the microorganisms to die (Ødegaard, 2014). Research done on EBPR at temperature ranging from 5 – 25°C showed that the EBPR efficiency was greater at lower temperatures than at higher temperatures in this range (Helmer & Kunst, 1998). High temperatures (>30°C) has shown to favor the growth of GAOs (Barnard & Scruggs, 2003). Tetrasphaera seems to be more dominant at lower temperatures, such as in Denmark, while Accumulibacter are dominant in tropical temperatures (Barnard, et al., 2017).

### 2.7.2 pH

The competition between GAOs and PAOs are affected by the pH. P–removal increase with higher pH (> 7.25) while low pH will favor GAOs (Barnard & Scruggs, 2003). Norwegian wastewater has in general low alkalinity and pH 7 – 8 which should be preferable for EBPR (Ødegaard, 2014).

### 2.7.3 COD/P ratio

The COD/P ratio do also influence the PAO/GAO competition. It is found that in periods with low COD fraction in the wastewater (such as heavy precipitation in a combined system) GAOs are more prominent. This is because GAOs can store more accumulated carbohydrates (Barnard & Scruggs, 2003). The lager potion of influent rbCOD the PAOs obtain will lead to a larger fraction of PAOs in the sludge. This again leads to a larger percentage of P–removal. The COD/P ratio should be lower than 50 mg/mg to favor PAO growth. The recommended interval should be between 15:1 – 25:1 ( Wang, et al., 2019).

The carbon source may also be of interest. Phosphorus removal stabilized when amino acids, peptone, or yeast extract were added, while GAOs favor polysaccharides, such as glucose (Barnard & Scruggs, 2003).

### 2.7.4 Oxidation-reduction potential (ORP)

The PAO – GAO competition under extended anaerobic conditions, like in side–stream configuration, is partially driven and captured by Oxidation-Reduction Potential (ORP) conditions (Varga, et al., 2020). Low ORP can inhibited the glycogen storage and reducing or eliminating GAOs. PAO have the ability to ferment readily biodegradable substrate under low ORP conditions, and a biomass dominated by PAOs is obtained. When the PAOs are subject to longer anaerobic SRTs as well as low ORP ideal conditions for Tetrasphaera growth occurs. Varga, et al. (2020) did a study where PAO – GAO completion was observed at ORP∼–50 mV and they were still coexisting at ORP∼–100mV. Under extreme low ORP conditions (lower than –150 to –200 mV) GAOs were disappearing and their model showed a more stable P–removal (Varga, et al., 2020).

### 2.7.5 Dissolved Oxygen (DO)

PAOs are obligate aerobes and need oxygen to grow and reproduce. Obligate aerobes are microorganisms which need aerobic environment to meet their energy need (Danielsen, 2018). The aerobic zone can help the PAOs grow a competitive advantage. A DO concentration of 2.5 to 3.0 mg/L has been shown to correspond with greater abundance of PAOs. A large fraction of DO in the RAS (>5.0 mg/L) will lead to oxygen in the anaerobic reactor, which will have a negative impact on the EBPR process (Lilleland , 2019, p. 11).

### 2.7.6 HRT/SRT

Typical recommended Hydraulic Retention Time (HRT) for anaerobic reactor is 0.25 – 1.0 hour to induce the target metabolisms (Coats, et al., 2011). Coats, et al. (2011) showed that HRT could be between 1 – 3 hours and would cause an enrichment of PAOs, specifically *Candidatus Accumulibacter phosphatis*, which would lead to successful P–removal. Too long HRT in anaerobic conditions will lead to emptying of VFA and rbCOD resources before the wastewater reaches the aerobic zone, which can lead to secondary release of P. The EBPR performance is sensitive to changes in the anaerobic nominal HRT.

The ideal Solid Retention Time (SRT) is discussed in the literature, and different sources suggest different SRTs. To complicate the matter further it may seem like the ideal SRT for side–stream configuration differs from conventional design. It has been suggested that the ideal SRT could be found between 8 – 16 days. A research done by Onnis-Heyden, et al. (2019) showed that they achieved lower and more stable effluent P–values with SRT < 10 days (Onnis-Hayden, et al., 2019). Longer SRT lead to GAO dominance and reducing

efficient use of rbCOD for EBPR. This is in line with Bernard & Scruggs (2003) who says that shorter SRTs and avoiding excess anaerobic or anoxic detention times will favor the PAOs. However, literature focusing on VFA fermentation and side–stream configuration for growing Tetrasphaera suggest that a longer SRT could be possible if it's combined with low ORT (Barnard, et al., 2017).

### 2.7.7 Anaerobic/aerobic fraction of biomass

The anaerobic/aerobic fraction of biomass affects the kinetic parameters, including the anaerobic VFA uptake rate (Oehmen, et al., 2010). The literature evolving around anaerobic/ aerobic fraction of biomass do often include nitrogen removal. The fraction given in these articles also depend on an anoxic reactor. Since IVAR is not designed for nitrogen removal an anoxic reactor is not included in its design. To complicate the matter further the anaerobic/aerobic fraction of biomass for side–stream configuration will not be the same as for conventional design. There is therefore difficult to give an estimation of this relationship for the design of a plant like IVAR. According to Dold & Conidi (2019) the anaerobic mass fraction should be in the range 15 – 25 % larger. The paper focused on the importance of the anaerobic zone and discusses the relevance of RAS fermentation and modeling of side–stream EBPR (Dold & Conidi, 2019).

# 3 IVAR SNJ

IVAR Sentralrenseanlegg Nord-Jæren is located in Mesjavik and is the largest wastewater treatment plant in the region. It collects and treat wastewater from Stavanger, Sola, Sandnes, and Gjesdal. The treatment plant has a capacity of 400 000 person equivalents (PE) (IVAR, 2018). Their goal is to turn the wastewater into useful resources by producing biogas and fertilizer. The treatment plant has been updated and expanded several times. In earlier configurations chemical treatment has been used. In order to meet the regulation for the growing population it was decided to change to activated sludge.

It is important to note that the treatment plant is not required to have biological P-removal only to have secondary treatment. IVAR release its effluent water into the sea, which is not sensitive to phosphorus release. The plant was planned with activated sludge as secondary treatment because it has a high removal of organic material. They wanted to take advantage of the opportunity to use EBPR to remove phosphorus and recycle it as a resource for sale. The plant is not designed for nitrogen removal.

The treatment plant has three treatment lines (L1, L2 and L3). Different configurations have been tasted on the lines in earlier assessments of the challenges at IVAR, but an optimized solution has not yet been found.

## 3.1 Description

Figure 4 shows a flow sheet of IVAR treatment plant. The different functions will be explained in the following chapter. A more detailed flow sheet is presented in Appendix 1.

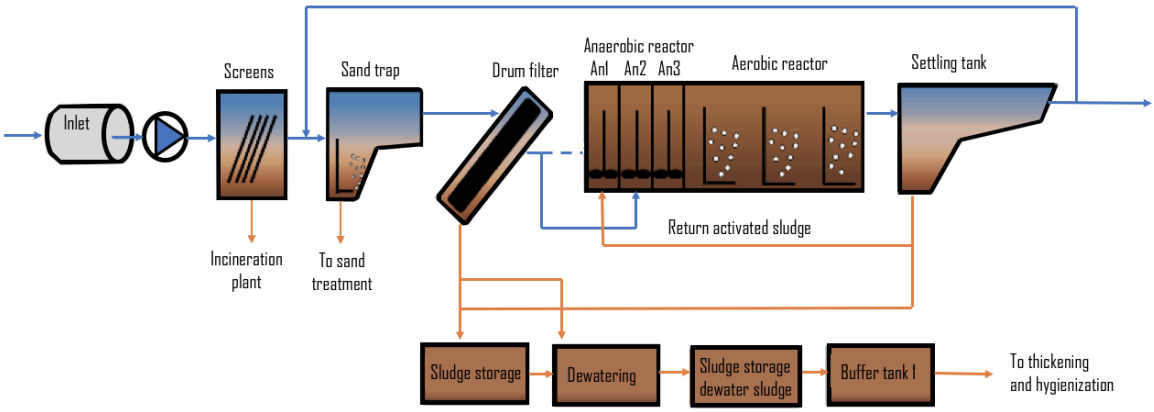



Figure 4: Flow sheet of the process line at IVAR SNJ.

### 3.1.1 Screens and sieves

The wastewater has to pass through a sieve to get into the treatment plant. IVAR has four Huber belt screen EscaMax sieves with a 6 mm opening and a capacity of 1 $m^3/s$ (IVAR, 2018). Its main function is to stop paper, plastic, wet wipes, Q–tips and other coarse material to enter the treatment plant. The wastewater flows through the sieve while the solids remain on the screen. The solids travel upward on the screen elements and are sent to a screw compressor before it goes to the incineration. The reject water from the compressor is sent back to the treatment line (Danielsen, 2018).

### 3.1.2 Sand and fat trap

As part of the primary treatment the water goes into a sand and grease remover. The purpose with the sand and grease removal is to remove sand, gravel, coffee, grease, etc, which may create operational problems in the treatment plant (IVAR, 2018). Air bubbles are added to the tank to make the grease float on the surface while the heavier particles, like sand, falls to the bottom (Ødegaard, 2014, p. 430). The sand is then sucked up with airlift pumps from the bottom of the tank and cleaned in a sand washer before it is deposited. The grease is scraped from the surfaced and sent to the sludge treatment process (IVAR, 2018). IVAR SNJ have one sand and grease trap with a total capacity of 2.8 $m^3/s$. It has a bypass for the surplus flow if the flow capacity is exceeded (Danielsen, 2018, p. 17). The volumes of the sand and grease remover are given in Table 3.

Table 3: Dimensions of the fat and grease trap *(Danielsen, 2018)*.

| DESIGN | SAND | GREASE | TOTAL |
|---|---|---|---|
| VOLUME [$M^3$] | 937 | 513 | 1450 |
| SURFACE AREA [$M^2$] | 247 | 270 | 517 |

### 3.1.3 Drum filter

IVAR has 20 drum filters with a 0.1 mm filter opening (IVAR, 2018). This is classified as a fine mesh (<0.5mm) (Ødegaard, 2014, p. 437). The drum filter at IVAR is mechanical and self–cleansing, and the filter is backwashed every 1 – 2 minute to remove the remaining material on the filter (Danielsen, 2018, p. 18). A drum filter is a surface filter. The water comes into a slowly rotating drum. The water pass through the filter and the particles is kept inside the drum. The sludge blanket on the filter is removed by a high pressure water spray on the outside of the filter and the sludge and backwash water are sent to the sludge treatment (Ødegaard, 2014, p. 438).

### 3.1.4 Biological treatment

IVAR has four reactors for biological treatment, where three of them are anaerobic (An1, An2, An3) and one is aerobic (IVAR, 2018). The dimensions for the reactors are given in Table 4 and other design parameters is listed in Table 5. The dimension is provided by personal communication with engineers at IVAR. The plant is designed as a side–stream configuration, where the influent water enters An2 and the RAS enter An1. This means that the RAS that enters An1 has already been through the system at least once. It exists a possibility to let influent water into An1, however, this is not used in daily operation. An1 has a lower and shorter retention time than An2 and An3 (Danielsen, 2018). HRT for An2 and An3 is equal, as well as the HRT for the aerobic reactor, since they all receive the same flow (Lilleland , 2019). The mixing power used in the anaerobic reactors are given by Table 6. It is possible to have intermittent mixing. This gives the sludge time to settle and makes it possible to have a longer retention time for the sludge than the water. The plant has a possibility to operate with different RAS–flows, and the HRT in An1 correspond to the RAS pumping rate.

Aeration in the anaerobic tank is given by diffusers at the bottom of the tank. The highest density of diffusers is found in the first 1/3 of the aerobic zone, some lower density in the next 1/3, and lowest density in the last 1/3 of the zone (Egeland, 2021).

Table 4: Dimension if the anaerobic reactors and aerobic reactor at IVAR *(Egeland, 2021)*.

| | AN1 | AN2 | AN3 | AEROBIC ZONE |
|---|---|---|---|---|
| VOLUME [$M^3$] | 550 | 950 | 950 | 5500 |
| DEPTH [M] | 9.5 | 9.5 | 9.5 | 9.5 |

Table 5: Design flows at IVAR *(Egeland, 2021)*

| | |
|---|---|
| DESIGN FLOWRATE | 1.5 $m^3$/sec |
| MAX DESIGN FLOWRATE (FILTER AND BIO): | 2.5 $m^3$/sec (0.83 $m^3$/s per module) |
| AVERAGE DRY WEATHER FLOWRATE | 1 – 1.25 $m^3$/sec |
| MAX FLOW RATE TO BIO (2/3 IN OPERATION): | 1 $m^3$/sec per module |
| SURFACE LOAD ON CLARIFIERS | 0.9 m/h at design flow; 1.8 m/h at max flow |

Table 6: Mixing powers in the reactors *(Egeland, 2021)*.

| ANAEROBIC ZONES | MIXING POWER |
|---|---|
| AN1 | 10 w/$m^3$ |
| AN2 | 6 w/$m^3$ |
| AN3 | 6 w/$m^3$ |

### 3.1.5 **Settling tank**

Each process line in IVAR has a rectangular settling tank. The settling tank volume is given in Table 7. The sludge is collected from the sludge pockets and send back to An1 as RAS or sent to sludge treatment as surplus sludge (Danielsen, 2018, p. 23). The settling tank can be driven with intermittent settling so that the sludge can thickens before it is sent as RAS.

Table 7: Design of settling tank *(Egeland, 2021)*.

| | |
|---|---|
| VOLUME [M3] | 2200 |
| AREA [M2] | 500 |
| DEPTH [M] | 4.5 - 5 |

### 3.1.6 Sludge treatment line

In IVAR the surplus sludge is sent to sludge treatment. The sludge treatment at IVAR consist of a thickener, goes through a strainpress to anaerobic digestion before it is dewatered and sent to thermal drying. The sludge treatment is not within the scope of the project and is therefore not described in detail.

## 3.2 Performance

Several studies have been done to show the performance at IVAR SNJ. The performance parameters given in this chapter is based on the test done by Lilleland at IVAR in the period of January – April 2019 (Lilleland , 2019). All the tests are done on L1.

### 3.2.1 Operation condition

The temperature under the experiment period was 8 – 12°C and the pH was 6.5 – 7.6 (Lilleland , 2019). The temperature and pH should not have a great impact on the process in line with the theory for EBPR. The average COD/P–ratio range between 17 – 33 mg/mg, which can indicate a coexistence between PAOs and GAOs which favor PAO growth. The HRT found by Lilleland was 0.25 – 0.99 hour for the anaerobic zone, and 0.74 – 1.25 hour in the aerobic zone, which is within the recommended interval. Average inflow was given as $Q_{in}$ = 2300 $m^3/h$ and the average RAS flow was given as $Q_{RAS}$ = 800 $m^3/h$.

### 3.2.2 Sludge settling properties

The sludge settling characteristics is given as an SVI ranging from 79 – 100 with an average ≈ 90 mL/g. It thickens up to 12 – 15000 mg/L SS in the tank (Lilleland , 2019). According to the theory these values indicate that the sludge has good settling properties.

### 3.2.3 P-removal efficiency

Table 8 shows the inlet and outlet values from IVAR. The values are calculated based on data from 24 hours composite samples taken once a week.

Table 8: IVARs performance in the period January – April 2019 *(Lilleland , 2019)*.

| | INLET | OUTLET |
|---|---|---|
| TOTAL P [MG/L] | 4.5 | 2.28 |
| PO4-P [MG/L] | 2.1 | 1.95 |
| TS [MG/L] | 236 | 25 |
| VSS/TSS [MG/MG] | 0.87 | 0.77 |
| COD/TS [MG/MG] | 1.23 | 1.25 |
| COD/VSS [MG/MG] | 1.41 | 1.62 |
| PO4-P/TS [MG/MG] | 0.010 | 0.021 |
| PO4-P/VSS [MG/MG] | 0.012 | 0.028 |

Base on Table 8 the total P in and out of the treatment plant was calculated. The result is shown in Table 9. The removal efficiency in the period was calculated to be 44 %.

Table 9: Calculated phosphorus in and out of the treatment plant *(Lilleland , 2019)*.

| | |
|---|---|
| $P_{IN}$ [KG/D] | 391.50 |
| $P_{OUT}$ [KG/D] | 215.76 |
| $P_{REMOVED}$ [KG/D] | 175.74 |

Lilleland found that the phosphorus concentration in the influent was 1.3 mg/L and the effluent was 1.08 mg/L (Lilleland , 2019). However, a batch test done in the laboratory showed that the release and uptake of $PO_4$–P in the anaerobic and aerobic reactor was close to zero after 3 hours anaerobic, and between 3 hours and 20 hours in aerobic conditions. This will indicate good potential for P–removal.

The result from her investigations shows that the fermentation in An1 works well. She observed an increase in VFAs as well as an increase in alkalinity. The VFA yield after 67 hours was approximately 384 mg/L (Lilleland , 2019). The study did not look into which PAOs were percent in the fermentation.

Lilleland also observed the P concentration in the reactors and settling tank. Her observation showed that the highest concentration of P was found in reactor An2. In An3 she found more P–uptake than P–release. She also observed that the concentration of P in the effluent water was higher than the concentration out of the aerobic reactor (Lilleland , 2019).

## 3.3 Challenges

As seen by the performance parameters IVAR has a P–removal effect at 44 %. Some challenges are detected on the performance parameters both in the anaerobic reactors as well as in the settling tank.

### 3.3.1 Anaerobic reactor

Lilleland detected uptake of P in the An3. This indicates that oxygen is found in the reactor and the reactor is no longer anaerobic. This may be caused by back–mixing between An3 and the aerobic reactor.

The highest P–release was expected to be found in An1 where the fermentation happens, and not An2. One could expect the highest P–release to be found in A1 which may indicate that this process also can be optimized even with the observed increase in VFAs.

### 3.3.2 Settling tank

The P concentration in the effluent water out of the settling tank is higher than the concentration into the tank. This indicates that the EBPR process work, but the settling tank is the main concern. The increase in phosphorus in the settling tank may be caused by secondary release. This can happen if the PAOs stay in the tank for too long. The long residence time in the tank results in anaerobic conditions. With the absence of VFA the phosphorus is released at a slow rate for the PAOs to maintain the cells (Barnard & Scruggs, 2003).

There are several challenges in the settling tank that may cause this problem. One of which may be low capacity on the sludge scrapers at the bottom of the settling tank. A low capacity will cause the sludge to stay in the settling tank long enough to cause secondary release. Low capacity of the scrapers would also limit the RAS pumping. If the pumping rate is too high compared to the amount of sludge in the hoper the RAS becomes diluted.

Unfavorable inflow conditions into the settling tank may also cause long resident time. Turbulence at the inflow section will make the sludge use longer time to settle and the sludge which will make the sludge settle far from the inlet. The combination of poor hydraulic and low capacity scrapers results in extended retention time.

# 4 The lab-scale pilot

The lab–scaled pilot is a 1:100 model of IVAR SNJ made to improve the EBPR treatment process for P–removal. One centimeter in the pilot is equal to one meter in the full–scaled plant. A flow sheet of the lab-scaled pilot is shown in

Figure *5*.

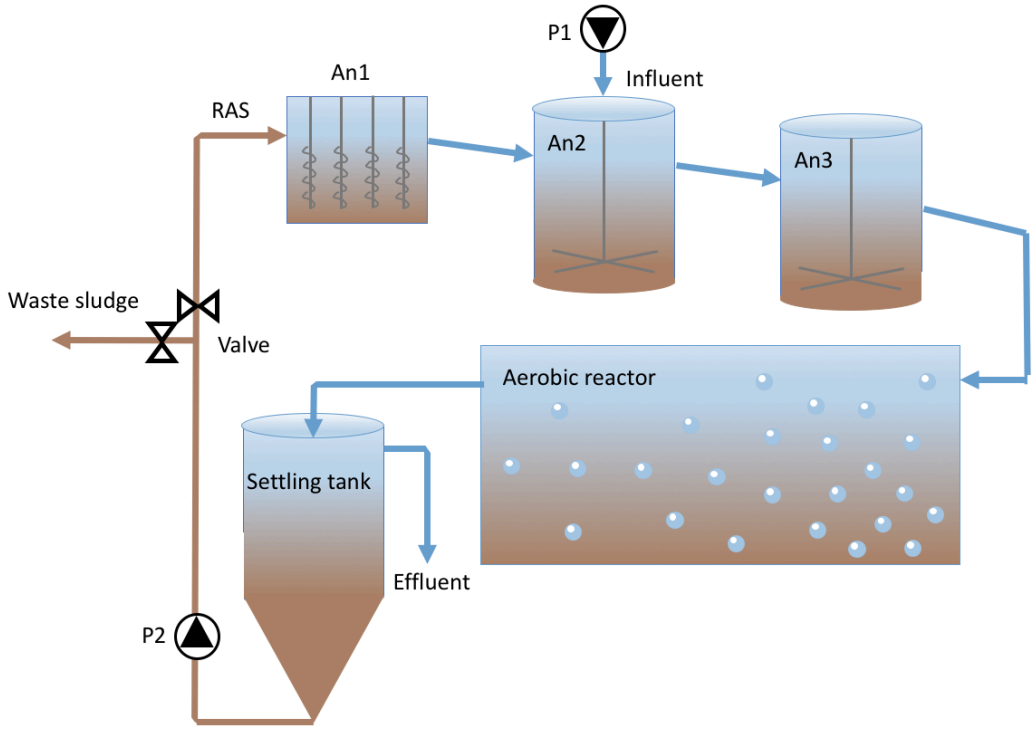



Figure 5: Flow sheet of the lab-scaled pilot.

Wastewater from the street in Trondheim will be used in the project work. As mention in Chapter *2.1 Norwegian wastewater characteristics* the wastewater at coastal areas can be similar. However, the wastewater in Nord-Jæren have a percentage of salt due to infiltration of seawater. Additional 10 % of seawater will be added to the wastewater used in the experiment.

Figure 6 shows a picture of the lab-scaled pilot. All pictures of the pilot found in this report show the lab–scaled pilot with tap water, since the project has yet to be started. The pilot includes three anaerobic reactors, on aerobe reactor, a circular settling tank with return activated sludge flow, two pumps, and a valve to control RAS and waste sludge flow. Primary treatment and sludge treatment are not a part of the lab–scaled pilot. A description of the lab–scaled pilot will follow.

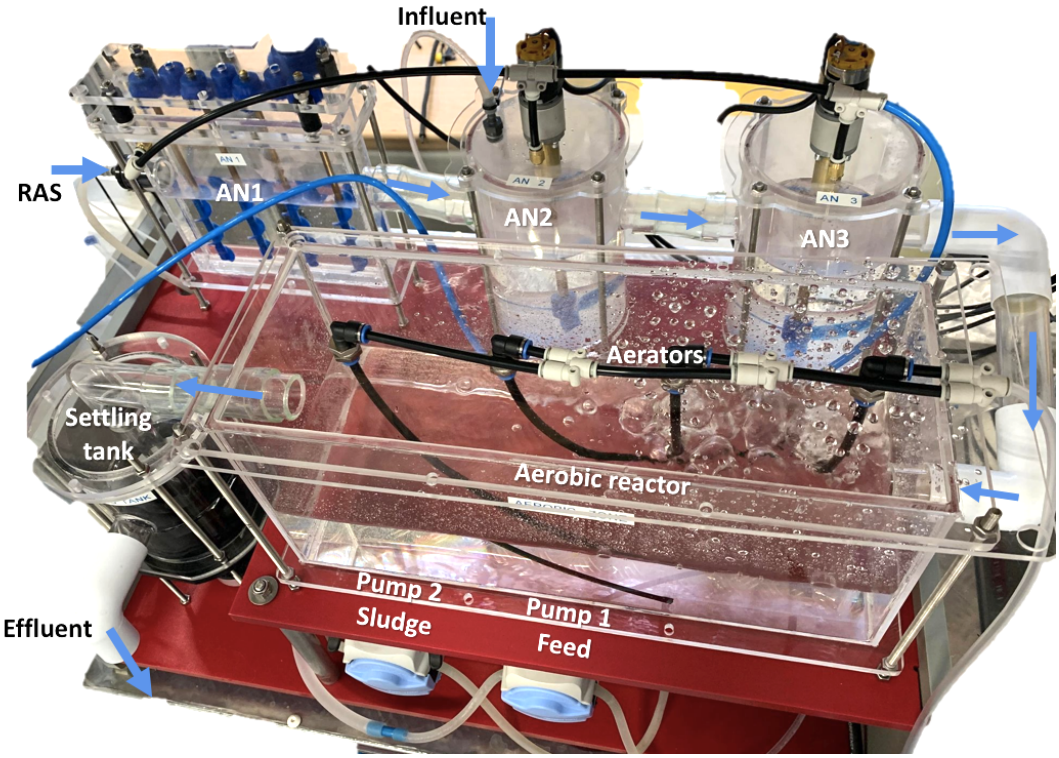



Figure 6: Picture of the lab-scaled pilot with names on each component.

### 4.1.1 Primary treatment

The primary treatment is not included in the lab–scaled pilot but will be done at the wastewater lab. The raw wastewater comes from the street into Tank A before it is filtered in a Saltness filter and returned to Tank B. This is shown in Figure 7.

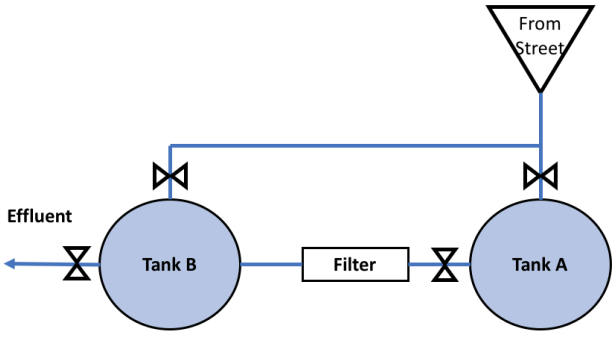



Figure 7: Flow sheet of primary treatment at the lab.

The wastewater for this project will go from Tank B to a storage where seawater is added to mimic the wastewater in Nord Jæren.

### 4.1.2 Anaerobic and aerobic reactor

Figure 8 shows the An1, An2 and An3. The stirring mechanism is controlled through a control panel. The stirrers are specially made for this pilot with 3D printing. All four stirrers in An1 are connected to the same motor and will therefore stir at the same speed. Intermittent stirring is possible. An2 and An3 is connected and will be stirred at the same speed and with the same frequency. The 3D printed stirring parts can be replaced if the stirring conditions are not satisfying. The stirring in the lab–scaled pilot should be enough for the sludge not to settle, but not so fast that it causes foaming.

What distinguish the lab–scaled pilot's anaerobic reactors from the full–scale treatment plant is the ability to add nitrogen gas. The gas can be added to achieve complete anaerobic conditions with no oxygen, is adjustable and possible to turn on as needed. This makes it possible to adjust the $O_2$ content in the anaerobic reacts.

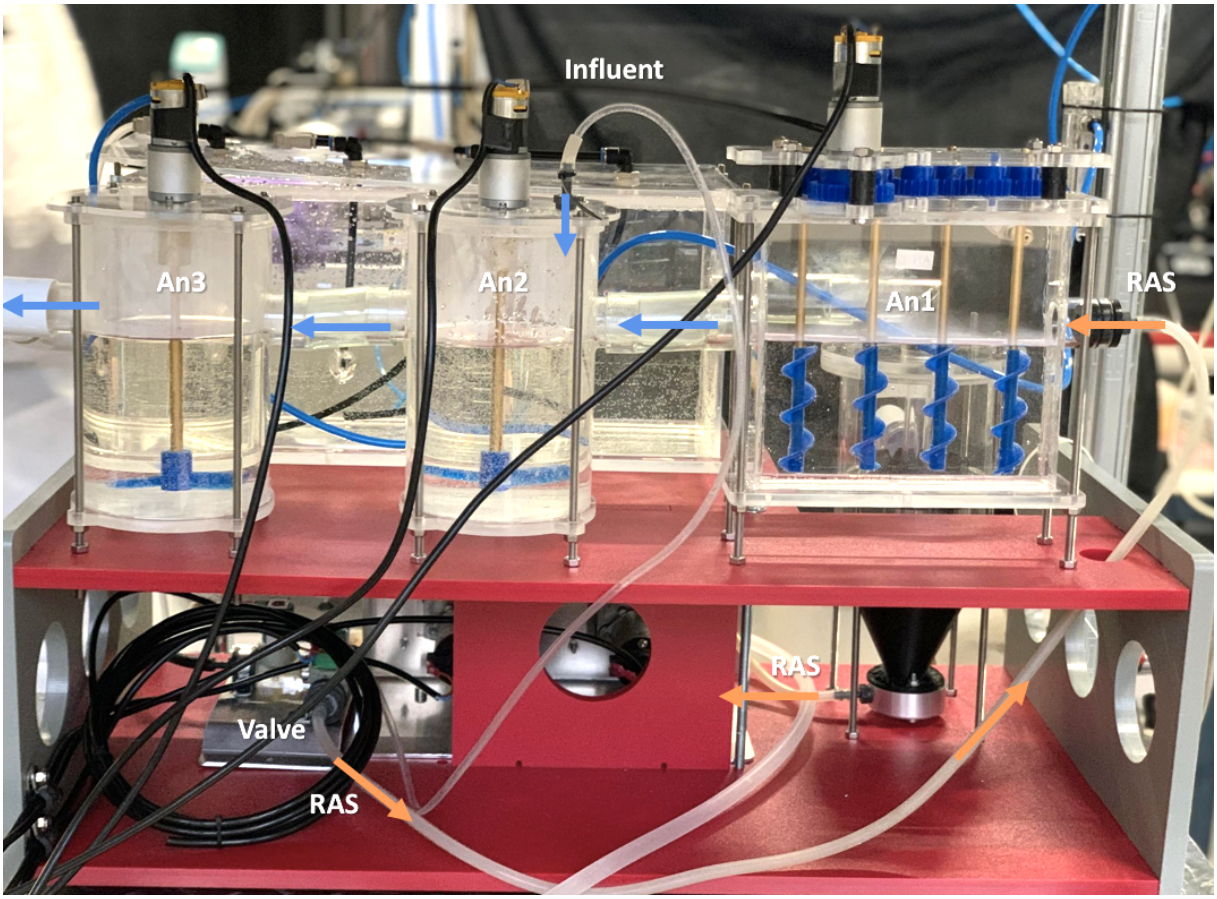



Figure 8: Picture of the anaerobic reactors in the lab-scaled pilot.

Table 10 shows the dimensions of An1, An2, An3 and the aerobic reactor. More information about the design can be found in Appendix 4 and 5. The configuration for An2 and An3 are the same.

Table 10: Dimensions of the reactors in the lab-scaled pilot.

| | LENGTH [CM] | WITH [CM] | HIGHT [CM] | HIGHT INN/OUT [CM] | CALCULATED VOLUMES ≈ [CM$^3$] |
|---|---|---|---|---|---|
| AN1 | 18.39 | 2.9 | 17.1 | 9.1 | 485 |
| AEROBIC | 40.2 | 14.4 | 18.3 | 9.3 | 5200 |
| | DIAMETER [cm] | | | | |
| AN2 | 10.9 | | | 10 | 930 |
| AN3 | 10.9 | | | 10 | 930 |

The reactors are installed with adjustable heights in relation to each other. The water flows from one reactor to the next by means of gravity. This gives the possibility to investigate the influence of back mixing in the pilot.

Figure 9 shows a closeup of the aerobic chamber. It is possible to see how the aerators blow oxygen at the bottom of the tank. As in the full–scaled pilot aeration is introduced in the first part of the reactor.

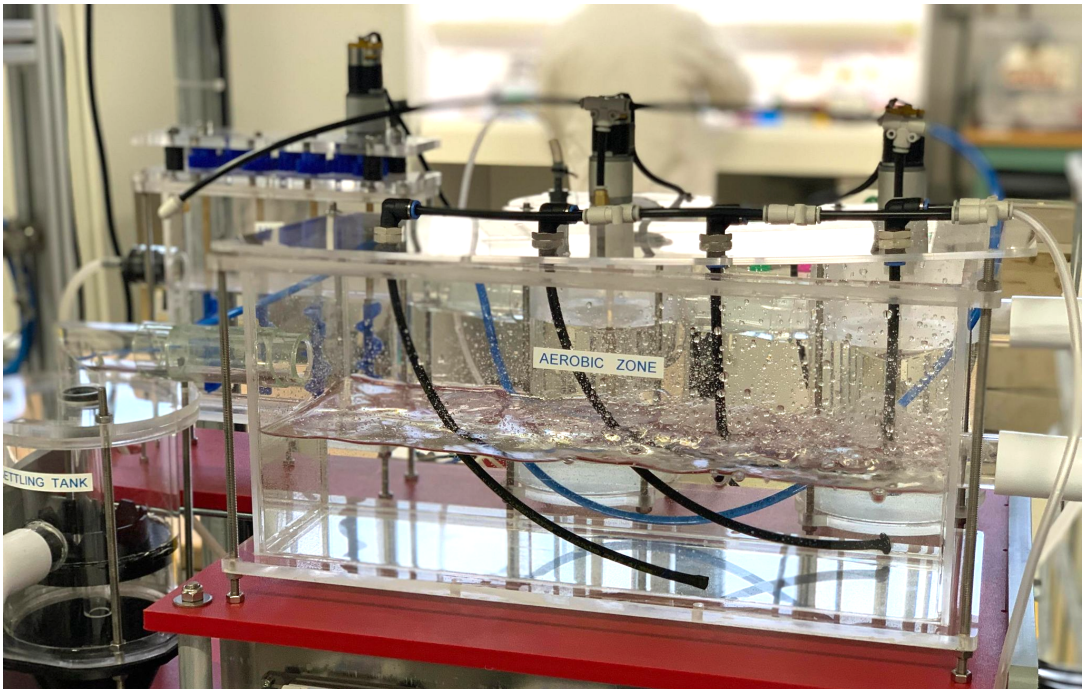
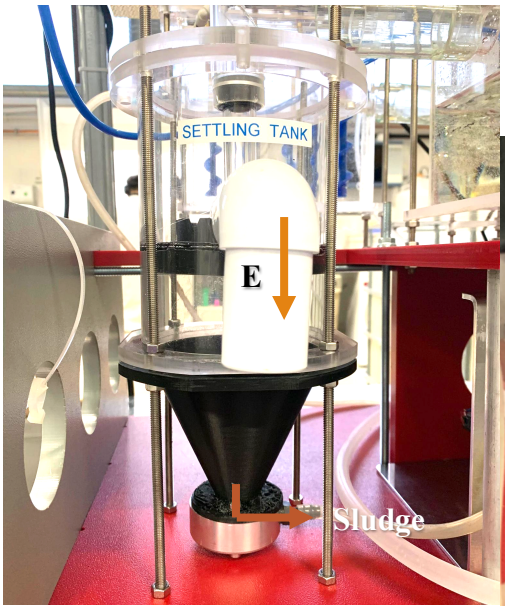



Figure 9: Picture of the aerobic reactor of the lab-scaled pilot.

### 4.1.3 Settling tank

The settling tank of the pilot has a different design than the one at IVAR. In the lab–scaled pilot a circular sedimentation tank has been introduced. This is to overcome the hydraulic problematic and the long retention time that has been observed in the full–scaled plant. A closeup of the settling tank is shown in Figure 10. The cleaned effluent water will go through the white pipe in picture while the sludge will settle at the bottom of the tank and transported to the valve in Figure 11. The valve is connected to the control panel which gives it several different operational modes.



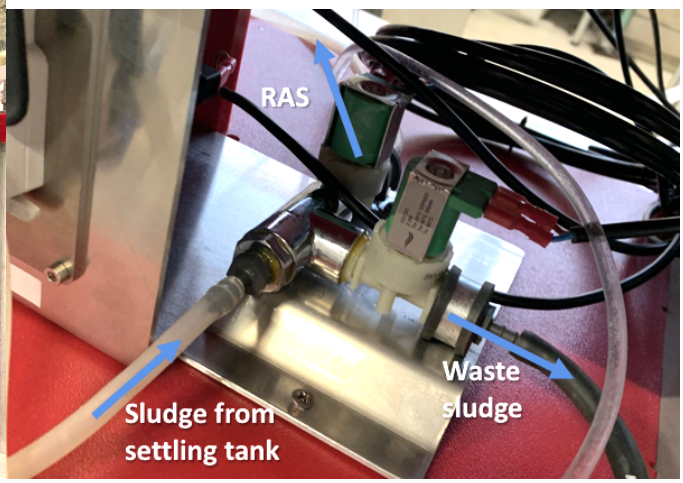




Figure 10: Picture of settling tank in the lab-scaled pilot.

Figure 11: Picture of the valve for waste sludge and RAS

The dimensions of the settling tank are given in Table 11. More detailed description can be found in Appendix 5.

Table 11: Dimensions of the settling tank in the lab-scaled pilot.

| | DIAMETER [CM] | HIGHT CONE [CM] | HIGHT CONE TO INLET OUTLET [CM] |
|---|---|---|---|
| SETTLING TANK | 11.4 | 9.87 | 6.2 |

## 4.2 Control systems

The lab-scaled pilot can be controlled by a control system. Figure 12 shows a picture of the system where several operation modes are available. Pump 1 (P1) refers to the feed pump, while Pump 2 (P2) pumps the sludge return and waste. An1 is the stirring mechanism in the fermentation reactor An1, while An2–3 is for the two other anaerobic reactors. The valve controls return sludge and waste sludge. The valve overrides the sludge pump, to ensure pumping every time the valve is open.

The lower part of the panel is used to control the speed of the two pumps and the stirring in the anaerobic reactors. The upper part of the panel is dedicated to control the frequency, which can allow the pump and siring mechanisms to operate intermittently. This can be altered from continuous operation to an on/off frequency down from a couple of seconds up to several hours. This gives a huge flexibility in operation modes. The datasheet for the panel is attached in Appendix 3. This configuration makes it possible to manipulate flowrate and speed to match the full–scaled plant and go beyond the limitation of the pump and valve while increasing the flexibility of the configuration. A parts list of different components found in the control panel of the lab–scaled pilot is given in Appendix 6.


Figure 12: Pictures of control panel for the lab-scaled pilot.

The pump that is used is a Peristaltic pump by RC Components. The pump specification is given in Appendix 2. The pump capacity is listed in Table 12. The capacity will also depend on the size of the tube. The sludge pump is depending on the valve.

Table 12: Pump capacity lab-scaled pilot.

| | NOMINAL FLOW RATE [ML/MIN] | | | | |
|---|---|---|---|---|---|
| TUBE | **0.8 mm** | **1.6 mm** | **3.2 mm** | **4.8 mm** | **6.3 mm** |
| 60 RPM | 4.6 | 16 | 64 | 140 | 224 |
| 100 RPM | 7.7 | 2.8 | 108 | 235 | 375 |
| 150 RPM | 12 | 42 | 162 | 352.5 | 562.5 |

## 4.3 Design flow

The design flow rate is based on the design flow for IVAR SNJ. The design flow from IVAR was given in Table *5*: Design flows at IVAR and 1 $m^3/s$ is the given max design flow for An2–3. Since the lab–scaled pilot is in scale 1:100 the design flow should be $10^6$ times smaller than the design flow of the full–scaled plant. This can be calculated as:

$$1\frac{m^3}{s} * 60\frac{s}{min} * 1000\frac{L}{m^3} * 1000\frac{mL}{L} * 10^{-6} = 60\frac{mL}{s}$$

The design flow for the lab–scaled pilot is 60 mL/s.

## 4.4 Possible challenges

Experience with a pilot in such a small scale is not widely common practice. Therefore, it can be difficult to point out possible challenges with drifting a pilot in such a small scale. 1 cm in the lab–scale pilot corresponds to 1 m in real life. For volumes and flows this corresponds to a $10^6$ reduction. There are generally three things that are considered to cause a problem when drifting the lab–scaled pilot. The first is problems with clogging. Since everything is of a much smaller scale it is more prone to clogging. Areas that could be expected to experience this is the bottom of the sedimentation tank, where the sludge will thicken, and pipes of small dimension. The aeration diffusers can also be a weak point for clogging. Changed viscosity and formation of foam can have much larger impact in the lab–scaled pilot and affect the processes to a greater extent. Processes and forces along the walls in the pilot can lead to complications. Formation of biofilm inside pipes can have greater consequences in a smaller pilot than the plant and contribute to reduced capacity. Other challenges may occur when the testing of the lab–scaled pilot starts.

# 5 Discussion

The aim of this project is to use the lab–scaled pilot to look at the processes in IVAR SNJ in more controlled environments. The unconventional small scale of the pilot may lead to challenges, but the main advantage of this small scale is full control over the volumes and flows. The aim is to get a broader understanding of how the challenges at IVAR can be solved.

The main challenges at IVAR is the settling tank. The lab–scaled pilot is design with a circular settling tank to avoid the challenges with the settling found at IVAR. The first step of the research will be to document how ideal settling can influence the treatment process at IVAR by running the lab–scaled pilot at the same operating values as the real treatment plant use today. An assumption is that the operating parameters are adjusted to cope with the challenges in the settling tank. The next step will therefore be to adjust the parameters to accommodate the new settling properties. The pilot allows a wide range in operation opportunities with different speeds and intermittent frequencies on the stirring mechanisms, pumping and return sludge. This can be used to find the optimal parameters for EBPR at IVAR.

The second challenge is back mixing. The lab–scaled pilot is designed to avoid back mixing by placing the reactors at different heights and letting the water travel between the reactors by gravity. It is also possible to put all the reactors at the same height to get a closer understanding of how much influence the back mixing has on the process. The possibility to add nitrogen gas to adjust the $O_2$ content in the anaerobic reactors makes it possible to achieve total anaerobic conditions. This makes it possible to eliminate other sources of oxygen than back mixing. An example of an oxygen source could be the influent water.

The pilot work will start by performing a test run with tap water. Sludge must be ordered from IVAR to get the right conditions for the experiments. After this the project work can start. The project work will be separated into the following steps:

Step 1: Test the EBPR performance in the tank with good settling. How does the effluent values look when the settling properties are good?

Step 2: Adjust operation parameters to accommodate the good settling.

Step 3: If needed: other adjustments to the process. Find the effect of variation in the water quality to see how robust the treatment process is. Look at the effect of back mixing. Improve fermentation in An1.

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