CONSULTING ENGINEERS

AQUA-K PVA-GEL STUDY
INVESTIGATIVE STUDY

65 Crown Road Pukekohe
Auckland

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TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Aqua-K NZ Limited engaged GWE to conduct an investigative study on MBBR PVA-Gel technology used in the existing MBR pilot plant in Paerata Business Park near NIG Nutritional Ltd milk processing dairy plant.

The totalised wastewater volume recorded from the Aqua-K plant meter shows that the daily total wastewater volume to the wastewater treatment plant was, on average, about 19.3m^3/d throughout the trial period.

The wastewater strength is generally weak at the start of the week and increases over the mid-week. The wastewater loads trend is similar to the wastewater concentration trend. This was expected since wastewater flows have been generally consistent over the trial period.

The pilot study results showed high-quality treated effluent results. The effluent organic and nutrient concentrations were consistently low.

During the pilot plant study, BOD and ammonia loading rate was about 18.7kg/m^3.d and 0.44kg/m^3.d, respectively. This was within the supplier's performance specification. Nitrate loading was 0.982kg NOx/N m^3/d, within the design loading between 1.0 – 3.0kg NOx/N m^3/d, according to the PVA-Gel supplier.

In summary, the PVA-Gel and MBR reactor achieved high treated effluent quality results, and lower sludge yields have been observed based on the results, compared to that typically observed in other activated sludge processes.

From the plant operation perspective, the only observation made was the exceptionally high MLSS concentration compared to other activated sludge process including MBR.

GWE also assessed the air requirement based on the activated sludge production, and it was found that the theoretical aeration requirement for the pilot plant closely matched the observed aeration demand.

1 INTRODUCTION

Polyvinyl Alcohol-Gel (PVA-Gel) technology is used in other countries for municipal and industrial wastewater treatment plants, and studies have been conducted to test PVA-Gel's performances. However, PVA-Gel technology has not been trialled full-scale in New Zealand.

Therefore, Aqua-K NZ Limited engaged GWE to conduct an investigative study on PVA-Gel technology used in the existing MBR pilot plant in Paerata near NIG Nutritional Ltd dairy processing plant.

GWE conducted a two-week pilot study and collected wastewater and sludge samples from various locations around the plant. The plant was operated by Aqua-K operators as per their procedures.

2 LITERATURE REVIEW

2.1 DESCRIPTION OF THE PVA-GEL MEDIA

The activated sludge process can be broadly divided into suspended growth and attached growth processes. The suspended growth process has microorganisms suspended in a liquid phase called activated sludge. In contrast, the attached growth process has microorganisms attached to the media and forms a biological film.

Unlike the typical fixed film attached growth process, the media is suspended in activated sludge in the Moving Bed Biofilm Reactor (MBBR) technology which combines both suspended growth and attached growth processes.

The PVA-Gel technology is essentially a type of MBBR process. However, unlike the conventional MBBR system, the beads are typically utilised at volumetric packing ratios of 5 to 15% as opposed to packing ratios of 50 to 70% for typical MBBR (Levstek M, 2010).

Due the gel's size and performance, PVA-Gel can achieve a comparably lower packing ratio. Unlike normal packing material, the PVA-Gel is a 4mm bead with a micropore network diameter of 20 μm (Kuraray Aqua Co., 2023).

Based on a research study *Appendix E: ITT Roorkee a Report on Pilot Scale Studies on Nutrient Removal PVA-Gel Based IFAS Process*, it is understood that the media has a high-water content due to its extensive porosity and high surface area (effective specific surface area of 2,500m^2/m^3). This high porosity allows for favourable oxygen and nutrient conditions for the bacteria to grow inside the beads. Therefore, the bacteria are shielded from predation (Kuraray Aqua Co., 2023).

Figure 1 shows the state of the PVA-Gel after being in operation for one month.

Figure 1: PVA-GEL image before and after one month inside a bioreactor (Kuraray Aqua Co., 2023)

2.2 LOWER SLUDGE PRODUCTION

Every living organism requires carbon as an energy source to reproduce and function properly. Organisms also require other inorganic nutrients such as nitrogen, phosphorus, sulphur, potassium, calcium, and magnesium.

Microorganisms are generally considered one of the simplest living organisms. However, their growth mechanisms are too complex to calculate the growth rate based on multiple carbon sources and nutrients using first principle mathematics.

Instead, engineers have predicted the growth rate based on the mass of microorganisms produced per mass of substrate utilised. This mass of microorganisms is represented by Volatile Suspended Solids (VSS), whereas different types of carbon sources are represented as Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD).

Usually, a conventional activated sludge plant is designed based on an empirical relationship based on kg of VSS generated per kg of COD consumed.

This empirical relationship is derived from selecting a substrate (glucose) to estimate biomass yield and oxygen requirements from stoichiometric equation or bioenergetics. Therefore, the VSS generation in terms of COD consumed can be accurately predicted without lab or pilot testing (Tchobanoglous G, 2002).

In contrast to the activated sludge process, the MBBR process, i.e. PVA-GEL performance, is often biofilm diffusion limited. Therefore, substrate removal rates are a function of diffusion rates, DO concentrations and substrate concentrations at various locations in the biofilm. Therefore, unlike activated sludge, estimating biomass yield is difficult without properly understanding the biofilm activity, and currently, based on our research, no such study is available. As a result, most MBBR processes are designed based on typical organic and nutrient removal rates.

Although MBBR lacks the empirical formula to compare it against the suspended growth processes, the use of the MBBR process dates back to the 1940s with Hays and Griffith process. Over the years, many studies have been conducted, and one of the advantages claimed for MBBR is lower sludge production.

2.3 PAST PVA-GEL STUDIES AND GAP IN THE STUDY

PVA-Gel technology studies have been conducted by two top universities, namely the University of Ljubljana , and the Indian Institute Technology (IIT) Roorkee.

2.3.1 ESTIMATION OF THE SPECIFIC SURFACE AREA (UNIVERSITY OF LJUBLJANA)

This study was based on operating two pilot plants as described below.

- First system consisted of a lab-scale reactor for studying the nitrification process
- Second system was a pre-denitrification pilot plant

Based on the observations, both the systems were calibrated with the GPS-X modelling tool (Hydromantis). The results indicated an effective specific surface area of 2,500m^2/m^3 versus a specific surface area of 1,000m^2/m^3 based on the outer surface of the gel beads. Refer to *Appendix F: Estimation of The Specific Surface Area for a Porous Carrier*.

(Levstek M, 2010)

2.3.2 A REPORT ON PILOT SCALE STUDIES (INDIAN INSTITUTE OF TECHNOLOGY, ROORKEE)

These pilot plant studies were conducted using raw sewage and operated under all seasonal conditions.

The 120Lit/d pilot plant consisted of one aeration tank with PVA gel, an anoxic tank, a post aeration tank and a final settling tank.

The system was operated under four different conditions:

- Start-up phase
- 6hr Hydraulic Retention Time (HRT)
- 5hr HRT
- 4.4 hr HRT

Note that the HRTs are based on total reactor volumes that include PVA-Gel aerobic tank, anoxic tank and oxic tank.

The results showed the average BOD, TSS and TN concentrations in the effluent were less than 10mg/L under all operating conditions. However, no observations were made on sludge yields.

(Kazmi, 2018)

2.3.3 GAP IN PAST STUDIES

The above studies were aimed at investigating the media's effective surface area and nutrient removal performance. However, a detailed investigation of treatment performance and sludge production has yet to be further investigated in a New Zealand-specific context.

2.4 LITERATURE REVIEW SUMMARY AND PURPOSE OF THE STUDY

Based on the literature review, the PVA-Gel process is expected to generate less sludge than conventional activated sludge while maintaining good effluent quality.

Naturally, this study aims to investigate the low sludge yields claimed by the PVA-Gel supplier Kuraray.

3 PILOT PLANT SET UP AND OPERATION

3.1 TESTING SITE OVERVIEW

The pilot plant site is located at 65 Crown Road Pukekohe as shown in the Figure below.

Figure 2: Pilot Plant Site Location (Auckland GIS Map)

The plant receives wastewater from NIG Nutritional Ltd dairy processing plant, and wastewater from several commercial facilities and about 20 homes.

3.2 AQUA-K PILOT PLANT PROCESS FLOW DIAGRAM (PFD)

Aqua-K Limited has integrated the PVA-Gel technology to work in conjunction with the Membrane Bioreactor (MBR) process. A process flow diagram of the pilot plant by Aqua-L Ltd is shown in Figure 3 below.

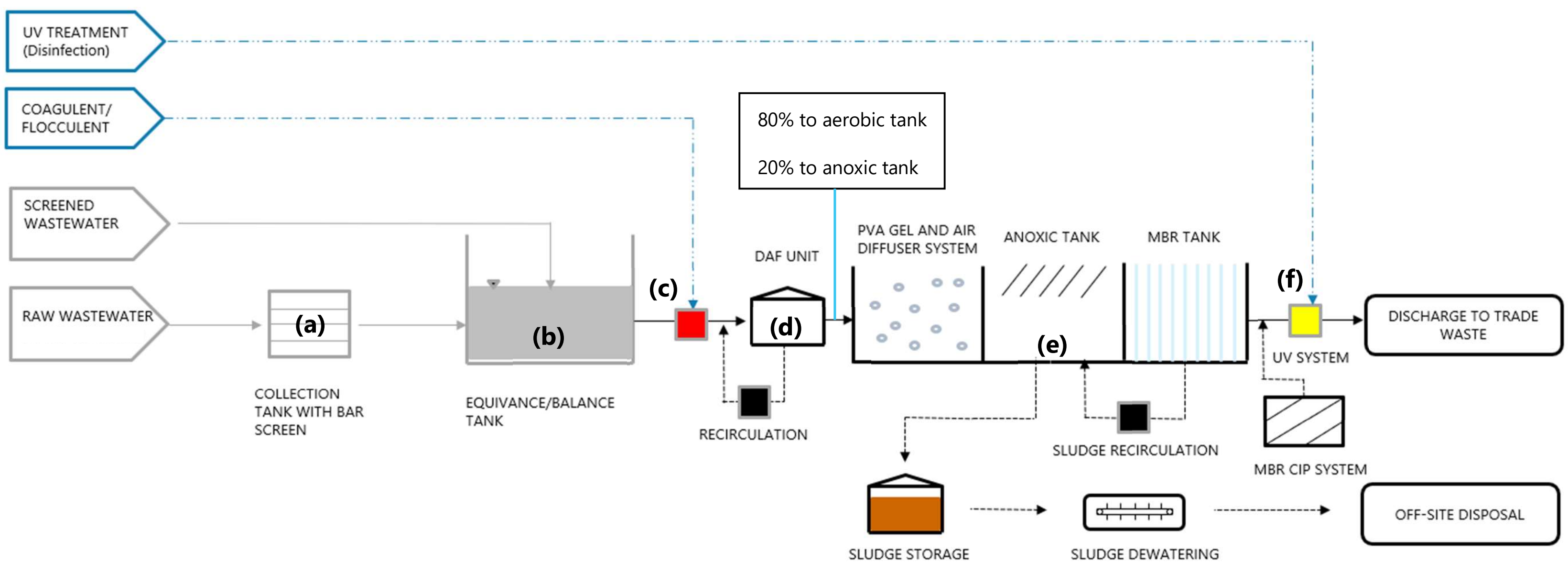

Figure 3: Aqua-K PVA-Gel Pilot Plant PFD

3.3 PROCESS DESCRIPTION

a. Collection Tank with Bar Screen

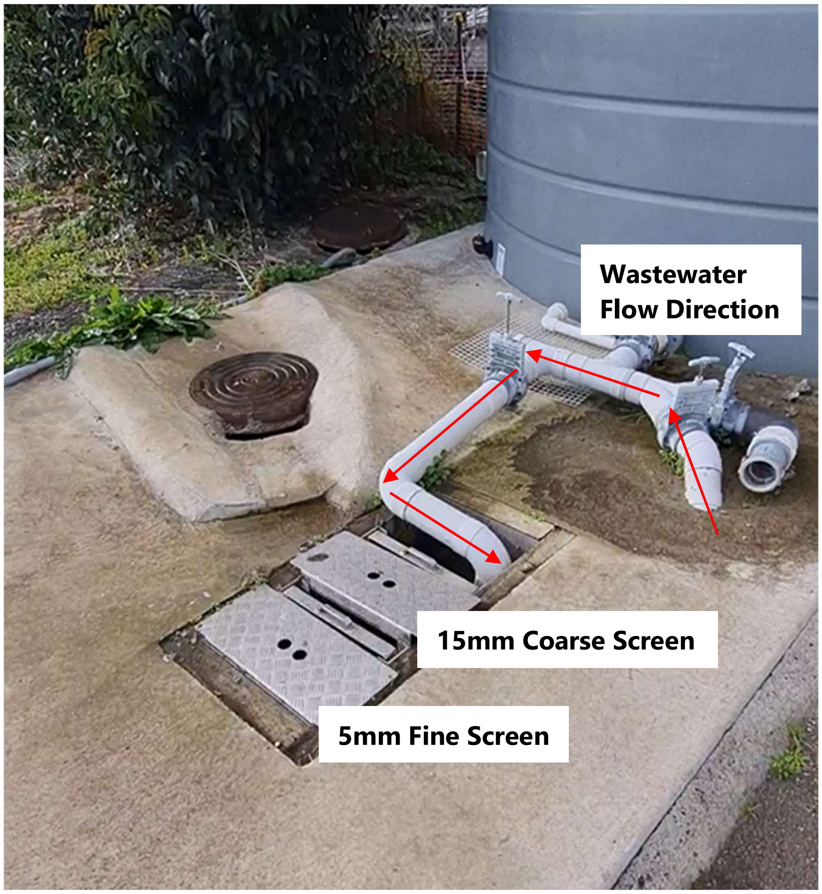

Figure 4: Coarse and Fine Screens

Wastewater is pumped to a mechanical bar screen to remove large debris from wastewater. Two screens are installed in series, with a 15mm primary screen upstream and a 5mm secondary screen installed downstream as shown in Figure 4. Generally, MBR vendors recommend 5mm primary and 2mm secondary screens combination.

Screened wastewater gravitates into a balance tank.

(Aldee, 2020)

b. Balance Tank

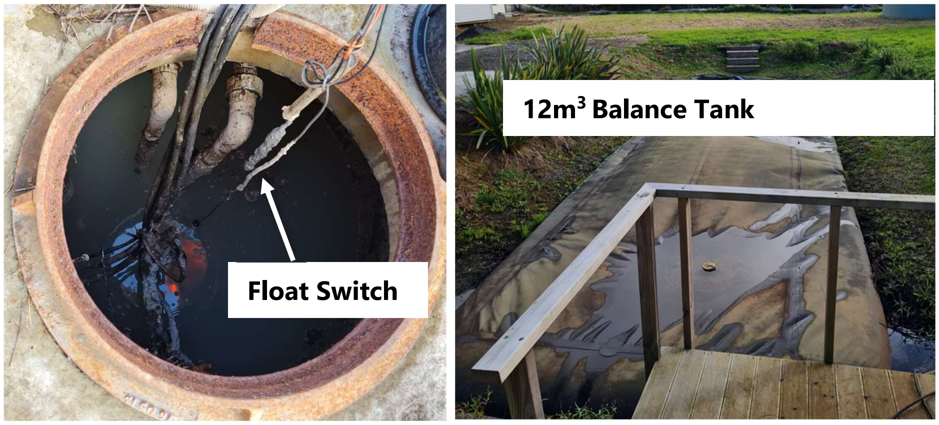

Figure 5: Pump Station (Left) and Balance Tank (Right)

The Balance tank system comprises a 12m^3 bladder wastewater storage tank and a wet well with two submersible pumps, each operating at about 1.5m^3/hr and controlled by the level switch in the wet well.

Screened wastewater is pumped to the Dissolved Air Floatation (DAF) tank.

(Aldee, 2020)

c. Chemical dosing (Alum, PAC, Hydrochloric Acid and Bicarbonate)

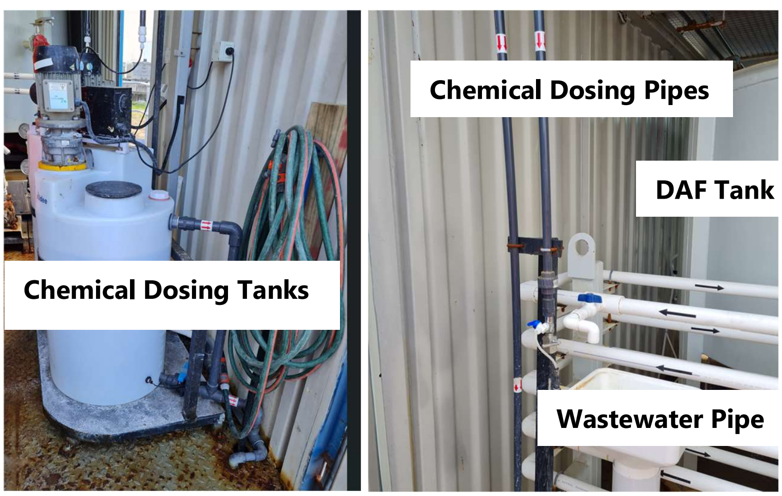

Figure 6: Chemical Dosing Tanks (Left) and Dosing Pipes (Right)

To enhance DAF performance, wastewater is dosed with alum and Polyaluminium Chloride (PAC) to coagulate and flocculate organic materials, solids, oil and grease.

Also, wastewater is dosed with hydrochloric acid or caustic soda for pH correction before pumping to the DAF tank.

(Aldee, 2020)

d. Dissolved Air Floatation (DAF) Unit Operation

Figure 7: DAF Tank Side (Left) and Top (Right)

The DAF tank reduces organic matter, suspended solids, oil and grease. The clarified wastewater overflows to the next treatment process via gravity.

e. PVA Gel and Membrane Bioreactor (MBR)

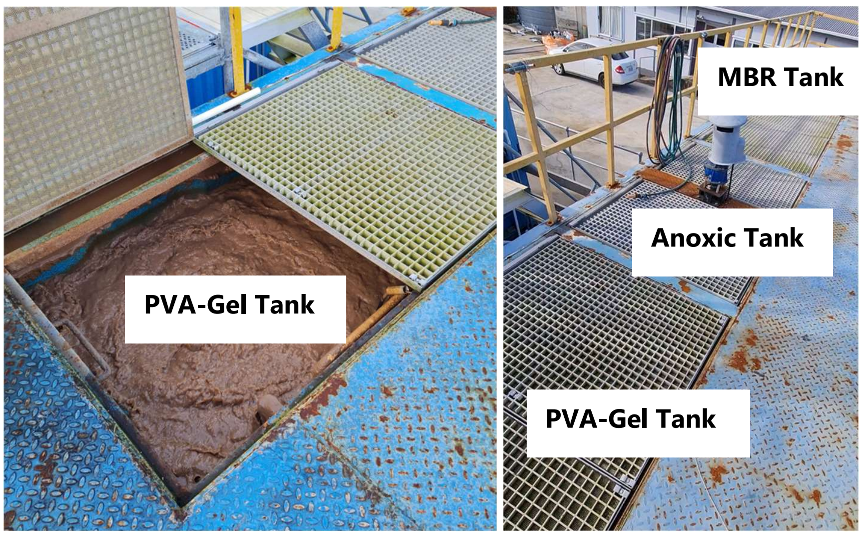

Figure 8: PVA-Gel and MBR Tanks

The biological reactor consists of PVA-Gel, anoxic and a MBR tank in series.

Approximately 80% DAF effluent flows into the PVA-Gel tank, and while 20% flows into the anoxic tank to provide carbon for denitrification.

The media in the PVA-Gel tank is prevented from flowing into the anoxic tank by a screen, so only mixed liquor from the PVA-Gel tank can flow into the anoxic tank and the MBR reactor.

PVA-Gel tank is fitted with a disc-type diffuser at the bottom of the tank to provide process air. The MBR tank is fitted with a bar type air diffuser for air scouring.

The MBR reactor uses Toray's MEMBRAY® flat sheet membranes to separate solids from the mixed liquor.

Activated sludge in the MBR tank is recirculated to the anoxic tank, while excess sludge is wasted via the wasting line in the sludge recirculation pipe, dewatered and transported off site.

f. UV System

Permeate water from the membrane is treated through a UV system before discharge.

3.4 DAILY PLANT OPERATION AND SITE RECORDING SHEET

The pilot plant is operated on a continuous basis and is manned by a full time operator between 9 a.m. to 5 p.m., Monday to Friday. The operator also attends on Saturday and Sunday for two hours in the morning and one hour in the evening.

A daily operational log is maintained to record completed tasks and events throughout the day as shown in *Appendix B: Operational Log Sheets*.

4 PILOT PLANT METHODOLOGY

4.1 PILOT PLANT STUDY OBJECTIVE

This study aimed to investigate the sludge production compared to conventional biological processes.

4.2 STUDY DURATION

The PVA-Gel pilot plant was first commissioned before the commencement of this study. It has been in operation for 18 months.

GWE was engaged to conduct a detailed investigation from 17th July to 28th July 2023.

During this study period, GWE attended the site on four separate occasions to check the sampling procedures and plant operation.

4.3 SAMPLING LOCATIONS AND FREQUENCY

The sampling locations, testing parameters and sampling frequency is summarised in *Appendix A: Sampling Locations and Frequencies*.

4.4 CALCULATED DAF OUTLET WASTEWATER CHARACTERISTICS

To conduct mass balance on the PVA-Gel tank, wastewater samples needed to be collected from the inlet and outlet of the PVA-Gel tank.

However, wastewater samples were collected from the DAF inlet by the operator due to a misunderstanding in the sampling location. Therefore, GWE had to collect inlet and outlet samples from the DAF unit to determine its organic matter and nutrient removal performance.

GWE back-calculated the PVA-Gel inlet wastewater quality based on the DAF removal performances *Appendix B: Pilot Plant DAF Performance*.

It should be noted that the DAF performance estimation is based on a single grab sample. However, TSS results and visual observations (e.g. lack of thickened sludge on top of the DAF tank) (Figure 9) indicate poor performance.

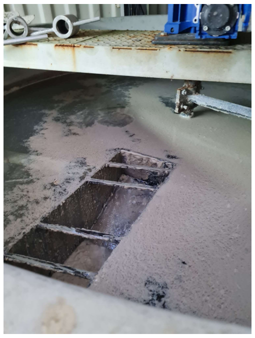

Figure 9: No thickened sludge on the DAF surface

5 RESULTS AND DISCUSSION

5.1 WASTEWATER FLOWS AND LOADS ANALYSIS

Two methods have been considered for conducting wastewater flows and loads analysis, but both methods have limitations.

Typically, the primary method requires a few months to a year of plant and sampling data to assess the flows and loads. However, this study was based on the two weeks trial period as opposed to a few months to a year.

The secondary method is estimating the expected flows and loads based on typical wastewater data. However, this method could not be used for the following reasons.

1. The pilot plant receives wastewater from various industries, commercial and residential properties. The main wastewater contributor is known to be NIG Nutritional goat milk processing plant.
2. Unlike typical dairy processing plants, the NIG Nutritional plant does not treat milk. Instead, they convert goat milk into other nutritional products (i.e. baby formula).

Therefore, estimating the wastewater concentrations based on typical dairy wastewater characteristics was difficult.

Although insufficient data constrains flows and loads studies, GWE observed some noticeable patterns in the wastewater volumes and concentrations. GWE used these patterns and past experience to interpret the data.

The totalised wastewater volume recorded by the plant inlet flowmeter shows that the average daily volume was 19.3m^3/d throughout the trial period, as shown in Figure 10.

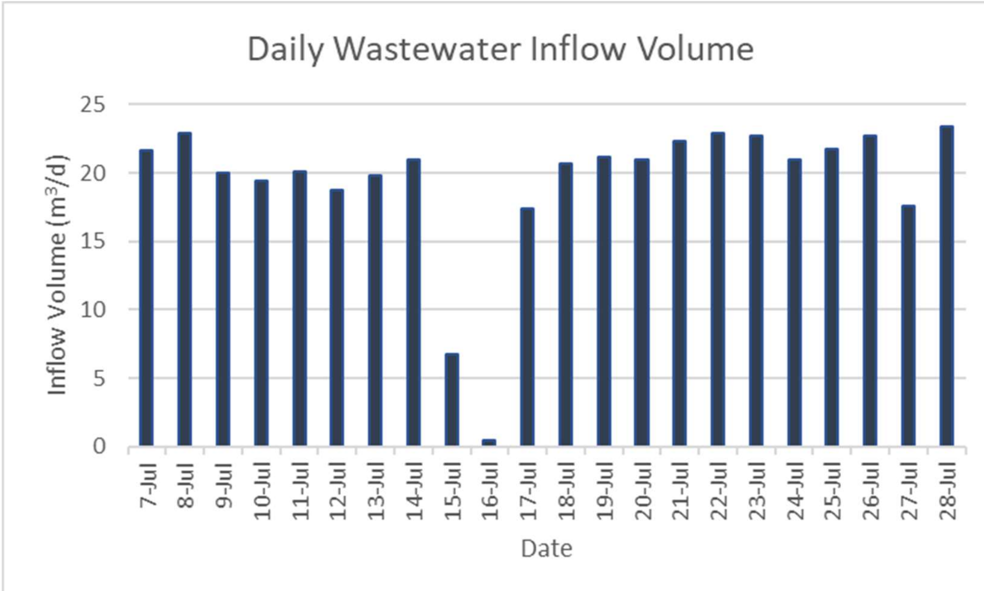

Figure 10: Daily Wastewater Inflow Volume

The figure shows no peak wet weather volume was recorded despite various wet weather events, especially on 21st July, with 30mm of rainfall on the day (MetService). Therefore, GWE assumed that stormwater infiltration is minimal and wastewater flow remained consistent throughout the trial period, and the "first flush" (flushing of accumulated contaminants) effect is assumed to be negligible in this study.

GWE could not analyse the hourly flow variations as this data was not available in the plant SCADA.

However, understanding changes in wastewater concentrations throughout the day is important for flows and loads study. This is because the most representative average daily wastewater concentration must be determined to calculate the loads. Therefore, GWE proposed collecting wastewater grab samples at three different time periods per the sampling locations and frequency shown in *Appendix A: Sampling Locations and Frequencies*.

GWE understand that grab sample results are not as accurate as the 24-hours composite sample results, but it does provide some insight into wastewater characteristics, as shown in Figure 11.

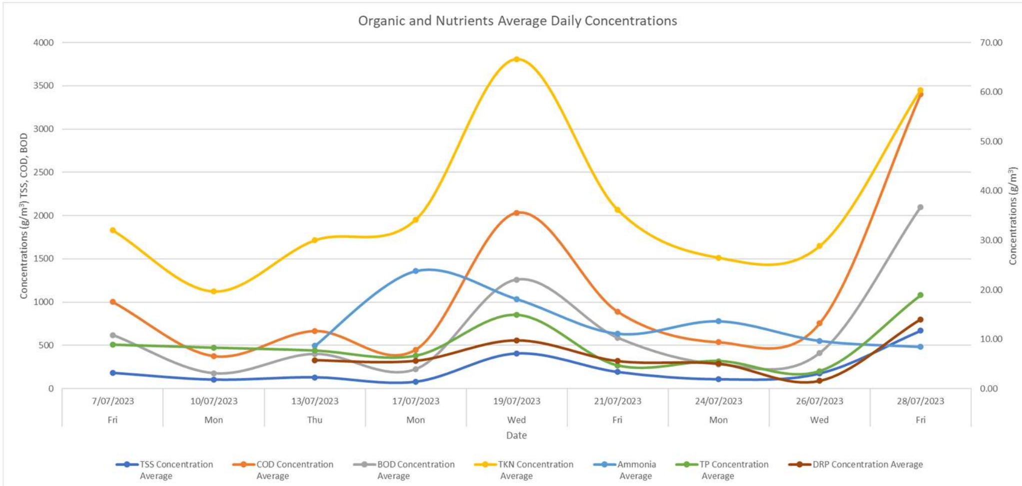

Figure 11: Average Daily Organic and Nutrients Concentrations

As shown in Figure 11, the wastewater strength is generally weak at the start of the week and increases over the mid-week. No samples have been taken over the weekend. Although, weekend wastewater concentrations were expected to be similar to the start of the week, given that most industrial activities slow down over the weekend and start ramping up again at the start of the week.

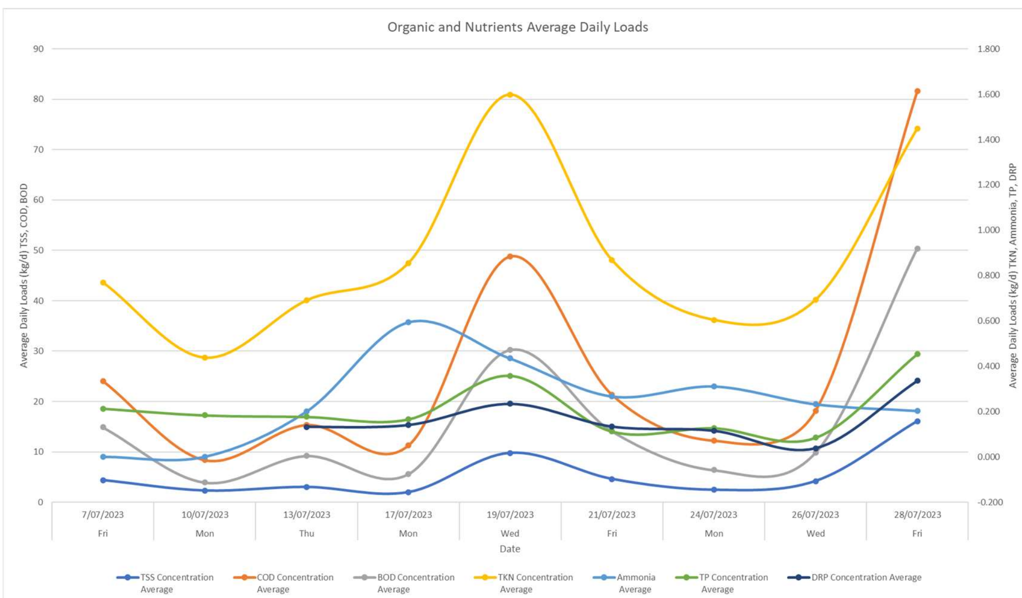

Figure 12: Average Daily Organic and Nutrients Loads

The wastewater loads trend is similar to the wastewater concentration trend, as shown in Figure 12. This was expected since wastewater flows have been generally consistent at about 19m^3/d over the trial period.

5.2 PVA-GEL AND MBR PILOT PLANT WASTEWATER TREATMENT PERFORMANCE

The organic and nutrient removal via PVA-Gel and MBR pilot plant is shown in the table below. Note that the influent and effluent average concentrations are calculated from the 25 samples collected between 7th July to 28th July.

Table 1: Summary of PVA-Gel and MBR Plant Wastewater Treatment Performance

PARAMETERS	PILOT PLANT AVERAGE INFLUENT (MG/L)	PILOT PLANT AVERAGE EFFLUENT (MG/L)	AVERAGE PERCENTAGE REDUCTION (%)
TSS	193.2	4.43	**98**
$cBOD_5$	498[1]	1.11	**100**
COD	879[1]	<32.28[2]	**>96**
TKN	30.3[1]	2.71	**91**
Ammonia	11.7[1]	1.87[3]	**84**
NO2	1.98[1]	0.07	Not Applicable
NO3	3.33[1]	1.26	Not Applicable
TP	8.01	0.39	**95**
DRP	5.93	0.23	**96**
Alkalinity	262	213.2	**19**
pH	6.7	7.7	Not Applicable

[1] Note: DAF performance factor applied

[2] Note: COD results were less than 30g/m^3 except one test where COD was 49g/m^3

[3] Note: Ammonia results were 0.4g/m^3 except one test where ammonia was 9.68g/m^3

The results demonstrate a high quality of effluent. The effluent ammonia concentration was consistently below 1mg/L except for a few occasions when the TKN level was as high as 14mg/L on 17th July 2023.

GWE also assessed the nitrification based on the aeration requirements and alkalinity consumption for the nitrification process.

Table 2: Summary of Aeration Requirements and Alkalinity Consumption due to Nitrification

METHOD	AERATION REQUIREMENTS (M^3/HR)	ALKALINITY CONSUMPTION (KG/D)
Theoretical based on calculation	119	1.37
Actual based on flow meter data	130	1.1

This aeration and alkalinity consumption supports 91% nitrogen (84% ammonia) reduction via nitrification.

Organic materials represented as COD and $cBOD_5$ are more efficiently removed than nitrogen components. Therefore, no further investigation is required other than sludge production, which is discussed in section 5.3 of this report.

Nitrite and nitrate percentage reductions are not relevant as influent wastewater generally contains negligible nitrites and nitrates. It was unusual to observe high nitrite and nitrate concentrations in the influent wastewater samples, and the source of these components is unknown. However, most of the nitrite and nitrate generated during the nitrification process seemed to be denitrified in the pilot plant anoxic tank.

GWE also assessed whether the influent quality was within the PVA-Gel performance specification.

Table 3: Summary of Aeration Requirements and Alkalinity Consumption due to Nitrification

DESIGN SPECIFICATION PARAMETERS	KURARAY DESIGN SPECIFICATION	PILOT STUDY RESULTS PER VOLUME OF PVA-GEL
BOD Loading	50 kg $BOD/m^3/d$	18.7 kg $BOD/m^3/d$
Nitrogen Loading	0.3 – 0.6 kg $NH_4N/m^3/d$	0.44 kg $NH_3*/m^3/d$
NOx Loading	1.0 – 3.0 kg NOx/N. m3/d	0.982 kg NOx/N. m3/d

*Assumed that ammonia concentration is in equilibrium with ammonium at pH 6.7

The table above shows that the BOD and ammonia loading rate was within the supplier's performance specification.

Nitrate loading has not been assessed, but the design loading is between 1.0 – 3.0kg NOx/N m^3/d, according to the PVA-Gel supplier.

In summary, the PVA-Gel and MBR reactor achieved high treated effluent quality results.

5.3 SLUDGE PRODUCTION

The activated sludge production is represented as VSS per mass of COD or BOD consumed in the biological reactor, as explained in section 2.2 of this report.

The table below shows the summary of excess sludge production using the PVA-Gel and MBR plant compared to a typical wastewater-activated sludge plant.

Table 4: Summary of Sludge Yield per Substrate Consumed

	SLUDGE YIELD PER COD CONSUMED KG VSS/ KG COD	SLUDGE YIELD PER BOD CONSUMED KG TSS/ KG BOD
PVA-Gel and MBR Reactor	0.03 (Based on Observed Yield)	0.05 (Based on Observed Yield)
Typical Activated Sludge Reactor (Tchobanoglous G, 2002)	0.4 (Based on Bioenergetics)	0.6 (Based on Bioenergetics)

The table shows that sludge generation from PVA-Gel and MBR technology is about ten per cent of the typical activated sludge plant.

However, it is important to note that the typical activated sludge yield per COD or BOD consumed is based on the bioenergetics described in section 2.2. In contrast, the PVA-Gel MBR reactor sludge yield is based on observation.

Based on the observation, PVA-Gel and MBR technology appears to produce less sludge because microorganisms tend to digest themselves via endogenous decay when sludge is retained in the reactor for a long time *(Appendix D: Calculations)* as opposed to a typical activated sludge plant which typically has five to 20 days SRT.

The pilot plant was operating at an average MLSS concentration of 20,615g/m^3, although the MBR membrane (Toray) has a maximum MLSS limit of about 18,000 g/m^3.

Also, a significant MLSS concentration fluctuation was observed on 17th July as shown in table below.

Table 5: PVA-Gel and MBR Pilot Plant Daily MLSS Concentrations

DATE	MLSS CONCENTRATION (G/M3)
7/07/2023	21733
10/07/2023	20300
13/07/2023	**12783**
17/07/2023	**31800**
19/07/2023	**23300**
21/07/2023	16050
24/07/2023	19067
26/07/2023	18400
28/07/2023	20200

Nevertheless, using the mass balance equation, GWE determined that the PVA-Gel and MBR plant produced less sludge than a typical activated sludge plant, as shown in the table below.

Table 6: Sludge Production with BOD as Substrate

	VSS PRODUCTION WITH BOD AS SUBSTRATE (KG/D)	TSS PRODUCTION WITH BOD AS SUBSTRATE (KG/D)
PVA-Gel and MBR	0.37	0.54
Typical Activated Sludge Plant	0.71	0.86

From the plant operation perspective, GWE did not find any parameters outside the normal range of the typical activated sludge plant except for the obvious high MLSS concentration.

The table below shows the summary of pilot plant operating parameters compared to typical activated sludge plant operating parameters.

Table 7: Summary of the PVA-Gel and MBR Plant Operating Parameters Compared to Typical Activated Sludge Plant

	PVA-GEL AND MBR PILOT PLANT	TYPICAL ACTIVATED SLUDGE PLANT
F:M Ratio	0.08g BOD/g VSS.d	0.05 – 0.1g BOD/g VSS.d
pH	7.1	7
Temperature	17°C	20°C
Hydraulic Retention Time	20hrs	24hrs
Internal Recycle Ratio	1.9	Two to Three

GWE also assessed the air requirement based on the activated sludge production, and it was found that the theoretical aeration requirement for the pilot plant closely matched the observed aeration demand for the plant, as shown in *Appendix D: Calculations*. Therefore, the pilot plant was achieving full nitrification, but PVA-Gel did not appear to improve the dissolved oxygen utilisation.

6 CONCLUSION

- GWE conducted a two-week pilot study.
- The PVA-Gel technology is a type of MBBR process, but PVA-Gel can achieve a comparably lower packing ratio due to the gel's size and performance.
- Wastewater loads were generally weak at the start of the week and peak around the middle of the week.
- The Pilot PVA-Gel and MBR plant was able to achieve high effluent quality.
- PVA-Gel produces less sludge than conventional biological wastewater treatment.
- The pilot plant was operating at very high MLSS.
- It is recommended that further studies need to be undertaken to investigate the sludge production quantities.

7 REFERENCES

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8 LIMITATIONS

Select statement which relates to the technical discipline of the report and delete heading and remaining statements.

General:

This report has been prepared for the sole benefit of **Aqua-K** as our Client, and their appointed representatives, according to their instructions, for the specific objectives described herein. This report is qualified in its entirety and should be considered in the light of our Terms of Engagement with the Client and the following:

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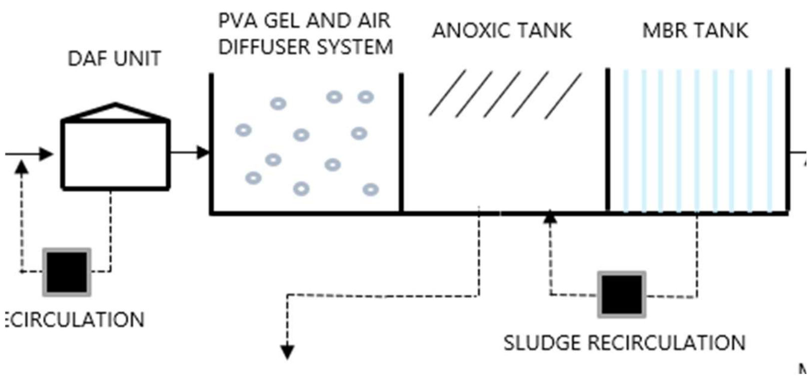
Pilot Study Specific:

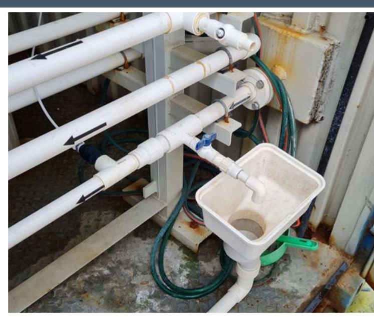
- Assumptions around DAF performance were based on single lab testing on .28th July 2023.
- The pilot study is based on two weeks testing period. This may not be representative of the annual average daily loads.
- Note the daily wastewater characterisation excludes late evenings and weekends.
- To improve the accuracy of the result, 24hrs composite samples or annual average results should be used. But, due to funding and time limits for the trial, this has not been carried out.

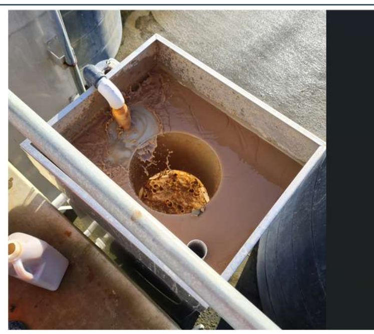
APPENDIX A: SAMPLING LOCATIONS AND FREQUENCIES

The sampling locations, testing parameters and sampling frequency is summarised in the table below.

PVA-GEL AND MBR TANK OVERVIEW



Sampling Locations	Photos	Testing Parameters	Sampling Days	Samling Frequency Per Day
DAF Inlet		$cBOD_5$ COD TSS VSS NO2 NO3 Alkalinity pH Temperature TKN Ammoniacal N Total Phosphorus Dissolved Phosphorus	17th Mon 19th Wed 21st Fri 24th Mon 26th Wed 28th Fri	9.00am 12.00pm 3.00pm
DAF Outlet		$cBOD_5$ COD TSS VSS NO2 NO3 Alkalinity pH Temperature TKN Ammoniacal N Total Phosphorus Dissolved Phosphorus		

PVA-GEL AND MBR TANK OVERVIEW		
PVA-Gel Tank Outlet (MBR Tank Outlet)		$cBOD_5$ COD TSS VSS NO2 NO3 Alkalinity pH Temperature TKN Ammoniacal N Total Phosphorus
Waste Sludge		TSS VSS pH Temperature

APPENDIX B: OPERATIONAL LOG SHEETS

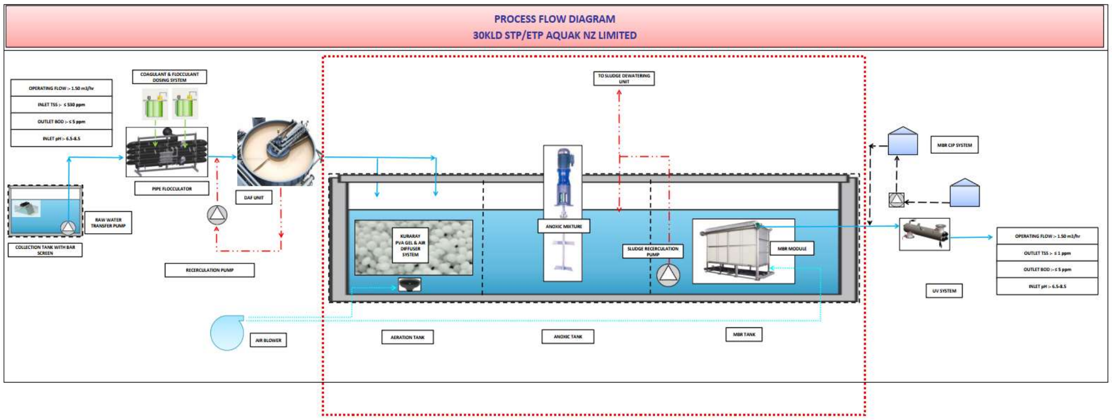
APPENDIX C: PILOT PLANT DAF PERFORMANCE

Summary of Pilot Plant DAF Performance

	TSS CONCENTRATION AVERAGE	VSS CONCENTRATION AVERAGE	COD CONCENTRATION AVERAGE	BOD CONCENTRATION AVERAGE	TKN CONCENTRATION AVERAGE	AMMONIA AVERAGE	NO2 CONCENTRATION AVERAGE	NO3 CONCENTRATION AVERAGE	TP CONCENTRATION AVERAGE	DRP CONCENTRATION AVERAGE	ALKALINITY AVERAGE	PH AVERAGE
Unit	g/m3	g/m3	g/m3	g/m3	g/m3	g/m3	g/m3	g/m3	g/m3	g/m3	g/m3	
DAF In (28/07/2023 9:00)	670.00	670.00	3400.00	2100.00	60.40	8.44	0.87	12.60	Not Available	Not Available	170.00	5.40
DAF Out (28/07/2023 9:00)	778.00	744.00	3200.00	1900.00	51.90	7.09	0.55	11.10	Not Available	Not Available	170.00	5.50
DAF Out In Difference	-108.00	-74.00	200.00	200.00	8.50	1.35	0.32	1.50	Not Available	Not Available	0.00	-0.10
DAF Out In % Difference	-16.12%	-11.04%	5.88%	9.52%	14.07%	16.00%	36.78%	11.90%	Not Available	Not Available	0.00%	-1.85%
PVA-Gel Influent Correction Factor	Not Applicable	Not Applicable	0.94	0.90	0.86	0.84	0.63	0.88	Not Available	Not Available	1.00	1.02

APPENDIX D: CALCULATIONS

GWE
CONSULTING ENGINEERS



MASS BALANCE AROUND THE BIOLOGICAL ONLY SINCE NO RETURN STREAMS

Mass Balance Based on Lab Results

Averaege Wastewater Flows, Concentrations and Loads	Units	Influent (Based on the Lab Results)	WAS (Calculate this from BOD removal)	Effluent	Reference	Comments
Average Daily Volume - Dry Weather	m3/d	19.30	0.0260	18.40	Plant Data	
Maximum Daily Volume - Wet Weather	m3/d	Not Applicable	Not Applicable	Not Applicable	Lab Data	
Instantaenous Flow Rate	m3/h	Not Applicable	Not Applicable	Not Applicable	Lab Data	
TSS Concentration - Average	g/m3	193.20	20615.91	4.43	Lab Data	
VSS Concentration (b) - Average	g/m3	182.92	12625.00	2.97	Lab Data	
COD Concentration (c) - Average	g/m3	879.46	Not Applicable	32.28	Lab Data	DAF Reduction Factor Applied
BOD Concentration - Average	g/m3	497.88	Not Applicable	1.11	Lab Data	DAF Reduction Factor Applied
TKN Concentration - Average	g/m3	30.28	Not Applicable	2.71	Lab Data	DAF Reduction Factor Applied
Ammonia - Average	g/m3	11.73	Not Applicable	1.87	Lab Data	DAF Reduction Factor Applied
NO2 Concentration - Average	g/m3	1.98	Not Applicable	0.07	Lab Data	DAF Reduction Factor Applied
NO3 Concentration - Average	g/m3	3.33	Not Applicable	1.26	Lab Data	DAF Reduction Factor Applied
TP Concentration - Average	g/m3	8.01	Not Applicable	0.39	Lab Data	
Alkalinity - Average	g/m3	262.00	Not Applicable	213.20	Lab Data	
TSS Load - Average	Kg/d	3.73	3.65	0.08	Lab Data	
VSS Load - Average	Kg/d	3.53	3.48	0.05	Lab Data	
COD Load - Average	Kg/d	16.97	16.38	0.59	Lab Data	
BOD Load - Average	Kg/d	9.61	9.59	0.02	Lab Data	
TKN Load - Average	Kg/d	0.58	Not Applicable	0.05	Lab Data	
Ammonia - Average	Kg/d	0.23	Not Applicable	0.03	Lab Data	
NO2 Load - Average	Kg/d	0.04	Not Applicable	0.00	Lab Data	
NO3 Load - Average	Kg/d	0.06	Not Applicable	0.02	Lab Data	
TP Load - Average	Kg/d	0.15	Not Applicable	0.01	Lab Data	
Alkalinity Load - Average	Kg/d	5.06	Not Applicable	3.92	Lab Data	
pH - Average		6.7	Not Applicable	7.7	Lab Data	
Temperature - Average	°C	16.94	16.94	16.94	Plant Data	

PVA Gel and MBR Reactor Dimensions	Units	Values	Reference	Comments
PVA Gel Tank Volume	m3	5.70	Aldee O&M	
PVA Gel Tank Effective Working Volume	m3	5.13	Aldee O&M	10% Volume occupied by PVA Gel, ignored volume occupied by the diffuser
Anoxic Tank	m3	5.60	Aldee O&M	Ignored volume occupied by the mixer
MBR Tank	m3	6.70	Aldee O&M	
MBR Effective Working Volume	m3	5.70	Aldee O&M	Assumed 85% Working Volume based on other MBR study refer to MBR Technology - A promising approach for industrial water reuse, ignored volume occupied by the diffuser and sludge recirc pump

PVA Gel and MBR Reactor Operating Parameters	Units	Values	Comments
Total Working Volume	m3	16.43	
Hydraulic Retention Time	hr	20.42	
Sludge Retention Time	days	631.73	
F/M Ratio		0.08	This is within range of the high SRT according to Metcalf and Eddy
Internal Recycle Ratio		1.87	1.5m3/hr or 36m3/d as per Aldee O&M

MBR sludge production	Units	Values	Comments
Sludge Yield Coefficient BOD	mg VSS/mg BO	0.60	Coefficient from Metcalf Eddy pg585
sludge Yield Coefficient COD	mg VSS/mg CO	0.40	Coefficient from Metcalf Eddy pg585
Decaying Coefficient	mg VSS/mg VS	0.06	Coefficient from Metcalf Eddy pg585
Cell debris	g VSS/g VSS	0.10	Coefficient from Metcalf Eddy pg586
nitrifying bacteria coeff at 20deg	g VSS/g NH4	0.12	Coefficient from Metcalf Eddy pg706
nitrifying bacteria decay coeff at 20deg	g VSS/g VSS	0.08	Coefficient from Metcalf Eddy pg706
SRT	days	**631.73**	-This incredibly long SRT is reducing the sludge production -Average wasting is 0.78m3/hr (SCADA). According to plant operator sludge wasting is done 2 to 3 minutes per day
Theoretical Sludge Production in Terms of VSS with BOD as substrate	kg/d	**0.71**	This is based on yield coeff of 0.6
Theoretical Sludge Productoin in Terms of TSS with BOD as substrate	kg/d	**0.86**	This is based on yield coeff of 0.6
Actual Sludge production using PVA-Gel and MBR in Terms of VSS with BOD as substrate	kg/d	**0.37**	This is based on observed yield from the pilot VSS is 69% of TSS based on pilot study
Actual Sludge production using PVA-Gel and MBR in Terms of TSS with BOD as substrate	kg/d	**0.54**	This is based on observed yield from the pilot

Observed Sludge Yield	Units	Values	Comments

PVA Gel and MBR Reactor SRT	days	631.7	-This incredibly long SRT is reducing the sludge production -Average wasting is 0.78m3/hr (SCADA). According to plant operator sludge wasting is done 2 to 3 minutes per day
Typical SRT Dyas	days	5 - 20	Metcalf Eddy table 8-30 pg 858
Nordkanal Wastewater Works at Kaarst, Germany	days	25.0	Biological Wastewater Treatment Principles, Modelling and Design
Sari Sewage Treatment	days	30.0	Biological Wastewater Treatment Principles, Modelling and Design
Observed Sludge Yield in terms of COD	kg VSS/kg COD	**0.03**	-Metcalf Eddy pg 585 shows 0.4kg VSS/kg bsCOD -Note that observed yield is different to normal sludge yield because normal sludge yield is based on bioenergetics where as observed yield is based on the pilot study
Observed Sludge Yield in terms of BOD	kg VSS/kg BOD	**0.05**	-Metcalf Eddy pg 585 0.6kg VSS/kg BOD -Aquak-K claim that 5-25% of the BOD turns into sludge -Note that observed yield is different to normal sludge yield because normal sludge yield is based on bioenergetics where as observed yield is based on the pilot study

Nitrification in PVA and MBR Reactor	Units	Values	Comments
Organic Nitrogen removed from the system	kg Org N	0.34	
kg Organic nitrogen removed via TVSS	kg Org N	0.26	Metcalf Eddy pg594 for VSS/TSS ratio of 0.85. Based on the lab results it appears about 0.69. Morgen Henz pg99 for VSS yield from organic N which is about 0.1.

PVA Gel Operating Performance	Units	Values	Comments
Gel Surface Area	m2/m3	1000.00	Estimation of the Specific Surface Area for a Porous Carrier Slovenia (Aqua-K Supplied paper). Used 1000m2 though
Gel Volume in the tank	m3	0.51	10% media volume in PVA-gel Tank according to Aqua-K spec
Ammonia loading per gel volume per day	kg/m3.d	**0.44**	
Ammonia loading per gel surface area per day	kg/m2.d	**0.00044**	
Nitification Rate	g/m2.d	0.37	Ignore ammonia used for cell synthesis for autotroph refer to Metcalf Eddy pg 613
Calculated Alkalinity Usage	kg/d	1.37	Ignore ammonia used for cell synthesis for autotroph refer to Metcalf Eddy pg 613, used 7.14g alkalinity per g ammonia nitrogen converted
Measured Alkalinity Usage	kg/d	1.1	Note that this is less than calculated because cell synthesis from ammonia is ignored as per Metcalff Eddy pg613
BOD loading per gel volume per day	kg/m3.d	**18.7**	
BOD loading per gel surface area per day	kg/m2.d	**0.0187**	
Nitrogen Oxidised	kg/d	**0.5039**	Using equation 8-18 in Metcalf Eddy pg 684
NOx loading per gel volume per day	kg/m3.d	**0.982**	
NOx loading per gel surface area per day	kg/m2.d	**0.000982**	

Theoretical and Actual Air Requirements	Units	Values	Comments
Influent nitrogen oxidised	kg/d	0.50	
Organic matter oxidised	kg/d	9.59	
Biomass produced/WAS mass	kg/d	0.37	Metcalf Eddy pg594 for VSS/TSS ratio of 0.85 but lab result showed 0.69
AOTR Oxygen Demand	kg/hr	0.47	
$C_{S,20}$	g/m3	9.08	
T Temperature	°C	17.00	
a Alpha Factor		0.18	Assumed based on Morgen Henz pg347 fig 13.13 for alpha factor
f Fouling		0.90	Metcalf Eddy pg 429
b Beta Factor		0.95	Metcalf Eddy pg 430
Diffuser depth	m	1.43	
$C_{\bar{S},t,H}$ Average DO in clean water at sat in T and elevation	g/m3	9.81	
-Pd Water depth to diffuser above atmospheric head	m	11.72	Based on O&M 1.43m water levels in MBR and PVA GEL tank
-Patm Atmospheric pressure	m	10.29	
-y Specific weight of water at temp 17°C	kN/m3	9.80	
-Ot oxygen concentration leaving aeration tank	%	19.00	Assumed based on Metcalf Eddy pg 712
-Cs,t,H	mg/L	9.60	
*C_{17}	mg/L	9.65	
*Pb/Pa change in atmospheric pressure with elevation		0.99	
-g gravitational acceleration	m/s2	9.81	
-M molar mass of Air	kg/kg mole	28.97	
-R gas Constant	kg m2/s2 kg m	8314.00	
-T tempreature in Kelvin		290.15	
-Za Elevation	m	46.00	
-Zb Sea Level	m	0.00	
C	g/m3	0.50	Assumed based on metcalf pg 858 table8-30. Output is not sensitive to this
SOTR	kg/hr	3.20	
Diffuser oxygen transfer efficiency		0.35	
Typical O2 composition in air	kg O2/m3 air	0.21	Typical oxygen concentration in air
Air Flow Rate	m3/hr	43.5	
The Amount Air Required for scouring	m3/hr	87.0	Twice that of air required for conventional system, pg6 in EPA Wastewater Management Fact Sheet
Total Air Required Based on Calc	m3/hr	**130.5**	
Actual Air Used in the plant	m3/hr	**130.0**	

-Confirm WAS production based on bag removal. This is to demonstrate that flow meter data information is correct and SRT is correct

	Influent Sample Data												PVA-Gel and MBR Data		Effluent Sample Data											
	TSS Concentration Average g/m3	VSS Concentration Average g/m3	COD Concentration Average g/m3	BOD Concentration Average g/m3	TKN Concentration Average g/m3	Ammonia Average g/m3	NO2 Concentration Average g/m3	NO3 Concentration Average g/m3	TP Concentration Average g/m3	DRP Concentration Average g/m3	Alkalinity Average g/m3	pH Average	TSS Concentration Average g/m3	VSS Concentration Average g/m3	TSS Concentration Average g/m3	VSS Concentration Average g/m3	COD Concentration Average g/m3	BOD Concentration Average g/m3	TKN Concentration Average g/m3	Ammonia Average g/m3	NO2 Concentration Average g/m3	NO3 Concentration Average g/m3	TP Concentration Average g/m3	DRP Concentration Average g/m3	Alkalinity Average g/m3	pH Average
7/07/2023 9:00	126		850	530	22.9		4.33	0.04	8		110	5.8	23500		1		30	0.81	2.08		0.02	0.02	0.794		230	7.7
7/07/2023 12:00	165		960	590	29.7		1.74	0.04	7.34		150	6.2	20000		1		30	0.93	2		0.02	0.02	0.945		210	7.6
7/07/2023 15:00	255		1200	740	43.6		8.12	2.33	11.3		250	6.6	21700		1		30	0.86	2		0.02	0.02	0.853		200	7.6
10/07/2023 9:00	124		370	160	16.8		15.8	42.2	9.9		180	6.6	19600		1.2		30	2.6	0.4		0.02	0.02	0.451		120	7.4
10/07/2023 12:00	66.5		340	170	18.2		0.49	0.02	7.52		190	6.7	20200		1		30	2.1	0.386		0.02	0.02	0.422		120	7.4
10/07/2023 15:00	119		420	200	24.1		8.19	6.22	7.38		230	6.6	21100		1		30	0.99	0.359		0.02	0.02	0.466		130	7.5
13/07/2023 9:00	129		640	380	28.6	6.55	0.02	0.02	7.84	4.83	280	7.1	19200		3.2		30	0.89	2	0.4	0.02	1.18	0.333	0.327	170	7.7
13/07/2023 12:00	149		700	420	29.5	7.7	0.02	0.02	7.86	6.51	320	7.3	9900		1.6		30	0.8	2.15	0.4	0.02	1.56	0.325	0.32	160	7.6
13/07/2023 15:00	114		660	400	31.9	11.8	0.02	0.68	7.36	5.96	310	7.1	9250		1.4		30	0.8	2.78	0.4	0.02	2.01	0.321	0.304	160	7.7
17/07/2023 9:00	52.5		380	210	29.9	21.5	0.02	0.02	6.42	5.71	240	6.8	34300		1		30	2.3	10.5	8.96	0.07	9.75	0.554	0.477	150	7.6
17/07/2023 12:00	101		460	200	39.3	24.7	0.02	0.02	6.94	5.65	240	6.8	32600		6.2		30	0.61	11.8	9.99	0.04	7.07	0.658	0.431	150	7.7
17/07/2023 15:00	82.5		510	260	33.3	25.1	0.02	0.02	6.54	5.53	230	6.7	28500		3.2		30	2	13.9	10.1	0.03	5.37	0.567	0.473	150	7.7
19/07/2023 9:00	557		2300	1600	74.2	18.4	0.04	1.06	16.2	10.1	270	6.5	23300		14.6		46	1.4	3.48	0.4	0.58	3.61	0.566	0.313	270	7.7
19/07/2023 12:00	346		1800	980	57.1	15.2	21	10.9	13.4	9.07	250	6.5	23300		9.4		49	1.1	2.69	0.4	0.02	0.02	0.374	0.384	350	7.9
19/07/2023 15:00	319		2000	1200	68.6	20.7	7.14	0.83	15.2	10.1	480	6.5			7.4		52	0.65	4.8	0.4	0.04	0.04	1.25	0.309	400	7.9
21/07/2023 9:00	163	149	670	480	30.4	12.2	0.1	1.28	0	5.24	280	6.7	16400	11000	4.4	3.6	30	1.9	0.617	0.4	0.04	0.04	0.16	0.159	280	7.8
21/07/2023 12:00	257	236	1200	770	47.5	12.6	2.22	0.64	8.58	7.8	280	6.4	15700	10600	6.4	6	30	0.5	0.571	0.4	0.04	0.04	0.187	0.16	260	7.9
21/07/2023 15:00	156	154	800	510	30.7	8.52	0.13	0.33	5.46	3.67	180	6.6			10.8	8.8	30	0.76	0.731	0.4	0.04	0.04	0.224	0.137	250	7.8
24/07/2023 9:00	89	79	470	250	22.9	10.6	0.1	0.1	4.96	4.5	340	7.2	19100	13800	4	2.8	30	0.5	0.369	0.4	0.1	0.1	0.065	0.062	160	7.7
24/07/2023 12:00	142	142	580	300	30.5	15.7	0.1	0.1	5.98	4.93	330	7	21200	14500	7	5.8	30	0.5	0.326	0.4	0.1	0.1	0.067	0.062	170	7.7
24/07/2023 15:00	90.5	89.5	560	290	26.1	14.6	0.1	0.1	5.76	5.74	350	7	16900	11200	3.2	2	30	0.5	0.4	0.4	0.1	0.1	0.057	0.054	150	7.7
26/07/2023 9:00	161	144	730	380	28.1	11.3	0.1	0.1	1.56	0.03	320	7	17400	12000	3.6	1	30	0.96	0.571	0.4	0.1	0.1	0.035	0.03	270	8
26/07/2023 12:00	188	174	780	440	29.6	8.03	6.35	8.41	5.48	3.13	330	7.1	20200	13900	6.6	1.6	30	0.94	0.303	0.4	0.1	0.1	0.032	0.025	270	8
26/07/2023 15:00	208	174	610	270	26.3	11.6	1.73	6.4	4.26	0.11	240	6.6	17600	12100	5.6	2.8	30	0.86	0.48	0.4	0.1	0.1	0.033	0.29	270	8
28/07/2023 9:00	670	670	3400	2100	60.4	8.44	0.87	12.6	18.9	14	170	5.4	20200	14000	5	3.6	30	1.4	2	0.4	0.1	0.1	0.036	0.023	280	7.7

Aqua-K NZ Ltd

Data Collection Sheet for Crown Rd Pilot Plant for week of July-2023

Date	7-Jul	8-Jul	9-Jul	10-Jul	11-Jul	12-Jul	13-Jul	14-Jul	15-Jul	16-Jul	17-Jul	18-Jul	19-Jul	20-Jul	21-Jul	22-Jul	23-Jul	24-Jul	25-Jul	26-Jul	27-Jul	28-Jul
Time	08:30:00	09:00:00	10:30:00	08:40:00	08:30:00	08:30:00	07:30:00	08:30:00	08:30:00	07:30:00	08:30:00	08:30:00	08:30:00	08:30:00	08:30:00	09:30:00	09:40:00	08:30:00	08:30:00	08:30:00	08:30:00	08:30:00
Hours in the period	24.000	24.500	25.500	22.167	23.833	24.000	23.000	25.000	24.000	23.000	25.000	24.000	24.000	24.000	24.000	25.000	24.167	22.833	24.000	24.000	24.000	24.000
Source of wastewater	BPWW	BPWW	BPWW	BPWW	BPWW	BPWW	BPWW	BPWW	BPWW	BPWW	BPWW	BPWW	BPWW	BPWW	BPWW	BPWW	BPWW	BPWW	BPWW	BPWW	BPWW	BPWW
Total Inlet Volume (m3)	8446.69	8469.65	8489.65	8509.08	8529.2	8547.94	8567.73	8588.67	8595.43	8595.91	8613.3	8634.02	8655.19	8676.2	8698.56	8721.48	8744.21	8765.14	8786.89	8809.6	8827.15	8850.55
Total Inlet Flow in the period (m3)	21.7	22.96	20	19.43	20.12	18.74	19.79	20.94	6.76	0.48	17.39	20.72	21.17	21.01	22.36	22.92	22.73	20.93	21.75	22.71	17.55	23.4
Average Inlet Flow by total hrs (m3/hr)	0.90	0.94	0.78	0.88	0.84	0.78	0.86	0.84	0.28	0.02	0.70	0.86	0.88	0.88	0.93	0.92	0.94	0.92	0.91	0.95	0.73	0.97
Average Inlet Flow by Pump hrs(m3/hr)	0.94	0.92	0.80	0.84	0.87	0.78	0.86	0.84	0.85	#DIV/0!	0.87	0.86	0.92	0.88	0.93	0.92	0.95	0.91	0.91	0.95	0.73	0.97
Inlet Flow (m3/hr)	0.89	0.85	0.76	1.02	0.8	0.8	0.87	0.87	0	0	0.83	0.73	0.9	0.8	0.85	0.87	0.93	0.9	0.91	0.92	0.6	0.92
Power reading (kWhr)	126428.6	126616.8	126800.4	126974.5	127155.5	127341	127523.7	127709.8	127864.5	128005.3	128157.9	128339	128515.3	128694.3	128876.6	129064.6	129255.4	129421.9	129608	129784.1	129965	130139.4
kW.hr used in the period	190.7	188.2	183.6	174.1	181	185.51	182.69	186.1	154.7	140.8	152.6	181.1	176.3	179	182.3	188	190.8	166.5	186.1	176.1	180.9	174.4
kW.hr/m3	8.8	8.2	9.2	9.0	9.0	9.9	9.2	8.9	22.9	293.3	8.8	8.7	8.3	8.5	8.2	8.2	8.4	8.0	8.6	7.8	10.3	7.5
kW/hr total hours	7.9	7.7	7.2	7.9	7.6	7.7	7.9	7.4	6.4	6.1	6.1	7.5	7.3	7.5	7.6	7.5	7.9	7.3	7.8	7.3	7.5	7.3
kW/hr Pump hours	8.3	7.5	7.3	7.6	7.9	7.7	7.9	7.4	19.3	#DIV/0!	7.6	7.5	7.7	7.5	7.6	7.5	7.9	7.2	7.8	7.3	7.5	7.3
pH Inlet	6.05	6.8	6.6	6.35	10.4	8.2	8.9	6.5	-	-	6.9	7.2	6.2	6.6	6.6	6.7	6.6	7.03	6.6	6.85	6.8	5.9
pH outlet	6.95	7.05	7.01	6.8	7.15	6.9	6.9	7.3	-	-	7.3	7.18	7.13	7.1	7.11	7.05	6.95	7.08	7.03	7.1	7.15	7.23
Transfer Pump Hour Meter	1808	1833	1858	1881	1904	1928	1951	1976	1984	1984	2004	2028	2051	2075	2099	2124	2148	2171	2195	2219	2243	2267
Transfer Pump Hrs in Period	23	25	25	23	23	24	23	25	8	0	20	24	23	24	24	25	24	23	24	24	24	24
Transfer Pump Hrs/Total Hrs %	96%	102%	98%	104%	97%	100%	100%	100%	33%	0%	80%	100%	96%	100%	100%	100%	99%	101%	100%	100%	100%	100%
Total Outlet Volume (dm3)	8772010	8793237	8813023	8831984	8851760	8871330	8889614	8909824	8916436	8916436	8932890	8953810	8972590	8993342	9015446	9037823	9059820	9080106	9100518	9119076	9136569	9155388
Outlet Vol in the period (m3)	21.535	21.227	19.786	18.961	19.776	19.57	18.284	20.21	6.612	0	16.454	20.92	18.78	20.752	22.104	22.377	21.997	20.286	20.412	18.558	17.493	18.819
Average Outlet Vol by total hrs (m3/hr)	0.90	0.87	0.78	0.86	0.83	0.82	0.79	0.81	0.28	0.00	0.66	0.87	0.78	0.86	0.92	0.90	0.91	0.89	0.85	0.77	0.73	0.78
Average Outlet Vol by Pump hrs (m3/hr)	0.94	0.85	0.79	0.82	0.86	0.82	0.79	0.81	0.83	#DIV/0!	0.82	0.87	0.82	0.86	0.92	0.90	0.92	0.88	0.85	0.77	0.73	0.78
Total Outlet flow (l/min)	15.66667	13.33333	13.66667	14	14	13.5	13.33333	14.16666667	0	0	14.16667	12.83333	15	14.16667	16.83333	14.83333	16.16667	14.66667	14.83333	13.83333	10.5	15.33333
Total Outlet Flow (m3/hr)	0.94	0.8	0.82	0.84	0.84	0.81	0.8	0.85	0	0	0.85	0.77	0.9	0.85	1.01	0.89	0.97	0.88	0.89	0.83	0.63	0.92
Dissolved Oxygen (ppm)	11.57	11.87	17.8	67.78	2.2	4.01	21.02	27.37	1.5	1.11	0.96	0.91	7.14	6.73	7.42	6.82	7.35	6.27	5.69	5.73	7.6	7.73
Temperature ^{o}C	19.7	20	19.68	17.3	18.5	18.4	14.1	14.9	18	18.6	17.3	17.2	16.4	17.1	17.4	16.2	15.3	16.1	15.3	15.5	14.1	15.6
Total Hours																						
								0.02	0.00	0.00	-0.02	-0.04	0.00	-0.05	-0.16	-0.02	-0.04	0.02	0.02	0.09	-0.03	0.00
Remarks								Plant is off from eve 5.00 P.M	Plant is off due to weekend.	CIP done so plant is off till 1.00 P.M							Rain	Rain	Rain	Rain	Rain	Rain

CLIENT / PROJECT LOCATION

Aqua-K PVA-Gel, Paerata

GWE CONSULTING ENGINEERS

TITLE	REFERENCE J4753	REVISION
PVA-Gel Operating Performance + Theoretical Alkalinity Used PH	DESIGNED D LEE	DATE
	CHECKED	DATE

1. BOD loading per PVA-Gel Volume and Surface Area

* PVA-Gel tank effective working volume $= 5.13\,m^3$
* PVA-Gel volume is 10% of the tank so $5.13\,m^3 \times 0.1 = 0.513\,m^3$
* Influent BOD loading $= 9.61$ kg/d
* PVA-Gel surface area is $1000\,m^2/m^3$

So

BOD, gel loading/m^3 gel $= \dfrac{9.61\,kg/d}{0.513\,m^3} = 18.73\,kg/m^3.d$

BOD, gel loading/m^2 gel $= \dfrac{18.73\,kg/m^3.d}{1000\,m^2/m^3} = 0.01873\,\dfrac{kg}{m^2.d}$

2. Ammonia loading per PVA-Gel Volume and SA

Influent ammonia loading $= 0.23$ kg/d

Ammonia, gel loading/m^3 gel $= \dfrac{0.23\,kg/d}{0.513\,m^3} = 0.45\,\dfrac{kg}{m^3.d}$

Ammonia, gel loading/m^2 gel $= \dfrac{0.45\,kg/m^3.d}{1000\,m^2/m^3} = 0.00044\,\dfrac{kg}{m^2.d}$

3. NO_x loading per PVA-Gel Volume and SA

Flow × (TKN_{in} − Ammonia$_{eff}$) − 0.12 × VSS = Nitrogen oxidised NO_x

Flow $= 19.3\,m^3/d$

$TKN_{in} = 30.28\,g/m^3$

Ammonia eff $= 1.87\,g/m^3$

VSS $= 0.37$ kg/d or 370 g/d produced

So

$$NO_x = \left(19.3\frac{m^3}{d}\left(30.28\frac{g}{m^3} - 1.87\frac{g}{m^3}\right) - 0.12 \times 370\frac{g}{d}\right) \Big/ 1000\,\frac{g}{kg}$$

$= 0.5039\,\dfrac{kg}{d}$

CLIENT / PROJECT LOCATION

Aqua-K PVA Gel, Paerata

GWE CONSULTING ENGINEERS

TITLE	REFERENCE J4753	REVISION
PVA-Gel Operating Performance + Theoretical Alkalinity Used Pt2	DESIGNED DLEE	DATE
	CHECKED	DATE

3. NOx loading per PVA-Gel Volume and SA continued

$$NO_x,\ \text{gel loading}/m^3\ \text{gel} = \frac{0.5039\ kg/d}{0.513\ m^3} = 0.98\ \frac{kg}{m^3.d}$$

$$NO_x,\ \text{gel loading}/m^2\ \text{gel} = \frac{0.98\ \frac{kg}{m^3.d}}{1000\ m^2/m^3} = 0.00098\ \frac{kg}{m^2.d}$$

4. Alkalinity used

Use 7.14 g alkalinity used / g ammonia nitrogen converted

Influent ammonia load = 0.23 kg/d
Effluent ammonia load = 0.03 kg/d

Alkalinity used = (0.23 − 0.03) × 7.14
= 1.43 kg/d

PAGE__OF__

CLIENT / PROJECT LOCATION

Aqua-K PVA Gel, Paerata

GWE CONSULTING ENGINEERS

TITLE	REFERENCE J4153	REVISION
PVA-Gel + MBR SRT Calc, HRT Calc	DESIGNED D Lee	DATE
	CHECKED	DATE

1. PVA-Gel + MBR Volumes

- PVA-Gel tank volume = $5.7 m^3$ (from Adlee O+M)
- PVA-Gel tank eff volume = $5.7 m^3 \times 0.9 = 5.13 m^3$ (from Adlee O+M)
  - * note that 10% volume is occupied with PVA-Gel so 90% factor applied
- Anoxic tank = $5.6 m^3$ (from Adlee O+M)
- MBR tank = $6.7 m^3$ (from Adlee O+M)
- MBR tank effective volume = $6.7 \times 0.85 = 5.7$
  - * 85% working volume (from Adlee O+M)
- Total working volume = 5.13 + 5.6 + 5.7 = $16.43 m^3$

2. SRT calc

- Average daily wasting = $0.78 m^3/hr$ (from SCADA)
- Operator is wasting for about 2-3 mins/d so
  $0.78 m^3/h \;/\; 60 \frac{min}{h} \times 2 min = 0.026 m^3/d$
- $SRT = \frac{16.43 m^3}{0.026 m^3/d} = 632 d$

3. HRT calc

- Average daily flow = $19.3 m^3/d$
- $HRT = \frac{16.4 m^3}{19.3 m^3/d} = 0.85 m^3/d = 20.4 h$

CLIENT / PROJECT LOCATION

Aqua-K PVA-Gel, Paeroa

GWE CONSULTING ENGINEERS

TITLE	REFERENCE J4753	REVISION
MBR Sludge Production (Theoretical) Pt 1	DESIGNED D Lee	DATE
	CHECKED	DATE

1. Flows and loads

Average daily volume = 19.3 m^3/d

Av daily BOD concentration = 497.9 g/m^3

Av daily TKN concentration = 30.3 g/m^3

Av daily TSS conc = 193.2 g/m^3

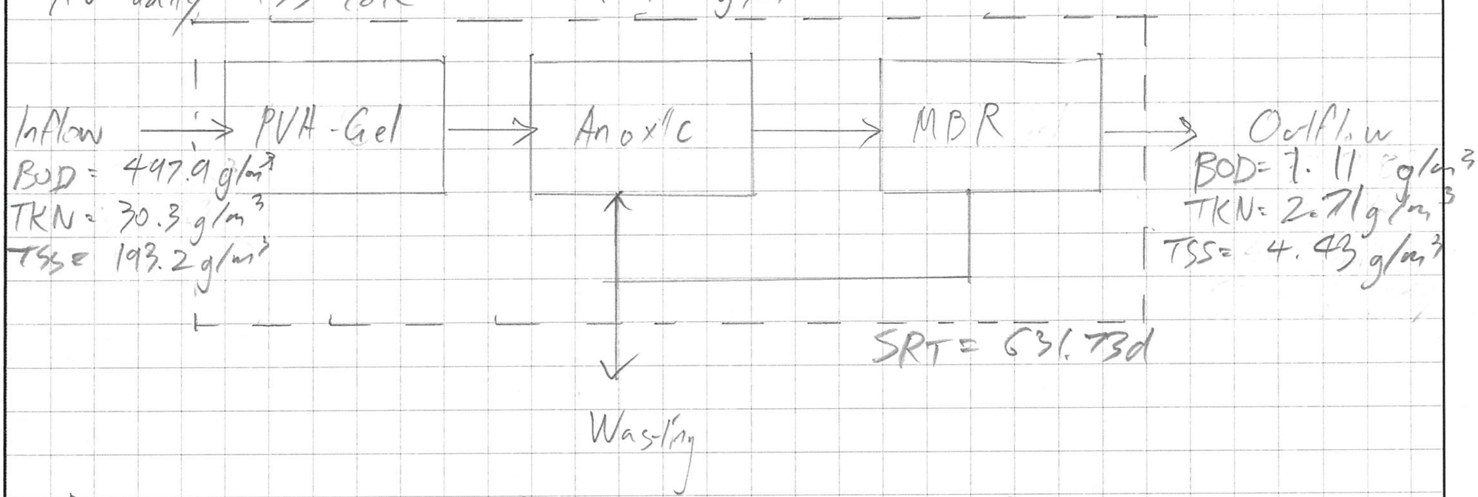
Y_n nitrifying bact coeff = 0.12

k_{dn} nitrifying bact decay = 0.08

Y sludge yield coeff = 0.6

(f_d) cell debris = 0.1

(k_d) decay coeff = 0.06



$$P_{X,VSS} = \frac{QY(S_o - S)}{1 + (k_d)SRT} + \frac{(f_d)(k_d)QY(S_o - S)SRT}{1 + (k_d)SRT} +$$

$$\frac{QY_n(NO_x)}{1 + (k_{dn})SRT} + Q(nbVSS)$$

Assumed 0 because influent VSS is only 4% of TSS and nbVSS will be even less

$$= \frac{19.3 \times 0.6(497.9 - 1.11)}{1 + 0.06 \times 631.73} + \frac{0.1 \times 0.06 \times 19.3 \times 0.6(497.9 - 1.11)631.73}{1 + 0.06 \times 631.73}$$

$$+ \frac{19.3 \times 0.12(30.3 - 2.71)}{1 + 0.08 \times 631.73} + 0$$

$= 147.9 + 560.5 + 1.24$

$= 709.64$ g/d

$= 0.7096$ kg/d

CLIENT / PROJECT LOCATION

Aqualia-K PVA-Gel - Paerata

GWE
CONSULTING ENGINEERS

TITLE	REFERENCE J4753	REVISION
MBR sludge production (theoretical) pt2	DESIGNED D Lee	DATE
	CHECKED	DATE

$P_{X,VSS} = 0.71$ kg/d

69% TSS based off sample results

$$P_{X,TSS} = \frac{P_{X,VSS}}{0.85} + \frac{Q\,(TSS_o - VSS_o)}{1000\ g/kg}$$

$$= \frac{0.71}{0.85} + \frac{19.3\,(4.43 \times (1-0.69))}{1000\ g/kg}$$

$$= 0.84 + 0.027$$

$$= 0.87\ kg$$

CLIENT / PROJECT LOCATION

Aqua - K PVA-Gel, Paerata

GWE CONSULTING ENGINEERS

TITLE	REFERENCE J4753	REVISION
Air requirement Pt 1	DESIGNED DLEE	DATE
	CHECKED	DATE

1. Oxygen Demand

$Q = 19.3 m^3/d$

$S_o (BOD) = 497.9 g/m^3$

$S (BOD) = 1.11 g/m^3$

$P_{x,bio} = 0.37 kg/d$

NO_x = $TKN_{in} - TKN_{out} - TKN_{sludge}$

From PVA-Gel operating performance calc

= 0.5 kg/d

Oxygen demand $R_o = Q(S_o - S) - 1.42 P_{x bio} + 4.33 Q (NO_x)$

$= 19.3 \left[\frac{(497.9 - 1.11)}{1000}\right] - 1.42 \times 0.37 + 4.33 \times 0.5$

$= 9.59 + -0.53 + 2.165$

$= 11.225 kg/d$

$= 0.47 kg/h$

2. SOTR Calc

α Alpha phactor = 0.18 from Morgan Henz pg 347

β Beta factor = 0.95 from Metcalf Eddy

F Fouling factor = 0.9 from Metcalf Eddy

$C_{S,T,H}$ = Average DO saturation in clean water in aeration tank at temp T and altitude H, mg/L

$= C_{S,T,H} \frac{1}{2} \left(\frac{pd}{P_{atm,H}} + \frac{O_t}{21} \right)$

i) from Metcalf Eddy Table D-1

$C_{20} = 9.08$

$C_{17} = 9.65$

ii) Determine relative P at elevation 46m to correct DO conc

$\frac{P_b}{P_a} = \exp\left[- \frac{gM(Z_b - Z_a)}{RT} \right]$

$= \exp\left[- \frac{9.81 \times 28.97 \times (46 - 0)}{8314 \times (17 + 273.15)} \right]$

$= 0.99$

$g = 9.81 m/s^2$

$M = 28.97 kg/kg mol$

$R = 8314 kg \frac{m^2}{s^2} mol K$

$Z_b = 46m$

$Z_a = 0m$

CLIENT / PROJECT LOCATION

Aquatic PVA Gel, Paerata

GWE CONSULTING ENGINEERS

TITLE	REFERENCE J4753	REVISION
Air requirement Pt2	DESIGNED DLee	DATE
	CHECKED	DATE

$C_{s,T,H}$ = Oxygen Conc at 46m and 17°C = 9.65 × 0.99 = 9.55 mg/L

iii) atmospheric pressure in m of water at elevation 46m and temperature 17°C is

$$P_{atm,H} = \frac{P_{atm,H}\ \text{kN/m}^2}{\gamma\ \text{kN/m}^3} = \frac{101.325 \times (0.99)}{9.798}$$ ← from (ii)

$= 10.24$

(iv) $$C_{\bar{s},T,H} = 9.55 \times \frac{1}{2}\left(\frac{P_{atm,H} + P_{w,\text{eff depth}}}{P_{atm,H}} + \frac{O_t}{21}\right)$$

$$= 9.55 \times \frac{1}{2}\left(\frac{10.24 + 1.43}{10.24} + \frac{19}{21}\right)$$ ← assume 19% O_2 conc

$= 9.76$ mg/L

3. $$SOTR = AOTR \times \left[\frac{C_{20}}{\alpha F(\beta C_{\bar{s},T,H} - C)}\right] 1.024^{20-T}$$

$$= 0.47 \times \left[\frac{9.08 \times 1.024^{(20-17)}}{0.18 \times 0.9(0.95 \times 9.76 - 0.5)}\right]$$

$$= 0.47 \times \frac{9.75}{1.42} = 3.22 \text{ kg/hr}$$

4. $$\text{Air flow rate} = \frac{SOTR}{\text{Diffuser efficiency} \times \text{Typical air composition}}$$

$$= \frac{3.22}{0.35 \times 0.21}$$

(0.35 Assumed)

$= 43.8\ m^3/h$

5. Amount of air required for Scouring = Twice that of conventional activated sludge

Therefore 43.8 × 2 = 87.6 m^3/h for scouring

6. Total air required = 43.8 + 87.6 = 131.4 m^3/hr

APPENDIX E: IIT ROORKEE A REPORT ON PILOT SCALE STUDIES ON NUTRIENT REMOVAL PVA GEL BASED IFAS PROCESS

सिविल इंजीनियरिंग विभाग

भारतीय प्रौद्योगिकी संस्थान, रुड़की - 247 667 (उत्तराखण्ड) भारत

DEPARTMENT OF CIVIL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY, ROORKEE - 247 667 (U.K.) INDIA

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Dated 18th May, 2018

To,
KURARAY CO. LTD
Ote Center Building, 1-1-3, Otemachi,
Chiyoda-Ku
Tokyo 100-8115, Japan

Subject: Pilot scale studies on Nutrient removal PVA-Gel based IFAS study at IIT Roorkee

Dear Sir,

Attached herewith the final report on the Pilot scale study on nutrient removal in a PVA-Gel based bioreactor system.

The performance assessment of PVA gel based 120 L/day IFAS pilot plant was conducted under ambient conditions in Department of Civil Engineering IIT Roorkee.

The pilot plant consists of three-reaction tanks 1) aeration tank with PVA gel, 2) anoxic tank, 3) oxic tank and a final settling tank. The system was operated at 4% filling percentage of PVA gel beads in first tank. For continuous one-year, the reactor was operated under four working conditions, first was start-up phase then Run I, Run II and Run III which deals with overall 6h 5h, 4.4h HRT conditions respectively. It was observed that the PVA gel based IFAS system can be able to bring the final effluent COD <30 mg/L, BOD < 10 mg/L, SS< 10 mg/L, NH4-N < 5mg/L and TN< 10 mg/L.

In addition, 20-50 mg/L alum dose can the effluent PO_4-P levels below 1 mg/L, whereas a dosing of bleaching powder (30% available Cl_2) up to 3 mg/L for 30 minutes contact time can bring the fecal coliforms to non-detectable limit.

Hence, effluent quality not only satisfies CPCB Effluent standards 2015, but also achieving the CPHEEO recommended guidelines (2013) for non-potable reuse.

With Best Regards

A. A. Kazmi

A REPORT ON PILOT SCALE STUDIES ON NUTRIENT REMOVAL PVA GEL BASED IFAS PROCESS

FEBRUARY 2018

DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE-247 667 (UTTARAKHAND)

EXECUTIVE SUMMARY

Long term PVA-Gel based IFAS pilot-plant studies were conducted for BOD, TSS and TN removal on actual sewage under ambient conditions at IIT Roorkee. The final objective is to achieve BOD, TSS and TN < 10 mg/L and COD < 50 mg/L under all seasonal conditions. The pilot plant comprises of 1) aeration tank with PVA gel (4% Fill ratio), 2) anoxic tank, 3) oxic tank and a final settling tank. The total treatment capacity is 120 L/d, out of which 80% (96 L/d) feeded to first PVA gel tank and 20% (24 L/d) diverted to second anoxic tank as carbon source for denitrification. The system was operated under four conditions, first was start-up phase, while Run I (6h HRT), Run II (5 h HRT) and Run III (4.4 h HRT) are second, third and fourth conditions.

Extensive monitoring and sampling (dated 26/12/2017 to 15/01/2018) results reveals excellent effluent quality in terms of BOD, COD, SS and TN. Almost complete nitrification as well as significant simultaneous nitrification-denitrification (40-50%) was observed in the first PVA gel reactor. Average BOD, TSS & TN in effluent were less than 10 mg/L and in all operating conditions.

Slight deterioration in BOD and TSS values was observed under lower sewage temperature (10-15^{o}C) in the last run (HRT 4.4 h). Effluent BOD and TSS exceeds 10 mg/L, however it recovers after increasing the HRT of final aeration tank from 0.4 h to 1h. Hence, it can be concluded that at least 5-h HRT of the system is needed for achieving BOD, TSS and TN < 10 mg/L in all seasons of India.

Prof. A. A. Kazmi **Dr. Ankur Rajpal**

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

Based on recent studies, polyvinyl alcohol(PVA) gel based IFAS process has been proven as an effective method for wastewater treatment (Kuraray 2005). PVA gel is less bulky and displayed better performance as an immobilization medium by providing higher nitrification rates and occupying very less space in the reactor (Rostron et al. 2001). It is 3-4 mm spherical bead with a network of 10–20 micron pores which allows cultivation of bacteria in a sheltered mode and thus reduces sloughing of biomass under shock loading (Kuraray 2005; Hoa et al. 2006; Gani et al. 2014; Singh et al. 2016). Due to its better fluidity, minimum energy is consumed for mixing. The larger porosity of gel beads also favors better supply of oxygen and carbon to residing bacteria, resulting in stable treatment under variable loading. Hence, present study aims at the optimization of PVA Gel based bioreactor for enhanced BOD, TSS and Nitrogen removal under varying seasonal conditions.

2.0 MATERIALS AND METHODS

2.1 Description of IFAS Configuration

IFAS pilot plant of 35 L Volume is installed at the Environmental Engineering Laboratory, Indian Institute of Technology-Roorkee, India. The system is composed of three reaction tanks and a settler. The three reaction tanks were 1) PVA Gel aerobic tank 2) an anoxic tank 3) an oxic tank. Volume of each reaction tank is 10 L while it is 5 L for settling tank (Figure 2.1 & 2.2). Initially, total hydraulic retention time (HRT) of the reactor was maintained as 6 hours with 2 hours HRT in each tank, thereafter it is successively decreased by replacing the volume of third oxic tank. The (PVA) gel media in first tank occupy 4% of reactor volume. Aeration in PVA Gel media and oxic tank was provided by diffusers. Anoxic tank mixing was carried out by vertical stirrer.

2.2 Start-up and operation methodology

The reactor was started on 26 Dec 2016 with average flow rate of 120 L/d. 400 mL of PVA gel was added to first tank resulting in media filling percentage as 4%. During startup period, 100 % raw sewage flow is fed to first PVA Gel tank. Thereafter, 20% of raw sewage was diverted to anoxic tank for external organic load to enhance denitrification process. Sludge is recirculated from the bottom of settling tank to the anoxic tank at a flow rate of 60 L/d (50 % of inflow). During start-up and Run I, Hydraulic retention time (HRT) of the reactor was maintained as 6 hours with 2 hours HRT in each tank. In Run II, third 10 L oxic tank was replaced by a 5 L tank to reduce the system HRT of to 5 hours. In Run III, again third 5 Liter oxic tank is replaced by a 2 L tank to reduce the system HRT to 4.4 hours.

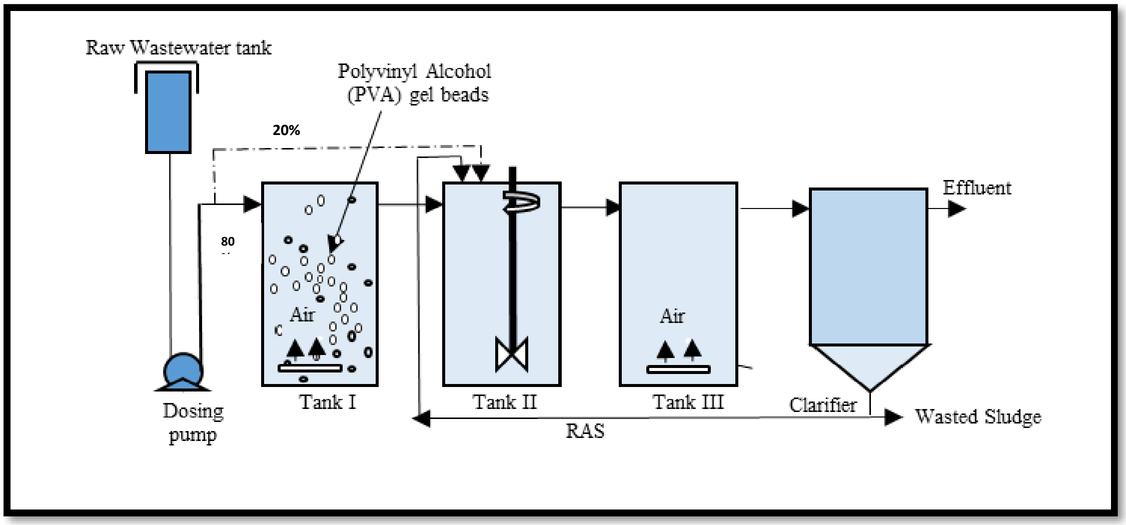

Figure 2.1. Flow diagram of the laboratory scale plant

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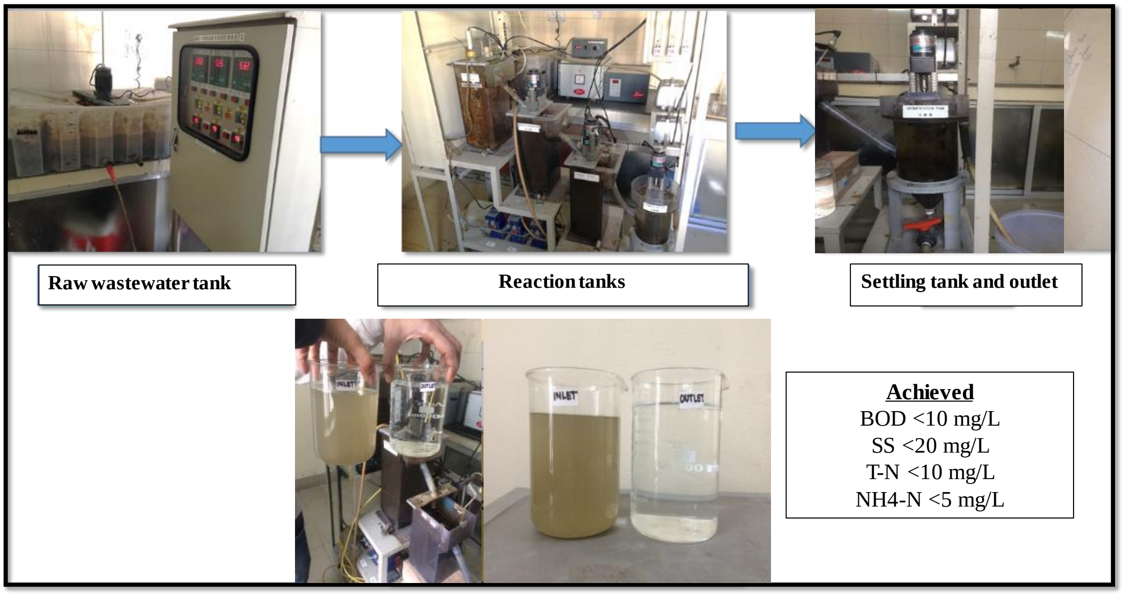

Figure 2.2. Pictorial diagram of the treatment process

3.0 RESULTS AND DISCUSSION

This study included several phases viz. Startup, Run I, Run II and Run III (Figure 3.1).There were few events during Startup, when the total nitrogen in effluent went higher than 10 mg/L. The problem was resolved by maintaining proper carbon to nitrogen ratio in the raw wastewater. Due to retention for 24 hours in the tank, the level of carbon in raw wastewater reduces which also reduces the availability of carbon source to anoxic tank, thereby decreasing denitrification efficiency. The reduction in COD of raw wastewater was compensated by addition of glucose er. During the operation period, about~1-1.5 liter sludge is wasted to maintain the SRT 7-10 days. Average sludge wastage was ~11-13 g/d (0.3-0.5 kg TSS/kg BOD) which is found to be less compared to other type of STPs

3.1 Start-up:- Performance during startup period

Phase I: Period from 26 Dec 2016 to 10Feb 2017

Performance: In this phase, 60% synthetic sewage along with 40% raw sewage applied directly to PVA gel tank. The reactor was started on 26 Dec 2016 using synthetic sewage with flow rate of 120 L/d initially. The results obtained from the analysis of physio-chemical parameters are summarized in table 3.1.

Table 3.1: Average value of performance parameters of the lab scale PVA gel based IFAS process during startup phase.

Parameter	Average values		
	Influent (mg/L)	**Effluent (mg/L)**	**Percentage removal**
COD	388±211	77±53	77
BOD	185±74	32±20	82
Ammonia-N	47±25	35±28	31
Nitrate-N	2±1.0	5±3.0	-
TN	59±31	43±32	31
PO4-P	8±5	4±2	47
Total Phosphate -P	14±3	7±1	49

Phase II: Period from 11Feb 2017 to 05Mar 2017

Performance: In this phase,100% raw sewage applied directly to PVA gel tank. Here, a total 120 L/d raw sewage inflow was completely fed to PVA gel media tank (Tank 1). The water quality data is summarized in Table 3.2.

Table 3.2: Average value of performance parameters of the PVA gel based IFAS process during startup using 100% raw sewage.

Parameter	Average values			New effluent standards, CPCB 2015
	Influent (mg/L)	**Effluent (mg/L)**	**Percentage removal**	
COD	375±68	33±11	91	-
BOD	199±49	**16±10**	91	10
Total suspended solids	250±89	13±7	94	10
Ammonia-N	43±10	1±1	97	5
Nitrate-N	1±1	5±4	-	-

Total Nitrogen –N	68±1	**20±9**	71	10
Ortho phosphate-P	4±1	3±1	31	2
Total Phosphate -P	7±2	4±1	37	-

Figure 3.1. Operation under three HRTs of the laboratory scale plant

3.2 Run I: - Performance based on 6hrs HRT

Period from 06 Mar 2017 to 06 May 2017

Performance: Out of total 120 L/d raw sewage, 80% (96 L/d) feed to PVA gel tank and 20% (24 L/d) diverted to the anoxic tank. The system HRT was maintained at 6.0 h. The water quality data is summarized in Table 3.3.

Table 3.3: Average value of performance parameters of the PVA gel based IFAS process during Run I

Parameter	Average values			New effluent standards, CPCB 2015
	Influent (mg/L)	Effluent (mg/L)	Percentage removal	
COD	439±120	29±8	93	-
BOD	195±61	7±2	96	10
Total suspended solids	318±46	7±2	98	10
Ammonia-N	16±8	1±1	95	5
Nitrate-N	1±1	7±2	-	-
Total Nitrogen –N	39±11	9±4	75	10
Ortho phosphate-P	3±1	2±1	35	2
Total Phosphate -P	8±1	6±2	24	-

3.3 Run II: -Performance based on 5hrs HRT.

Period from 07 May 2017 to 15August 2017

Performance:HRT lowered from 6 hours to 5 hours by reducing HRT of tank 3 (oxic tank) only on volume basis by replacing 10L oxic tank volume to 5 L.Th performace data is summarized in Table 3.4.

Table 3.4: Average value of performance parameters of the PVA gel based IFAS process during Run II

Parameter	**Average values**			**New effluent standards, CPCB 2015**
	Influent (mg/L)	**Effluent (mg/L)**	**Percentage removal**	
COD	363±192	30±6	94	50
BOD	179±80	7±2	96	10
Total suspended solids	270±104	4±1	98	10
Ammonia-N	23±12	1±1	94	5
Nitrate-N	1±1	3±2	-	-
Total Nitrogen –N	36±13	6±2	82	10
Ortho phosphate-P	3±1	2±1	21	2
Total Phosphate -P	7±3	6±2	22	-

3.4 Run III: -Performance based on 4.4 hrs HRT.

Period from 15August, 2017 to 15 January, 2018

Performance: HRT lowered from 6 hours to 5 hours by reducing HRT of tank 3 (oxic tank) only on volume basis by replacing 5L oxic tank volume to 2 L. Average values of the analysis of the collected samples is shown in below table 3.5.

Table 3.5: Average value of performance parameters of the PVA gel based IFAS process during Run III

Parameter	Average values			New effluent standards, CPCB 2015
	Influent (mg/L)	Effluent (mg/L)	Percentage removal	
COD	446±92	26±7	94	-
BOD	216±66	7±2	97	10
Total suspended solids	284±56	6±1	98	10
Ammonia-N	35±13	1±1	96	5
Nitrate-N	1±1	2±1	-	-
Total Nitrogen –N	42±13	6±1	86	10
Ortho phosphate-P	3±1	3±1	18	2
Total Phosphate -P	4±1	3±1	19	-

3.5 Performance evaluation plots based on startup and 3 HRTs

3.5.1 Operational sludge parameters

- ***MLSS and MLVSS***

PVA gel based IFAS pilot plant was operated under average MLSS and MLVSS 475mg/L to 600mg/L and 117mg/L to 294 mg/Lin PVA gel tank. In anoxic tank MLSS and MLVSS was maintained 4862 mg/L to 5430mg/L and 2115 mg/L to 2580 mg/Land in Oxic tank 4932 mg/L to5419 mg/Land 2191 mg/L to 2635 mg/L respectively in all operating conditions (Fig. 3.2 and 3.3).

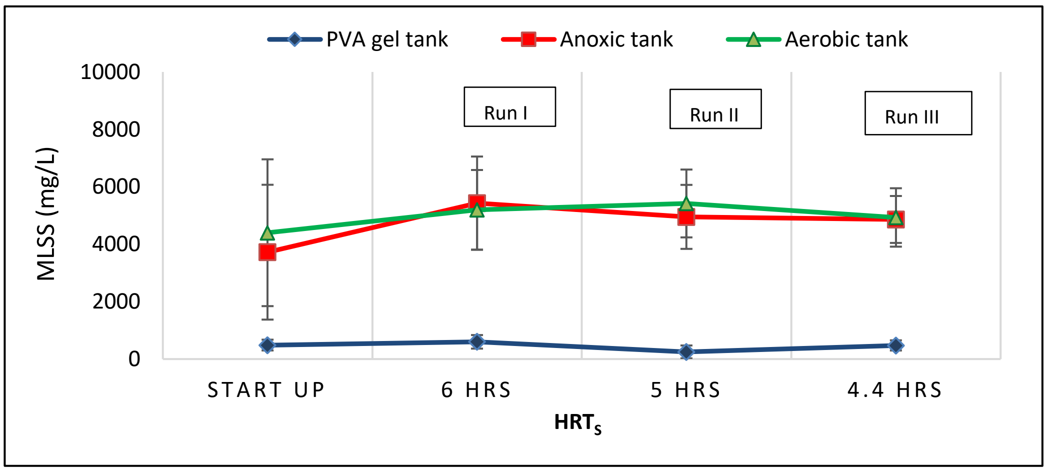

Fig 3.2. Variations in MLSS of the pilot plant for the study period

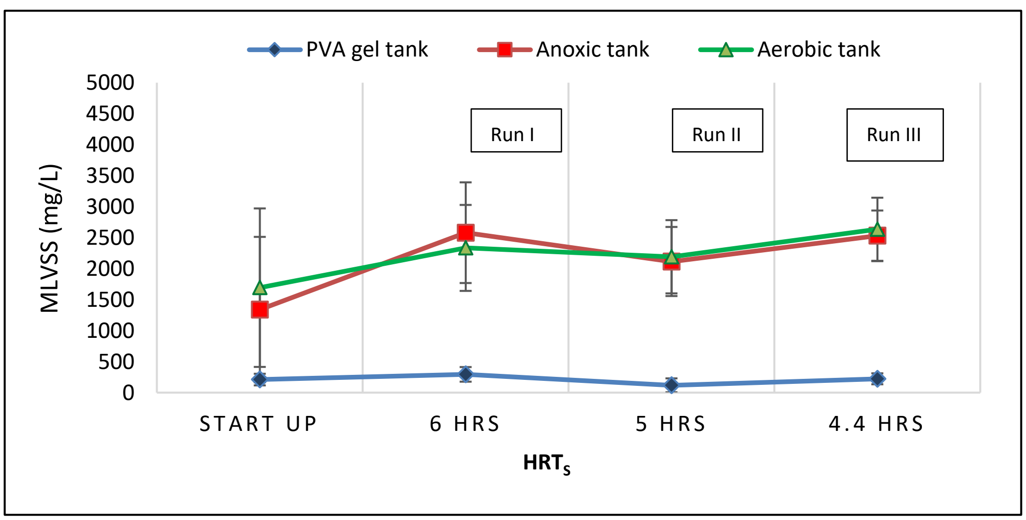

Fig 3.3. Variations in MLVSS of the pilot plant for the study period

3.5.2 Physico-chemical parameters

- ***Temperature, pH, Oxidation reduction potential (ORP) and Dissolved oxygen (DO)***

The temperature of the influent and effluent was varies 10 to 25 ± 2 °C which is ~±3-5°C ambient temperature (5-35°C) from startup phase to Run III. pH is the measure of acidity (or alkalinity), or hydrogen ion activity on logarithmic scale. The average pH of the influent was 8.0 ± 0.5 and for effluent was found to be 7.5 ± 0.5, which is close to neutral, showing the buffering capacity of IFAS process.

Table 3.6: Temperature, pH, ORP and DO variations in all 3 reaction tanks of the pilot plant during the process.

Parameter	Tank	HRTs (Average)			
		Start up	6 Hrs	5 Hrs	4.4 Hrs
Temperature (^oC)	Ambient	22.7	26.8	30.7	27.9
	PVA gel tank	19.0	26.6	30.5	28.0
	Anoxic tank	18.8	26.7	30.5	28.0
	Aerobic tank	18.9	26.7	30.5	27.9
pH	PVA gel tank	8.1	8.5	8.2	8.1
	Anoxic tank	8.0	8.3	7.8	7.5
	Aerobic tank	8.0	8.4	7.9	7.7
ORP (mV)	PVA gel tank	56.5	52.2	61.8	50.7
	Anoxic tank	-29.1	-73.1	-135.2	-139.7
	Aerobic tank	58.3	56.4	71.1	62.0
DO (mg/L)	PVA gel tank	7.1	6.3	6.4	7.3
	Anoxic tank	1.1	0.3	0.2	0.2
	Aerobic tank	6.1	5.1	3.6	4.7

Average value of ORP was observed +16.5 to + 61.8 mV, -29.1to -139.7 mV and 24.6 to 62.0mV in PVA gel tank, anoxic tank and oxic tank respectively during all phases. During all

Run, ORP was negative in anoxic tank leads to high denitrification. This may be due to 20% diversion of raw sewage to anoxic tank as a carbon source after completion of startup phase. DO was maintained 6.3 to 7.3 mg/L , 0.3 to 1.0 mg/L and 3.6 to 6.1 mg/L in PVA gel tank, anoxic tank and oxic tank respectively throughout the process. All variation shown in Table 3.6.

- ***COD, BOD and TSS***

Fig. 3.4 and 3.5 depicts the remarkable reduction in COD and BOD with time in PVA gel. In all HRTs, the average values of COD and BOD in the influent were ~363 ±192 to 446±92mg/l and 179±80 to 216±66and COD and BOD in the effluent were26 ± 7 mg/L to 30 ± 6 mg/Land 7 ± 2 mg/L respectively. Average removal of COD and BOD were observed 85% and 85% during startup phase, 93% and 96% in Run I, 90% and 96% in Run II and 94% and 97% in Run III respectively. Similarly, TSS decreased remarkably during all Run, with mean removal efficiency of 98% (Fig.3.6).

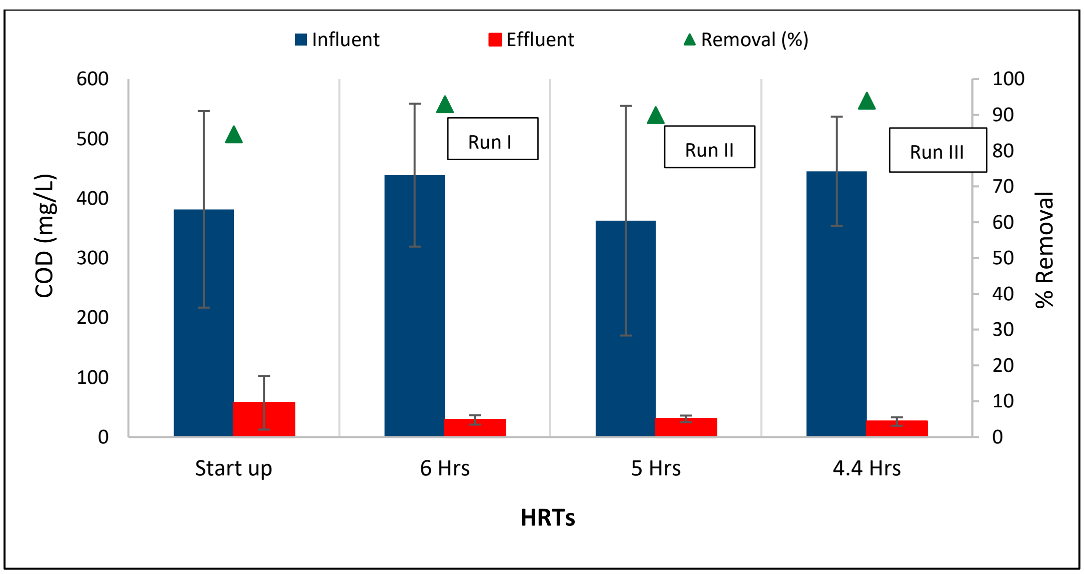

Fig 3.4. COD variations in influent and effluent samples of the pilot plant and its percentage removal.

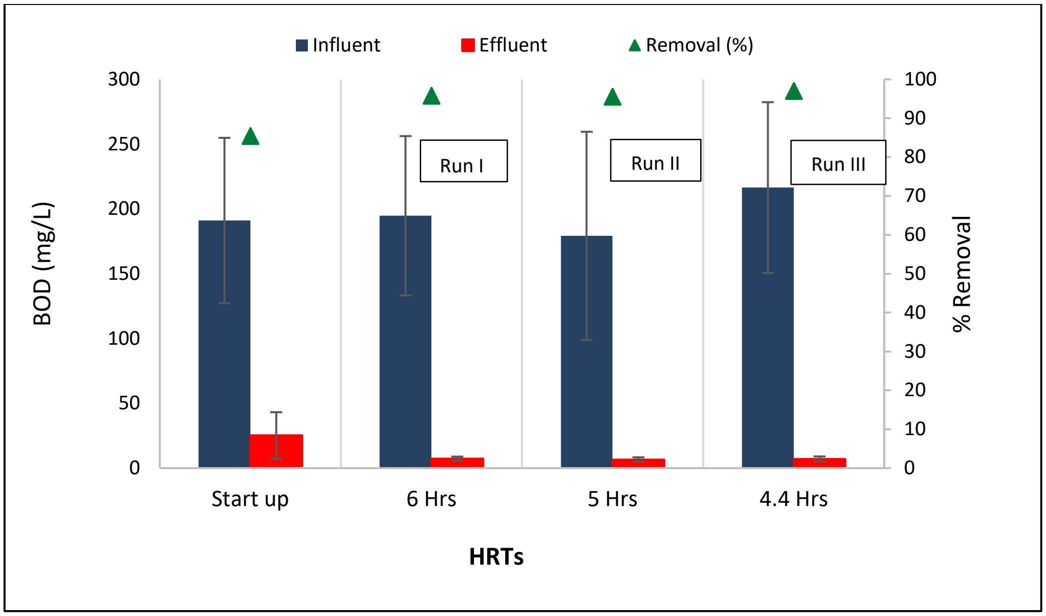

Fig. 3.5. BOD variation in influent and effluent samples of the pilot plant and its percentage removal.

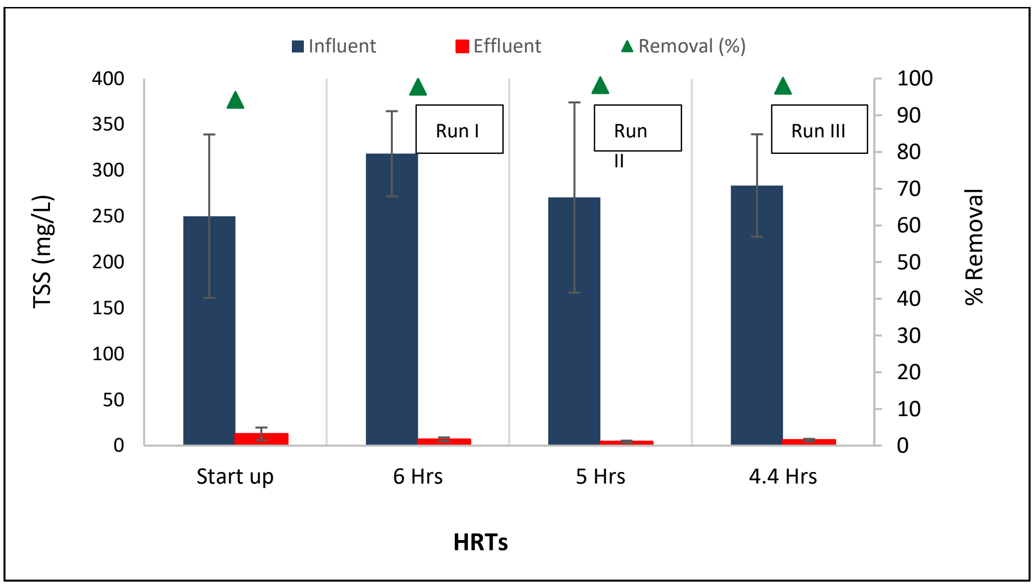

Fig 3.6. TSS variations in influent and effluent samples of the pilot plant and its percentage removal.

- ***Ammonia-N and Total Nitrogen (TN)***

Average removal of Ammonia-N and Total-N was observed 62% and 41% during startup, 95% and 75% in Run I, 94% and 82% in Run II and 96% and 86% in Run III respectively (Fig. 3.7 and 3.8).

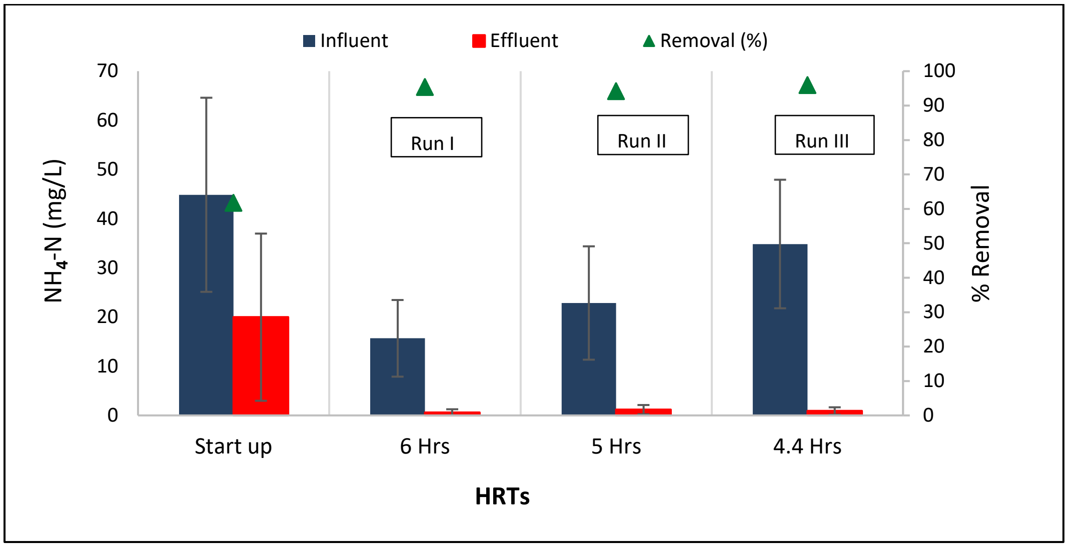

Fig 3.7. Ammonia-N variations in influent and effluent samples of the pilot plant and its percentage removal.

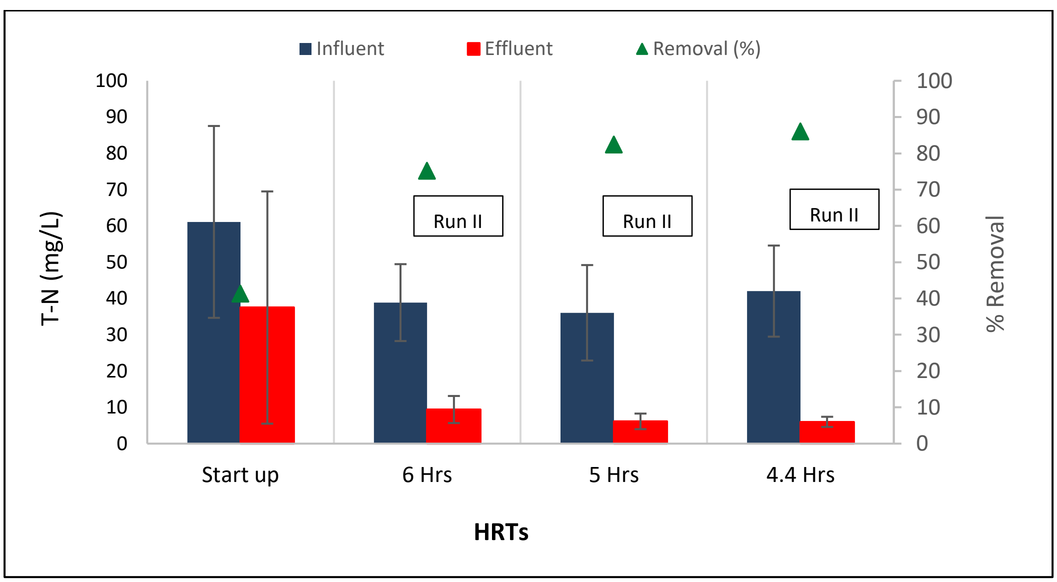

Fig 3.8. Total nitrogen variations in influent and effluent samples of the pilot plant and its percentage removal.

- **Ortho phosphate-P**

However, very less removal of Ortho phosphate-P was observed during all runs (Fig. 3.9).Average removal of Ortho phosphate-P was observed 40% during startup, and 35%, 21% and 18% in Run I, Run II, and Run III respectively.

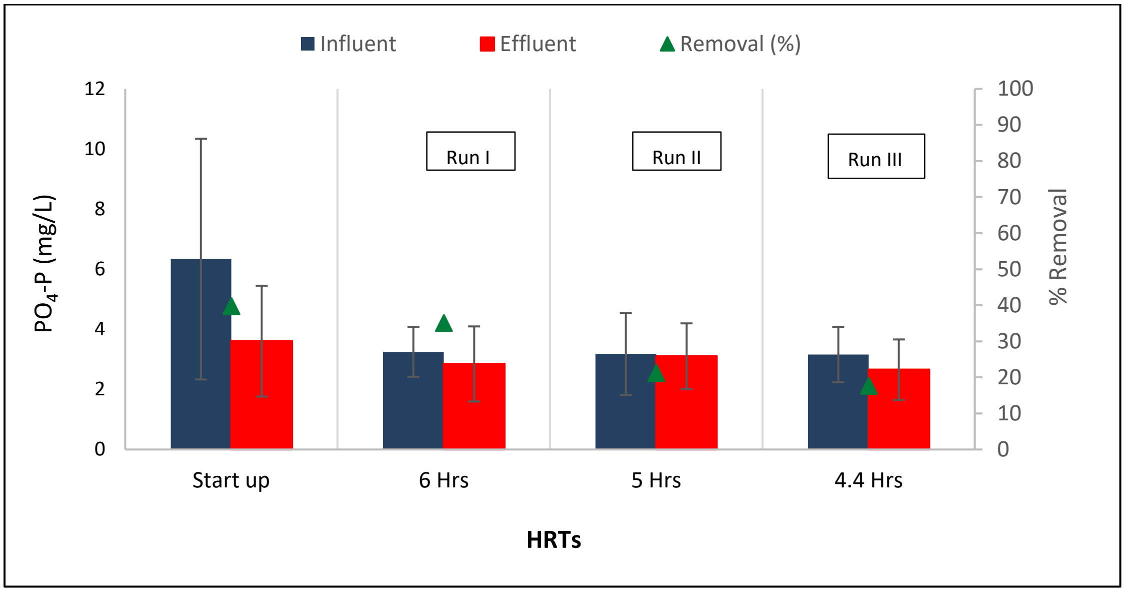

Fig 3.9. Ortho phosphate-P variations in influent and effluent samples of the pilot plant and its percentage removal.

3.6 Monthly performance evaluation plots

3.6.1 Operational sludge parameters

- ***MLSS***

The pilot plant was operated under average ranges of MLSS ~250 - 697 mg/L in PVA gel tank, 2982 – 5536 mg/L in anoxic tank and 3449 - 6803mg/L in Oxic tank(Fig. 3.10). Similarly, average ranges of MLVSS ~77 - 297 mg/L in PVA gel tank, 1321 - 2974mg/L in anoxic tank and 1630 - 3168mg/L in tank 3 (Aerobic tank)(Fig. 3.11).

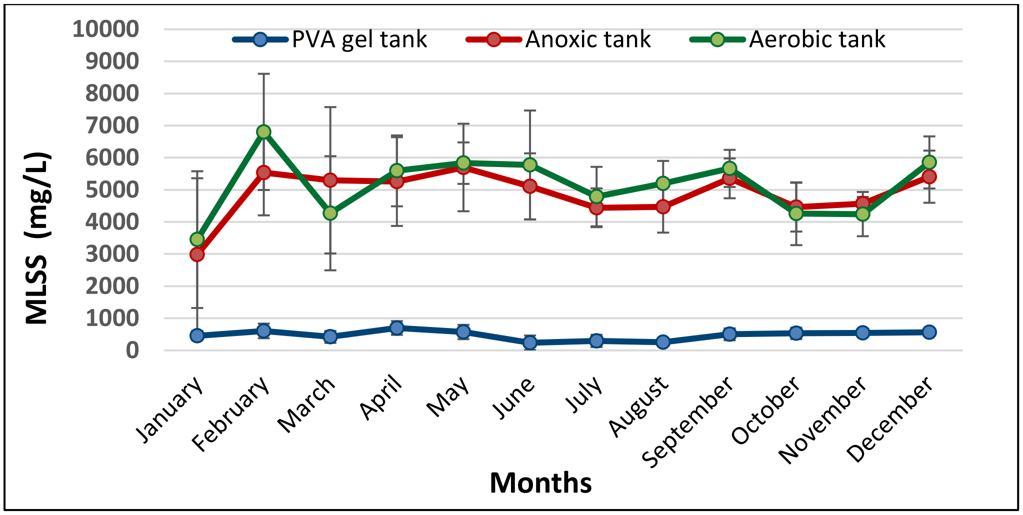

Fig 3.10. Variations in MLSS of the pilot plant during the process

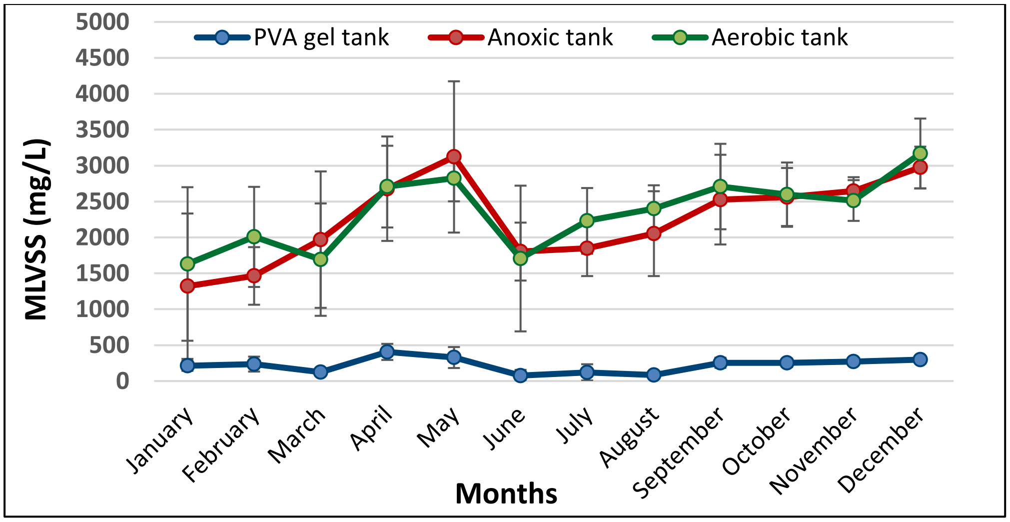

Fig 3.11. Variations in MLVSS of the pilot plant during the process

3.6.2 Physico-chemical parameters

- ***Temperature, pH, Oxidation reduction potential (ORP) and Dissolved oxygen (DO)***

The temperature of the influent and effluent was varies ~ 10 to 25 ± 2 °C which is ~ ±3-5°C ambient temperature (5-35°C) from startup phase to Run III.. The average pH of the influent was ~8.0 ± 0.5and for effluent was found to be ~ 7.5 ± 0.5, which is close to neutral, showing the buffering capacity of IFAS process.

Average value of ORP was observed ~ +39 to +68 mV, ~ -18to -156 mV and ~+25 to +85 mV in PVA gel tank, anoxic tank and oxic tank respectively during all phases. After completion of startup phase, ORP was negative in anoxic tank leads to denitrification. It is due to 20% diversion of raw sewage to anoxic tank as a carbon source during all Runs. DO was maintained ~ 5.4 to 7.4 mg/L , ~ 0.2 to 1.0 mg/L and ~ 2.9 to 7.6 mg/L in PVA gel tank, anoxic tank and 3rdoxic tank respectively throughout the process. All variation shown in Table 3.7.

Table 3.7: Temperature, pH, ORP and DO variations in all three reaction tanks of the pilot plant during the process.

Parameter	Tank	January	February	March	April	May	June	July	August	September	October	November	December
Temperature (ºC)	Ambient	16.5	24.5	23.7	28.5	31.5	31.5	29.7	29.3	28.8	26.4	21.1	15.7
	PVA gel tank	17.5	21.0	23.6	28.1	31.1	31.3	29.7	29.3	29.1	26.4	22.9	18.3
	Anoxic tank	17.5	20.9	23.7	28.3	31.4	31.5	29.4	29.2	29.0	26.4	23.0	18.4
	Aerobic tank	17.5	20.8	23.7	28.2	31.0	31.1	29.6	29.6	28.8	26.6	22.9	18.3
pH	PVA gel tank	8.1	8.1	8.6	8.5	8.2	8.2	8.2	8.1	8.1	8.2	8.2	8.2
	Anoxic tank	8.0	7.9	8.3	8.4	8.0	7.8	7.7	7.5	7.3	7.7	7.7	7.6
	Aerobic tank	8.0	7.8	8.5	8.3	8.0	7.8	7.8	8.0	7.8	7.5	7.4	7.4
ORP (mV)	PVA gel tank	51.8	56.1	64.2	38.7	57.2	67.9	63.3	51.3	49.5	55.1	34.9	56.8
	Anoxic tank	-158.0	-18.0	-61.7	-62.5	-156.1	-116.0	-138.7	-129.7	-145.6	-141.6	-145.5	-153.8
	Aerobic tank	67.8	56.7	65.7	52.3	44.4	84.9	75.0	65.0	64.0	63.6	39.2	52.4
DO (mg/L)	PVA gel tank	7.1	7.1	7.4	5.4	5.9	6.4	6.9	6.7	7.4	7.4	7.5	7.9
	Anoxic tank	1.6	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	Aerobic tank	7.6	3.8	5.9	4.9	2.9	4.2	3.6	4.3	5.1	4.0	4.1	4.9

- ***COD, BOD and TSS***

Fig. 3.12 and 3.13 depicts the remarkable reduction in BOD and COD with time in PVA gel. The average values of COD and BOD in the influent were ~ 257 ± 48 mg/l to 515 ± 126 mg/l and ~ 187 ±78 to 258 ± 35 and COD and BOD in the effluent were ~19 ± 5 mg/L to 83 ± 54 mg/Land ~4 ± 1 mg/L to 21 ± 9 respectively.

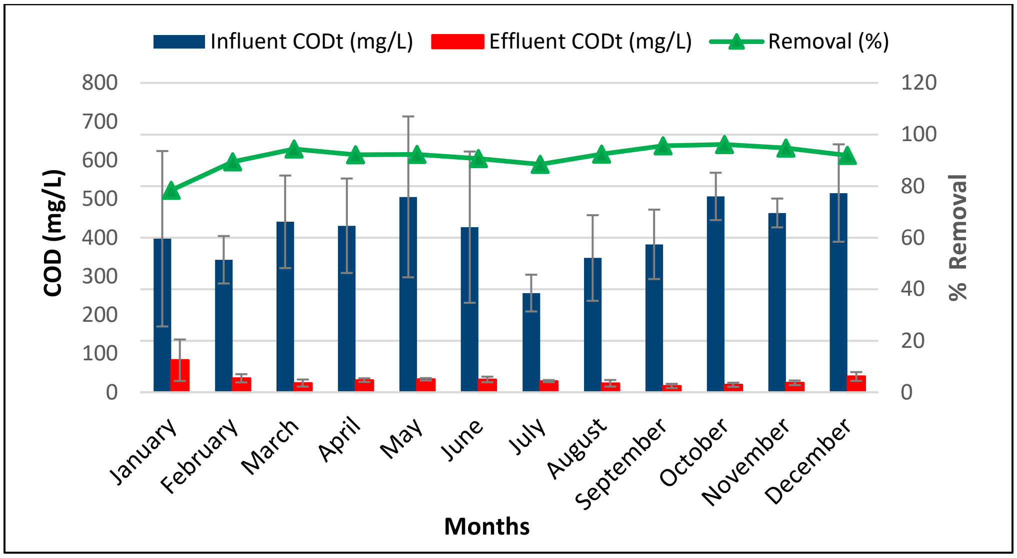

Fig 3.12. COD variations in influent and effluent samples of the pilot plant and its percentage removal.

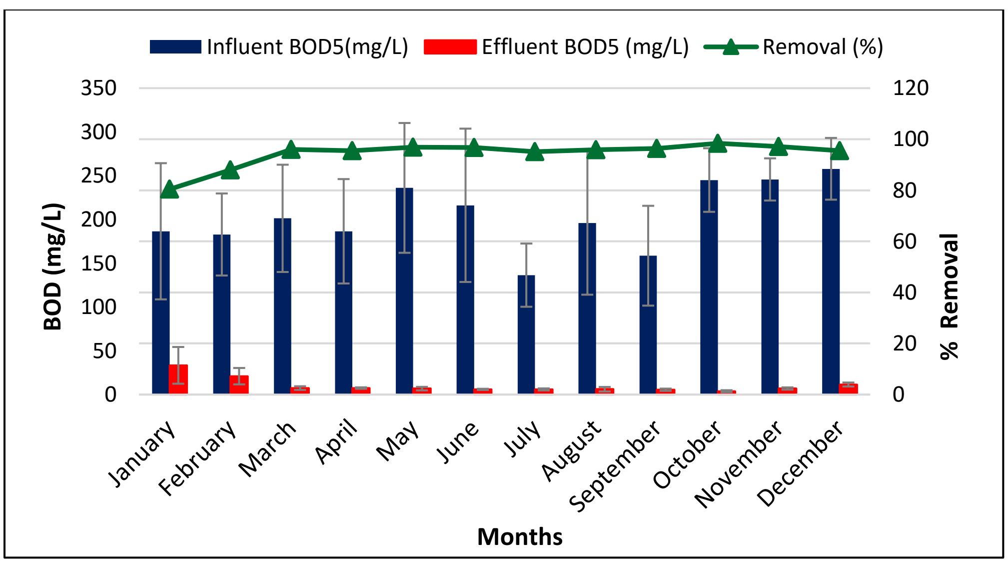

Fig 3.13. BOD variations in influent and effluent samples of the pilot plant and its percentage removal.

Average removal of COD and BOD were observed ~ 78% to 96% and ~80% to 98%respectively.Similarly, TSS decreased remarkably during all Run, with mean removal efficiency of ~ 82% to 98% (Fig.3.14).

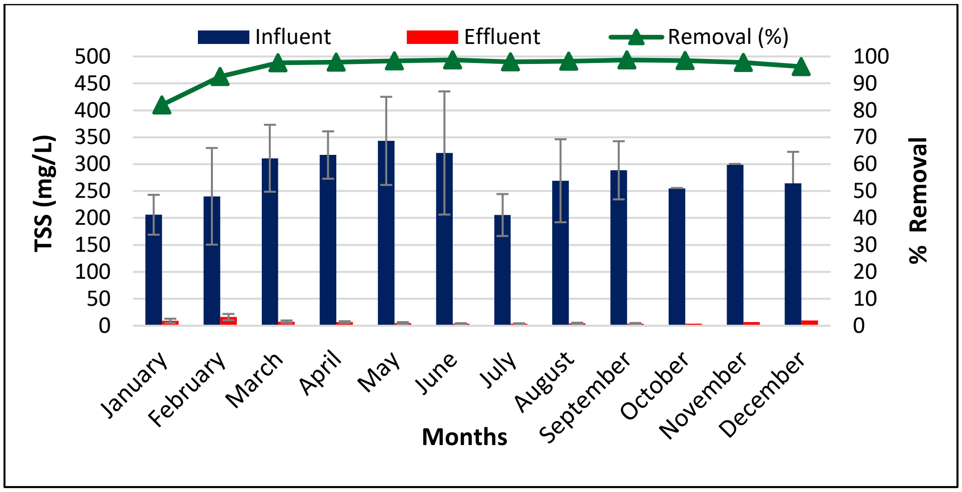

Fig 3.14. TSS variations in influent and effluent samples of the pilot plant and its percentage removal.

- ***Ammonia-N and Total Nitrogen (TN)***

Average removal of Ammonia-N and Total-N was observed 31% to 98% and 14% to 91% during process respectively (Fig. 3.15 and 3.16).

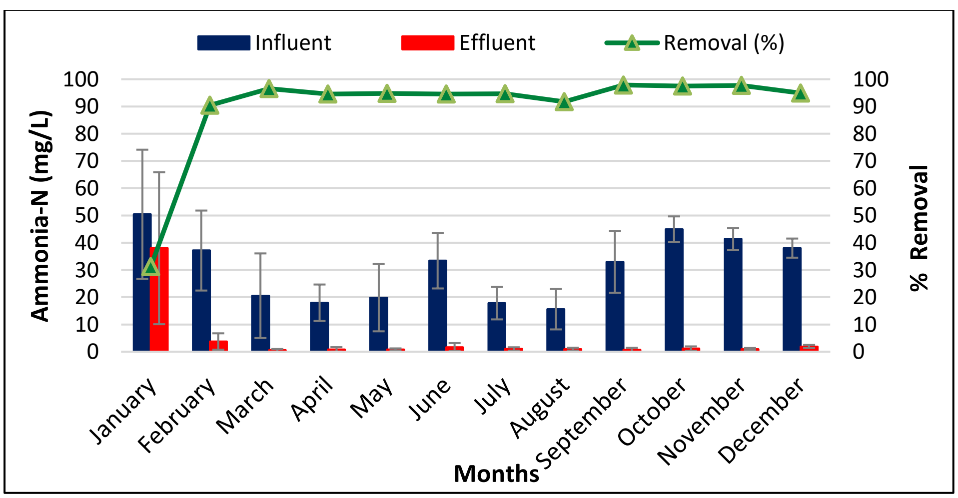

Fig 3.15. Ammonia-N variations in influent and effluent samples of the pilot plant and its percentage removal.

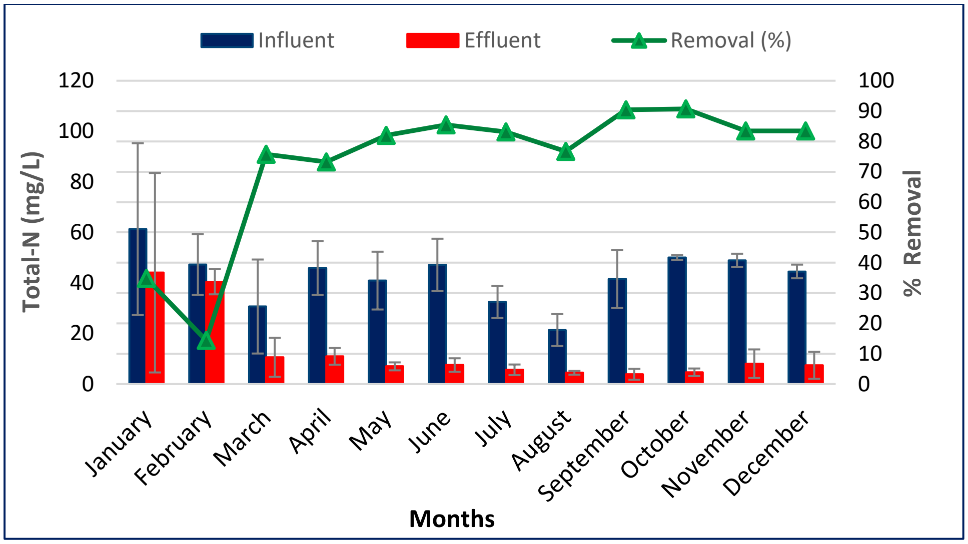

Fig 3.16. T-N variations in influent and effluent samples of the pilot plant and its percentage removal.

- **Ortho phosphate-P**

Very less removal of Ortho phosphate-P was observed during all runs (Fig. 3.17).Average removal of Ortho phosphate-P was observed 17% and 46% during process. The main mechanism is assimilation of phosphorus in cell

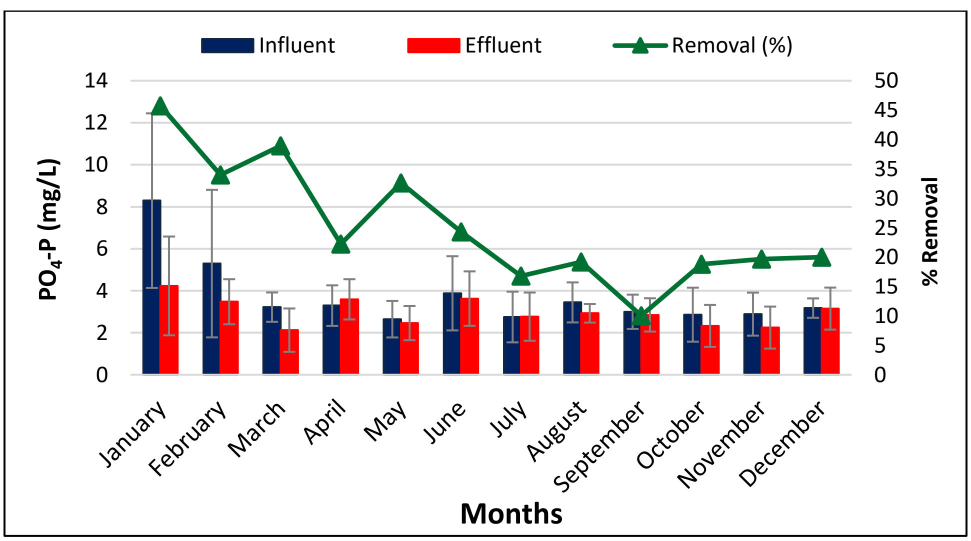

Fig 3.17. PO_4-P variations in influent and effluent samples of the pilot plant and its percentage removal.

3.8 Performance evaluation at low temperature

In Northern India, ambient temperature from last week of December to full month of January varies from 5 - 15°C. Hence, IFAS performance was critically observed during this period. The plant the this period, plant was operating at 4.4 h HRT up to 16 January 2018 with 4% filling percentage of PVA gel in tank 1 (PVA gel tank) but due to lowering of temperature, the performance started deteriorating in terms of BOD, TSS and TN. Hence, to improve plant performance, HRT of the system to 5h by replacing third aeration tank from 2 Liters to 5 Liters (from 17 January 2018 onwards).

3.7.1 Physico-chemical parameters

Fig. 3.18 and 3.19 depicts the effluent COD,BOD & TSS variation wrt to reducing temperature. The increase in effluent COD, BOD and TSS is more pronounced when the sewage temperature was lowering below 15-18 ºC. Both BOD and TSS exceed the desired values of 10 mg/L at 4.4 HRT under low temperature conditions. Hence, HRT of the system was increased from 4.4h to 5 h by replacing the HRT of final aeration tank from 0.4 h to 1 h.

The system shows remarkable improvement in effluent quality by increasing HRT.

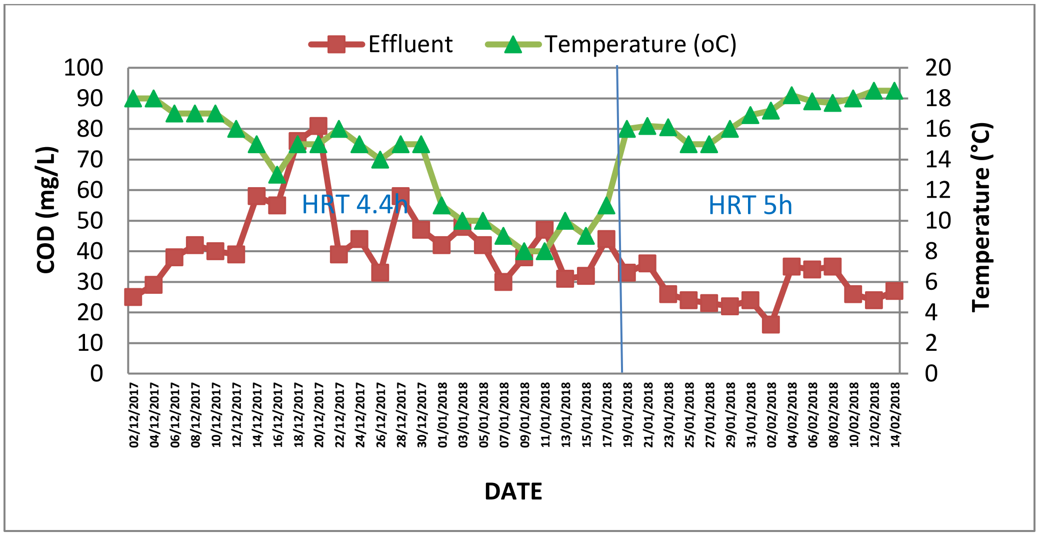

Fig 3.18. Effluent COD variation at low temperature and variable HRT.

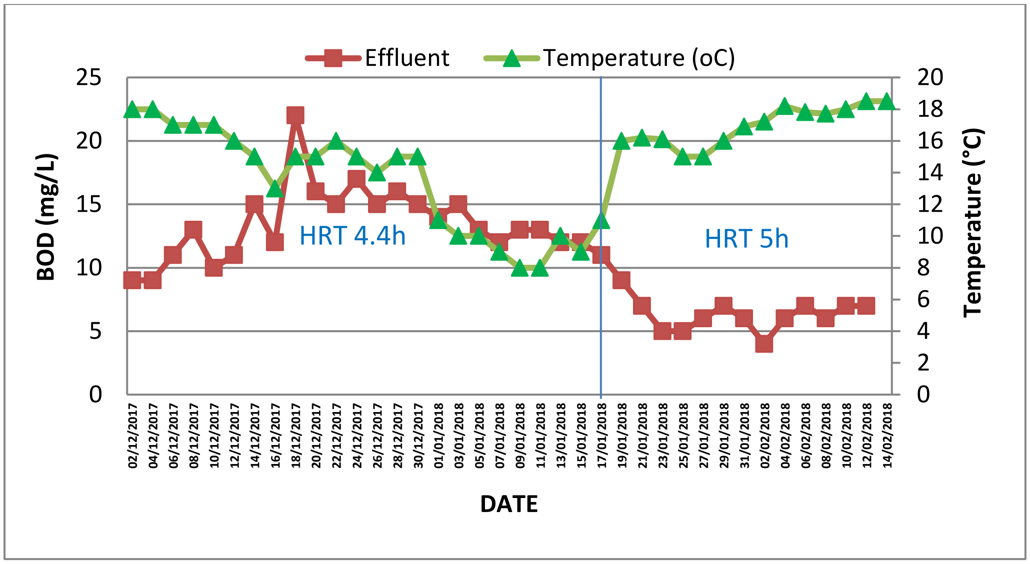

Fig 3.19. Effluent BOD variations at low temperature and low HRT

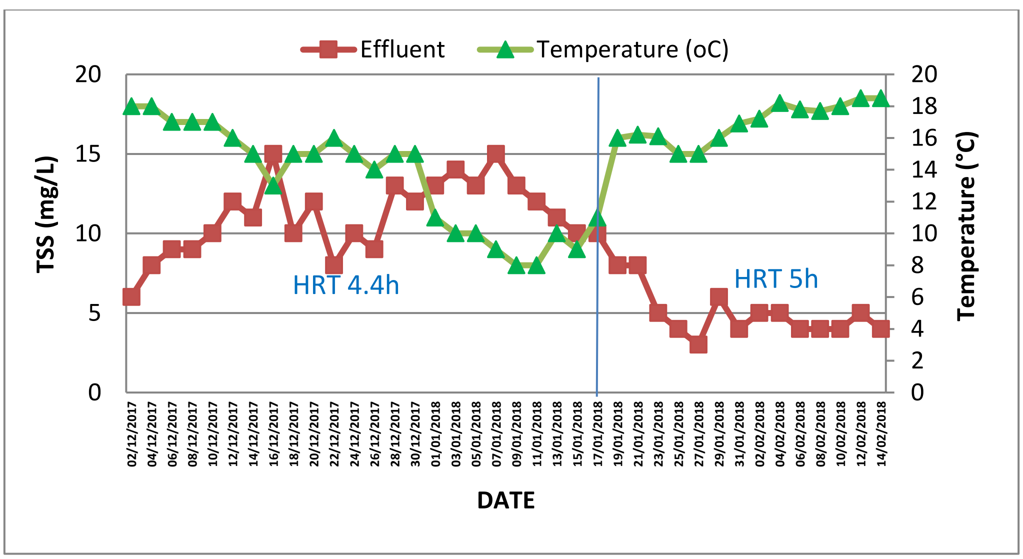

Fig 3.20. Effluent TSS variations at low temperature and variable HRT

- ***Ammonia-N and Total Nitrogen (TN)***

Maximum removal of Ammonia-N and Total-N was 97% and 89% respectively under 4.4h HRT, while ~100% and 89% was observed under 5h HRT during this period (Fig. 3.21 and 3.22).

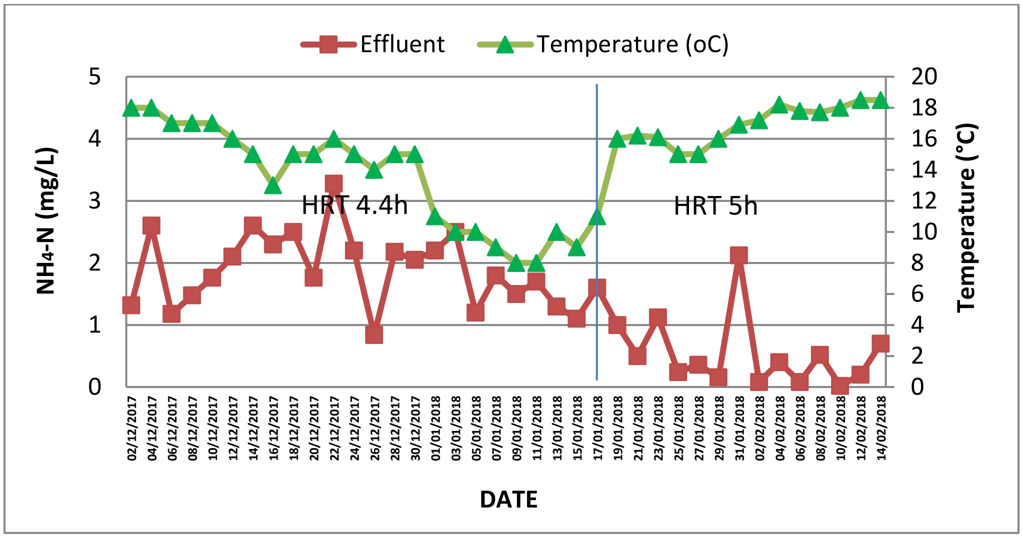

Fig 3.21. Effluent Ammonia variation at low temperature and variable HRT.

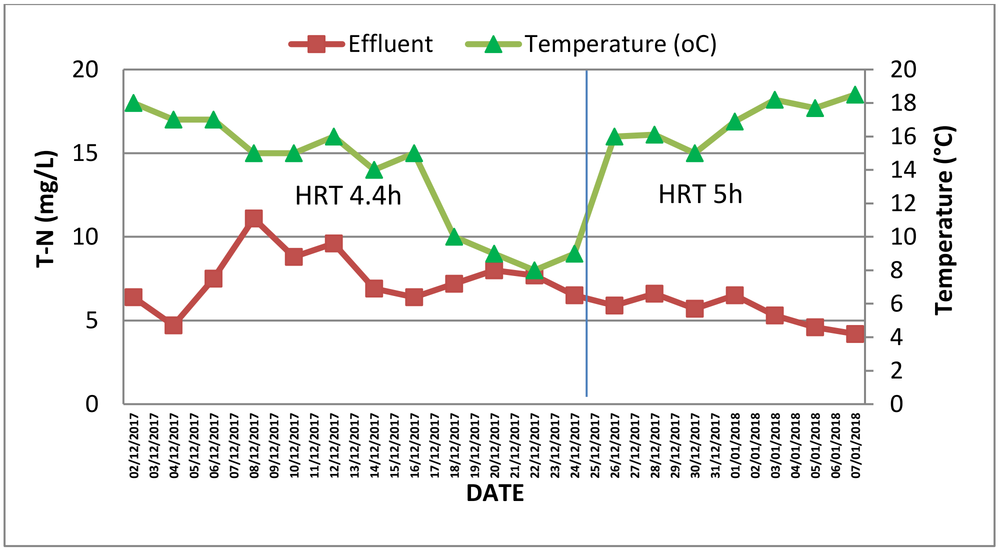

Fig 3.22. Effluent T-N variation at low temperature period and variable HRT .

4.0 ALUM DOSING FOR PHOSPHORUS REMOVAL

Additional alum dosing tests were performed in the pilot plant for the checking the efficacy of chemical phosphorus removal in the reactor. Different doses of alum (Aluminum sulfate, $Al_2(SO_4)_3.18H_2O$) were added to the final aeration tank and TP was analyzed before and after dosing . Table 1 shows the TP removal at various alum doses.

It is observed that alum dose of 60 mg/L can bale to reduce the TP level to less than 1 mg/L.

Table 4.1: TP removal at different dose of alum

Alum Dosing (mg/L)	Effluent(mg/L)		Percentage removal
	TP (Before treatment)	TP (After treatment)	
10	4.9	3.1	37
20	4.6	2.7	41
30	5.1	2.2	57
40	5.0	1.8	64
50	5.2	1.2	77
60	5.3	0.4	92

5.0 CHLORINE DOSE FOR DISINFECTION

Studies were conducted on the removal of fecal indicators by conventional chlorination process. Table 5.1 shows the removal of coliforms at different chlorine dose. Different doses of bleaching powder, $Ca(ClO)_2$ (30% available Cl_2) was added to final effluent for disinfection tests. It is observed that 3 mg/L chlorine dose @ 30 min HRT can remove all fecal indicators.

Table 5.1: Coliform removal at different dose of bleaching powder

Chlorine dosing (mg/L)	**Fecal Coliforms (MPN/100mL)**		**Log removal**
	Before (treatment)	**After (treatment)**	
1	2.4 X 10^3	930	1 Log
2	2.4 X 10^3	120	1 Log
3	2.4 X 10^3	<1.8	3 Log

6.0 SLUDGE WASTAGE AND SOLID RETENTION TIME

Table (6.1) provides average sludge quantity wastage during all operations of IFAS plant. Overall, average 12.5 g (1.28 L) sludge was wasted daily during the operation. Solid Retention

Operation	**Sludge wasted in L/d**	**Sludge wasted in g/d**

Time (SRT) was calculated on the basis of sludge mass wasted and the sludge biomass in in all the three tanks along with the average biomass concentration inside the beads. Overall operating SRT was found to be varying between 6-12 days (Fig 5.1).

6 hours HRT (Start-up)	1.71	About 12 g/d
6 hours HRT (Run I)	1.81	About 13 g/d
5 hours HRT (Run II)	0.95	About 9 g/d
4.4 hours HRT (Run III)	1.21	About 13 g/d
4.4 hours HRT (At lower temperature from December, 2017 to January, 2018)	1.53	About 12 g/d
AVERAGE	**1.28**	**12.5 g/d**

Table 6.1: Sludge production during start-up and all runs

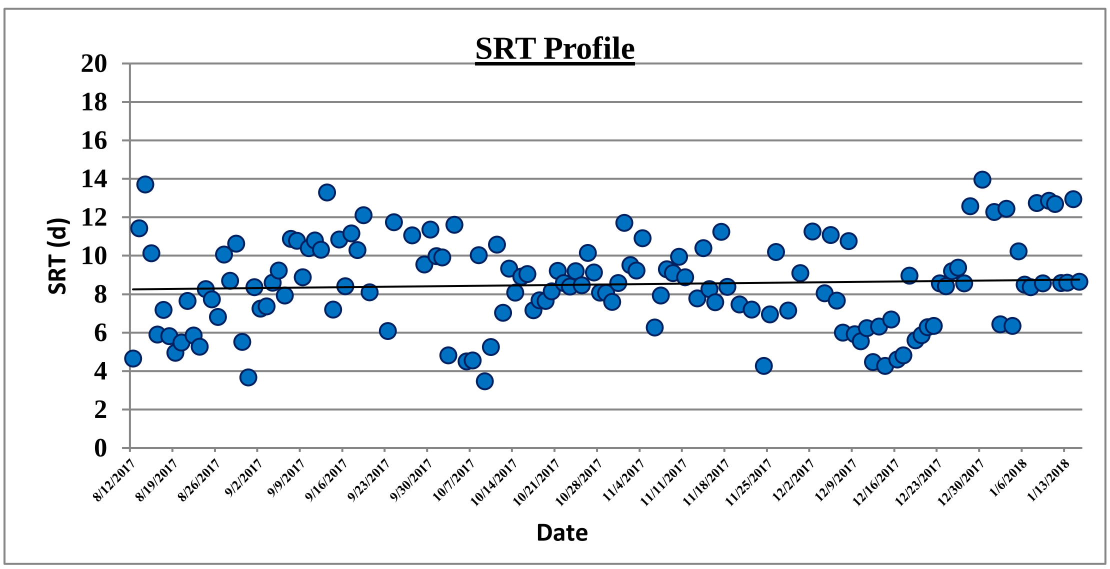

Fig 5.1: Variations in SRT during all operations

7.0 CONCLUSION

Long term pilot-scale studies were conducted on PVA Gel Aeration Tank-Anoxic Tank-Aeration tank-settling tank configuration on actual sewage under ambient conditions. The final goal is to achieve BOD, TSS and TN < 10 mg/L under all weather conditions. The reactor was operated at several HRTs and ambient temperature conditions.

It has been observed that the reactor operated at 6 hour HRT (2 h PVA Gel +2 h anoxic + 1 h Aeration Tank) with 7-10 days SRT and 20 % sewage augmentation to anoxic tank can provide the best quality of effluent in terms of BOD, COD, TSS and T-N. Only 4% PVA Gel in the first reactor can able to achieve more than 90 % nitrification and 50 % BOD/COD reduction. The second anoxic tanks further reduced the BOD and denitrify the nitrate produced in the PVA Gel reactor. The third tank removes the residual BOD, TSS of the effluent from anoxic tank.

PVA gel provides very high specific surface for complex bacterial community for nitrification, simultaneous nitrication-denitrification and organic removal in the same reactor.

Finally, it can be concluded that the above configuration can provided BOD, TSS & TN < 10 and NH4-N < 5 mg/L at 10-15 ^{o}C Sewage temperature. The final treated effluent not only satisfies stringent effluent standards but can also be utilized for non-potable reuse such as toilet flushing, fire protection, vehicle exterior washing, non-contact impoundments, horticulture, landscaping, agriculture.

References:

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APPENDIX F: ESTIMATION OF THE SPECIFIC SURFACE AREA FOR A POROUS CARRIER

Scientific paper

Estimation of the Specific Surface Area for a Porous Carrier

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Dedicated to the memory of the late Prof. Dr. Valentin Koloini

Abstract

In biofilm systems, treatment performance is primarily dependent upon the available biofilm growth surface area in the reactor. Specific surface area is thus a parameter that allows for making comparisons between different carrier technologies used for wastewater treatment. In this study, we estimated the effective surface area for a spherical, porous polyvinyl alcohol (PVA) gel carrier (Kuraray) that has previously demonstrated effectiveness for retention of autotrophic and heterotrophic biomass. This was accomplished by applying the GPS-X modeling tool (Hydromantis) to a comparative analysis of two moving-bed biofilm reactor (MBBR) systems. One system consisted of a lab-scale reactor that was fed synthetic wastewater under autotrophic conditions where only the nitrification process was studied. The other was a pre-denitrification pilot-scale plant that was fed real, primary-settled wastewater. Calibration of an MBBR process model for both systems indicated an effective specific surface area for PVA gel of 2500 m^2/m^3, versus a specific surface area of 1000 m^2/m^3 when only the outer surface of the gel beads is considered. In addition, the maximum specific growth rates for autotrophs and heterotrophs were estimated to be 1.2/day and 6.0/day, respectively.

Keyword: Surface area, biocarrier; biofilm; MBBR; nitrification rate; PVA gel

1. Introduction

Based on wastewater treatment performances of moving-bed biofilm reactor (MBBR) systems utilizing biocarriers of variable size and shape, the authors demonstrated that similar treatment levels could be expected where the loading rates were compared on an equal footing with respect to the effective surface area of the biocarriers.[1,2] Surface-area loading rate was thus shown to be a valuable tool not only for design of MBBR unit processes but also for making fair comparisons between MBBR systems regardless of the type of biocarrier being used where the effective surface area for biomass attachment can be known.

Working with the spherical PVA-gel biocarrier, though, that relies predominately on the network of microscopic pores in the core of the gel beads for retention of active biomass, the authors were confronted with the dilemma of how to determine the effective surface area for biofilm growth.[3] They thus set out to make a comparison between a PVA-gel based MBBR unit process with that of another unit process containing a biocarrier for which the surface area characteristics are easily know by direct observation. Thus, employing the cylindrical Kaldnes K1 biocarrier (effective specific surface area, 500 m^2/m^3) in parallel testing, they were able to establish nearly equal relative maximal nitrification rates for the two units. However, considering that a lower volumetric filling of PVA gel (9.7%) versus that of K1 (37%) was used, the observed results could not be explained by considering only the measurable exterior specific surface area (1000 m^2/m^3) of the PVA-gel beads; rather, a considerably larger specific area was required (2500 m^2/m^3), inferring a significant contribution from the porous interior of the gel beads.

Parametric models such us ASM1 used in simulation software are mainly used for the design and optimization of wastewater treatment plants.[4] The most crucial steep in the overall modeling process is the calibration.[5] This can be done from different approaches involving the knowledge and experience of the modeler. Some proposed a procedure for calibrating a general model from a process engineering perspective.[6] The most important elements included the determination of reactor hydraulics, characterization of wastewater and biomass as well calibration of model parameters.

The aim of the study was to estimate by calibration the effective specific surface area for PVA-gel beads under two differing testing conditions using the simulation software known as GPS-X. The testing modes consisted of a lab-scale reactor that was fed synthetic wastewater and operated solely under autotrophic conditions and a pilot-scale plant that was fed real municipal wastewater and thus operated simultaneously under heterotrophic and autotrophic conditions. Both tests were conducted under previous studies[3,8] and thus were not designed and operated for nor influenced by the purpose and goal of this study.

Based on the application of the GPS-X simulation tool to the experimental data the effective specific surface areas were estimated and evaluated in light of the limitations of the simulation methods used.

2. Materials and Methods

2. 1. Carrier

The PVA-gel carrier is slightly heavier than water (S.G., 1.025). The gel beads Figure 1 (a) consist of 4-mm diameter spheres that are hydrophilic in nature and have a very porous structure with only 10% solids and a continuum of passages 10 to 20 μm in diameter tunneling throughout each bead Figure 1 (b). A volume of 100 mL can hold approximately 2000 beads. Water displaced by the gel beads is 0.08 m^3/m^3 at a 9.6% volumetric filling. It is claimed that bacteria cultivated inside the core of the beads do not slough off and are protected from predation, thus being highly retained.[7] The gel beads are typically used at volumetric packing ratios of only 5% to 15% versus much higher ratios of 30% to 70% common to the Kaldnes K1 carrier. Loading rates are normally determined with respect to the settled-bed volume of the PVA-gel beads (or total reactor volume with consideration to filling ratio) instead of the surface area of the carrier because the biomass is cultivated and retained primarily inside the beads rather than on the surface.[8] In this paper the rates are with respect to the reactor volume.

2. 2. Lab-scale Test

The lab-scale reactor had a volume 3.54 L and was filled with 0.34 L (9.6 vol%) of the PVA-gel carrier (Figure 2). The gel beads had previously been enriched with heterotrophic and autotrophic biomass and were taken from an oxic reactor of a semi-industrial-scale (200 L) pilot plant used for nitrogen removal and fed for more than one year with wastewater following the primary mechanical stage of the Domzale-Kamnik, Slovenia, wastewater treatment plant. The reactor was continuously fed with synthetic wastewater containing only ammonium ($(NH_4)_2SO_4$), phosphate (KH_2PO_4) and growth minerals (Nitritox monitor, Growth Powder, Art. 704751; LAR Germany). The average concentrations in the synthetic wastewater were 85.6 ± 3.8 mg NH_4–N/L, 0.7 ± 0.1 mg PO_4–P/L, 8.2 ± 0.3 mg NO_x–N/L, 12.5 ± 1.5 mgCOD/L and some trace compounds. The nitrification process was automatically regulated to pH 7.5 ± 0.1 using a buffer solution (Na_2CO_3). With selective enrichment over six months, most of the heterotrophic organisms were considered washed out of the reactor, as was evident by changes in the appearance of the biofilm.

During the six months of selective feeding, nitrification activity was regularly checked and the ammonium loading was increased stepwise to maintain at least 1 mg-NH_4–N/L in the effluent. The reactor was operated at a temperature of 20 ± 1 °C and oxygen was maintained at

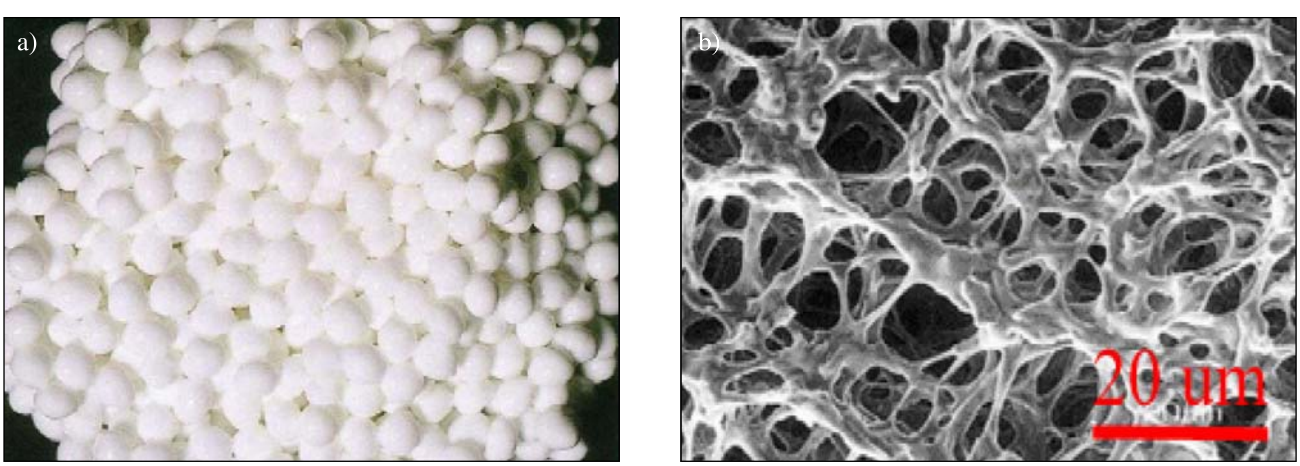


Figure 1: (a) Appearance of the PVA-gel carriers before use (Kuraray, Japan); (b) Surface of a PVA-gel bead showing the microscopic structure.[7]

8.0 ± 0.5 mg/L. The inner walls of the lab-scale reactors were cleaned weekly to reduce bacterial wall-growth effects. Influent and effluent samples were analyzed for ammonium, nitrate and nitrite nitrogen and Kjeldahl nitrogen according to ISO standards. The influent and effluent values were based on daily spot samples. At the end of the test, a mixer was used to remove biofilm from the carrier to analyze the biomass composition. The COD concentration of the biomass was 1.2 mgCOD/mgVSS and the nitrogen content 0.034 mgN/mgCOD.

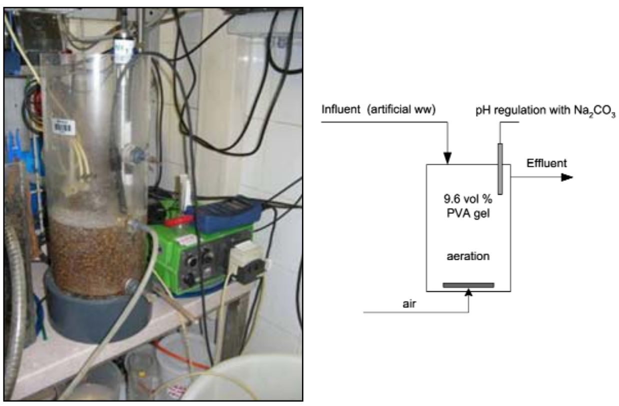


Figure 2: Photo and schematic diagram of the lab scale pilot plant.

2. 3. Pilot-scale Test

The semi-industrial-scale pilot plant consisted of two biological parts: the first being a nitrogen-removal process, consisting of pre-denitrification with recycle of nitrified liquor (Figure 3). This process included an anoxic reactor followed by an aerobic (oxic) reactor, both containing the PVA-gel biocarrier. Biological treatment activity was attributed to attached growth because suspended activated sludge was not returned to (or retained in) this process. Subsequently, a sludge elimination process was used for total-oxidation of excess organic solids (biomass). The experimental program included a series of seven runs conducted at various loading rates (dependent on hydraulic retention time (HRT) and influent composition), internal recycle levels and temperatures. All reactors used in this study were constructed of Plexiglas and had operational volumes of 200 L. The anoxic and oxic reactors of the nitrogen-removal process contained a 15% volume of PVA-gel beads, which were kept in suspension by mechanical mixing and retained in their respective zones by using slotted strainers. Detailed results were presented in a previous study.[8] In this paper we considered only the data of the nitrification and denitrification processes in the pilot plant and not the sludge elimination unit (Tox).

Wastewater after the mechanical stage of the Domžale-Kamnik wastewater treatment plant was fed to the system and recycled between units by using peristaltic pumps. Inflow parameters measured on-line consisted of TOC and total nitrogen (TN) (Shimadzu, Japan) and NH_4–N (WTW, Germany). Treatment performance was monitored by following total Kjeldahl nitrogen (TKN), NH_4–N, NO_2–N, NO_3–N, COD and BOD_5 as determined on spot samples. All analysis of spot samples were conducted in accordance with ISO methods. Samples for determi-

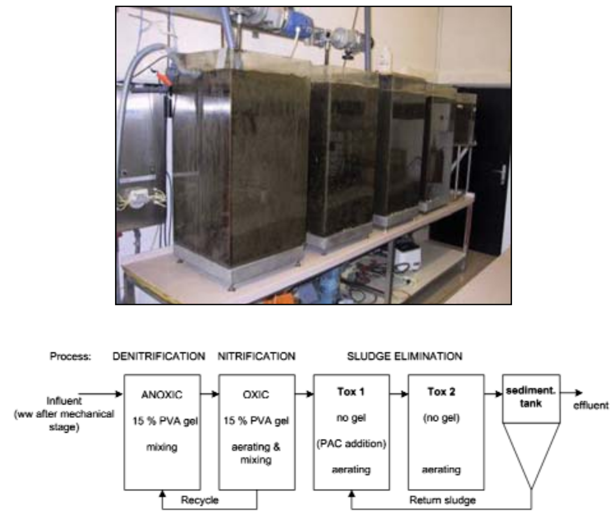


Figure 3: Photo and schematic diagram of the semi-industrial scale pilot plant.

nation of soluble components were passed through Sartorius cellulose nitrate membrane filters prior to analysis.

2. 4. Mathematical Model

The specific surface area was estimated by using the GPS-X simulation software.[9] To estimate the surface area in the MBBR process, a hybrid-system model was used, which combines a standard plug-flow tank configuration with suspended growth biomass, and a biofilm model representing fixed-film growth on the carrier inserted into the tank. In the model, the reactor contents are represented with 6 layers, the first layer representing the bulk liquid, while the remaining five flat layers represent the biofilm formed on the carrier. The transfer of soluble state variables between each of these layers is by diffusion only (Fick's second law). Each layer of the biofilm is modeled as a CSTR with the same biological reactions as the suspended-growth biological reactor. In our case we used the Mantis model, which is similar to the well-known Activated Sludge Model No. 1 (ASM1)[4] with some minor modifications[9]. Attachment and detachment coefficients are used to provide for a means of transfer of particulate components between the biofilm surface and the liquid.

The default kinetic and stoichiometric GPS-X parameters were used in our study, except the maximal autotrophic and heterotrophic growth rates were adjusted to get the best fit with the experimental data. The range in the literature for maximal growth rate for the autotrophs is from 0.14/day to 1.12/day and for the heterotrops is from 1.3/day to 6/day. The calibration of the model was done by a manual procedure based on visual inspection of the simulated and measured results.

3. Results and Discussion

3. 1. Lab-scale Test

The wastewater used for the lab-scale test consisted of tap water supplemented only with ammonia nitrogen, thus a detailed characterization was not deemed necessary. In Figures 4 and 5, the best fit of the simulation results with the experimental data was shown to occur at a specific surface area of about 2500 m^2/m^3 with a maximal autotrophic growth rate of 1.2/day, which is higher than the model's default value of 0.75/day, though within the range of typically reported values. The specific surface area obtained by this method is in agreement with estimated area in our previous study by making a comparison with the well characterized Kaldnes K1 carrier having a known specific surface area.[3] With selective feeding of only ammonia nitrogen and no substances that could inhibit growth of nitrifying organisms, a maximum nitrification rate as high as 3.1 gNOx–N/m^2.day was obtained in the previous study.[3] Typically, nitrification rates with mixed cultures are observed only to reach about 1.5 gNOx –N/m^2.day (at 20 °C). Microbiological analyses (PCR 16SrDNA) have shown that biofilm cultures fed only with an ammonium substrate select for different species of nitrifying organisms than of those fed with municipal wastewater.[10,11] Although the influent contained only 12.5 mgCOD/L, some heterotrophic microorganisms would still be thought to be present. At the low influent COD concentration used here, though, there was no observable influence of heterotrophic activity in the simulation study. Simulation with influent COD concentration higher than 50 mg/L, though, did show an influence on nitrification performance coupled with a poorer correlation with the experimental data (results not shown).

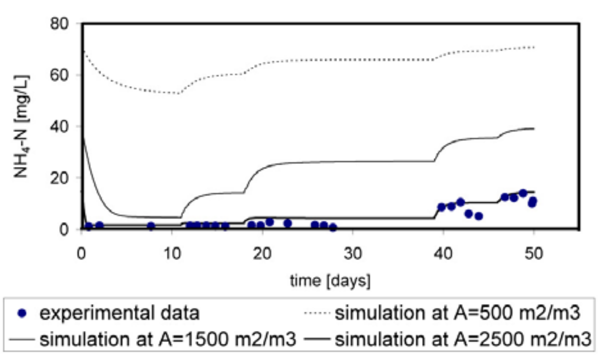


Figure 4: Correlation between experimental data for effluent NH_4–N and simulation curves at different specific surface areas.

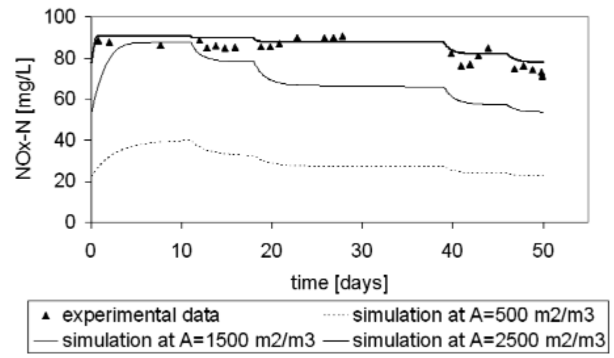
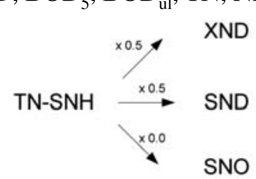


Figure 5: Correlation between experimental data for effluent NO_x–N and simulation curves at different specific surface areas.

The GPS-X simulation indicated that the biofilm thickness was 30 µm, the concentration of active autotrophic biomass was 48.2 mg COD/L (0.021 mgCOD/carrier) and heterotrophic biomass was 16.4 mg COD/L (0.007 mgCOD/carrier); thus the autotrophic biomass would appear to be 74.6 % of all active biomass in the biofilm.

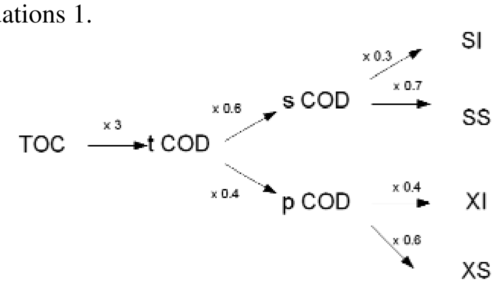
3. 2. Pilot-scale Test

The pilot plant was operated for more than one year under various testing conditions.[8] Influent levels of TOC, TN and ammonia were followed online and daily averages of the data were applied to the GPS-X model according to our prior studies.[12] For use in the GPS-X mathematical model, constant ratios between measured data (TOC, TN, NH_4–N) and model state variables (XND, SND, SNO, SS, SI, XS, XI) were maintained for the entire period. The ratios in Equations 1 and 2 are averaged factors from two weeks of detailed influent wastewater characterization and were calculated using the Hydromantis Influent advisor software. The measured parameters were total and soluble COD, BOD_5, BOD_{ul}, TN, NH_4–N, NOx–N, TSS and VSS.



(1)

The levels of particulate organic nitrogen (XND), soluble organic nitrogen (SND) and nitrate nitrogen (SNO) were calculated from the measured values of total nitrogen (TN) and ammonia nitrogen (SNH) as shown in Equations 1.



(2)

From the known TOC data, total COD (tCOD), soluble COD (sCOD) and particulate COD (pCOD) were calculated first and then the model state variables as soluble inert COD (SI), soluble biodegradable COD (SS), particulate inert COD (XI) and particulate biodegradable COD (XS) were determined based on known relationships as shown in Equations 2.

For this modeling study, data covering 326 consecutive days of operation in the pilot-scale test (Runs II through VIII) were used.[8] Time-series data for HRT, reactor temperature, influent TOC, influent TN, and influent NH_4–N are shown in Figure 6 and Figure 7.

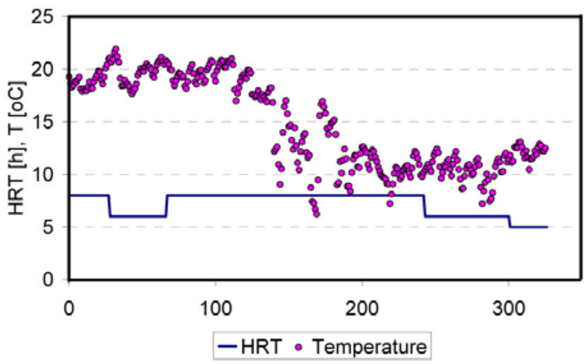


Figure 6: Time-series data for total HRT in the pilot plant and the temperature in the first reactor.

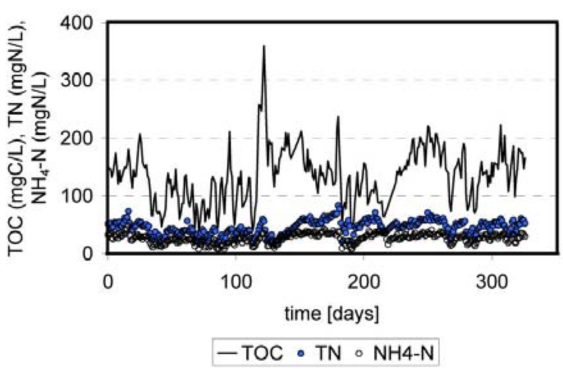


Figure 7: Time-series data for daily average values for influent TOC, TN and NH_4–N.

As shown in Figure 8 through 13, specific surface areas from 500 to 3000 m^2/m^3 were evaluated in an attempt to calibrate the model to the experimental data. For this purpose, simulation curves for ammonia nitrogen, nitrate nitrogen and COD in the pre-denitrification reactor and in the post-nitrification reactor were used. The overall best fit with the experimental data occurred at a specific surface area between 2000 and 2500 m^2/m^3, although on some days the correlation was very poor, for which various reasons are considered:

– Assuming a constant ratio between the measured influent parameters and the model variables may significantly miss the mark in some cases.
– The number of sampling events under some operational conditions may have been inadequate for accurate determinations.
– The possibility of inhibitory substances from local industries appearing in the wastewater used as influent for the pilot study may have occurred.
– With great variations in loading conditions at times, shock loads may have temporarily had inhibitory effects on treatment performance.
– For the GPS-X model, certain parameters in the biofilm model were assumed, leading to some degree of uncertainty in the simulation results.
– The model assumes the biofilm to be a flat surface; the actual conditions, though, in the porous matrix of the PVA gel could be quite contorted and in cases perhaps even non-biofilm like in nature. In this case, though, the surface of the PVA gel is spherical and the biofilm thickness appears to be about 300 μm; thus, some deviations can be expected.

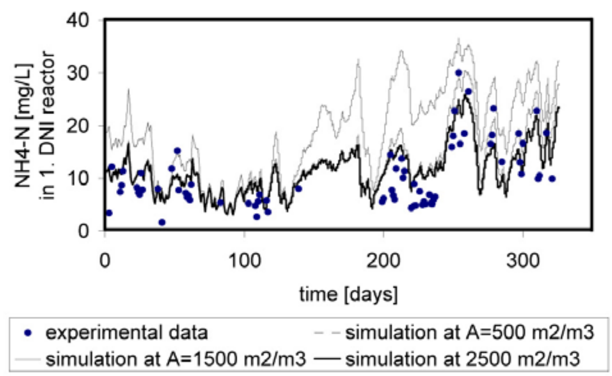


Figure 8: Simulation of ammonium at different specific surface areas in the anoxic reactor.

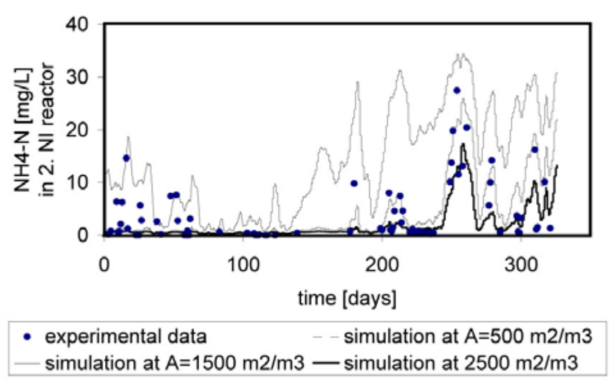


Figure 9: Simulation of ammonium at different specific surface areas in the oxic reactor.

Furthermore, some influence on the modeling accuracy might be due to the assumed heterotrophic growth rate. A change in the maximal heterotrophic growth rate from the default value of 3.2/day to 6.0 /day does offer an

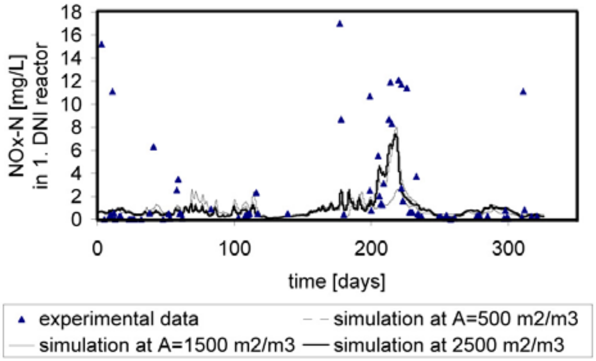


Figure 10: Simulation of nitrate at different specific surface areas in the anoxic reactor.

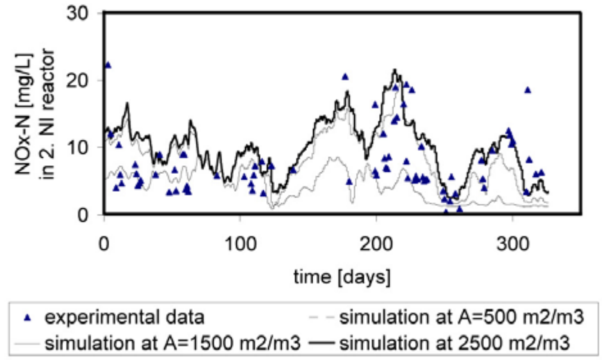


Figure 11: Simulation of nitrate at different specific surface areas in the oxic reactor.

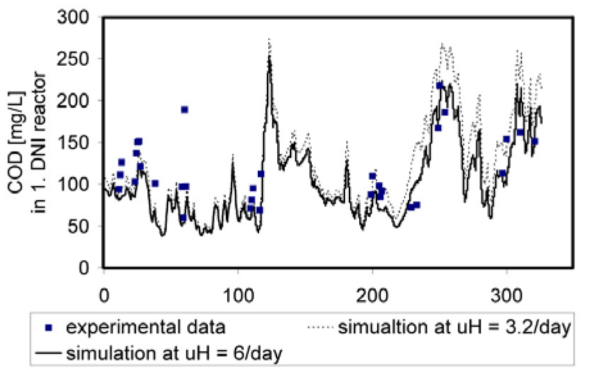


Figure 12: Simulation of filtered COD at different heterotrophic growth rates in the anoxic reactor.

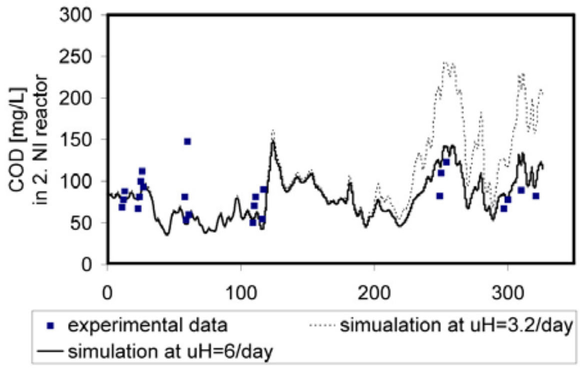


Figure 13: Simulation of filtered COD at different heterotrophic growth rates in the oxic reactor.

improved correlation between the simulation results and the experimental data (see Figures 12–13). For the autotrophic decay rate the default GPS-X value (0.04/day) was used.

The maximum simulated nitrification rate was 14.5 mgN/L.h (0.9 gN/m^2 day) at 16 ºC, versus 15 mgN/L.h at 15 °C in the experimental data.[8] Furthermore, the GPS-X simulation indicated that the biofilm thickness was 290 µm, the concentration of active autotrophic biomass in the second nitrification reactor was 213 mgCOD/L (0.07 mgCOD/carrier) and heterotrophic biomass was 1937 mgCOD/L (0.63 mgCOD/carrier); thus the autotrophic biomass would appear to be 10% of all active biomass in the biofilm.

Table 1: Comparison of different parameters under the two testing conditions

parameter	**unit**	**lab -scale nitrification reactor**	**pilot-scale nitrification reactor**
max. obtained nitrification rate	mg N/m^2.d	3.1 (20 °C)	0.9 (15 °C)
1.1 (20 °C)			
best fit for the specific surface area	m^2/m^3	2500	2000–2500
bifilm thickness	µm	30	290
active autotrophic biomass:			
biofilm+suspended	mgCOD/L	48.2	213
biofilm	mgCOD/L	40.1	209
biofilm	mgCOD/carrier	0.021	0.07
active heterotrophic biomass:			
biofilm+suspended	mgCOD/L	16.4	1937
biofilm	mgCOD/L	13.8	1878
biofilm	mgCOD/carrier	0.007	0.63
autotrophic fraction in total biomass	%	75	10

3. 3. Comparison

In Table 1 the comparison between different parameters under two testing conditions are presented. From the table we can see that the maximum obtained nitrification rate and autotrophic fraction of the biomass is higer in lab-scale nitrification reactor fed only with artificial wastewater. The best fit for the specific surface area was in the same range for both the lab-scale and pilot-scale plants (2000–2500 m^2/m^3).

4. Conclusions

Commercially available simulators with process models capable of describing biofilm systems, can assist in the estimation of unknown factors such as the effective surface area of porous media. For the PVA-gel carrier, using a calibrated mathematical model, the effective specific surface area was shown to be 2500 m^2/m^3, which was in agreement with that obtained by other means in a previous study. In this study, though, the correlation between experimental data obtained using real wastewater was not always in good agreement with simulated results. As an avenue of further research, more understanding is needed on the use of the hybrid model function for simulation of the spherical biocarriers where the biofilm thickness is in excess of 100 μm.

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Povzetek

Učinkovitost procesa čiščenja odpadne vode s pritrjeno biomaso v obliki biofilma na nosilnih elementih temelji na celotni razpoložljivi površini nosilnega elementa v reaktorju. Specifična površina je tako parameter, ki omogoča primerjavo delovanja procesov čiščenja odpadne vode z uporabo različnih nosilnih elementov. V naši študiji smo določili aktivno specifično površino sferičnih poroznih nosilnih elementov iz polivinil alkohola (PVA gel) podjetja Kuraray (Japonska), katere predhodne študije so pokazale učinkovito naselitev tako heterotrofnih kot avtotrofnih mikroorganizmov. Določitev smo izvedli na osnovi kalibracije napovedi matematičnega modela v GPS-X (Hydromantis) orodju in empiričnih rezultatov procesa čiščenja v dveh različno vodenih pilotnih sistemih. Prvi sistem je bila pilotna naprava, kjer je potekal proces nitrifikacije z dotokom umetno pripravljene odpadne vode le na avtotrofnem nivoju. Drug sistem pa je bila pilotna naprava, kjer se je vršil proces denitrifikacije in nitrifikacije z dotokom odpadne vode po mehanski stopnji. Kalibracija obeh procesov je pokazala, da je najboljše ujemanje z merjenimi podatki pri aktivni specifični površini PVA gela 2500 m^2/m^3, maksimalni hitrost rasti avtotrofov 1,2/dan in heterotrofov 6,0/dan. Izračunana zunanja površina aktivnega PVA gela je znašala 1000 m^2/m^3.