Vortex Powered Aeration Standard 3022 (VPA-S3022) Technical Report

VPA™ Retrofit of a Municipal Wastewater Treatment Facility

Executive Summary

A municipal wastewater treatment plant in Ireland, serving a population equivalent (PE) of approximately 3,333, faced challenges of rising load variability and ageing aeration equipment. The facility's diffused aeration system inefficiently managed fluctuating loads which resulted in increased energy requirements. Compounding these issues, ongoing blower maintenance and diffuser fouling progressively reduced system performance. This would have eventually resulted in significant costs being incurred to drain the reactor for cleaning or replacement of the existing equipment. The aeration facility was upgraded in 2021 with Vortech's Vortex Powered Aeration (VPA™) technology as part of an innovation demonstration project with the utility. The VPA-S3022 provided a solution that addressed the aforementioned challenges. It was easily retrofitted to the existing activated sludge reactor in less than three days, where the existing diffused aeration equipment was kept in place. All VPA™ equipment for inspection and maintenance was made accessible above the water level, resulting in no requirement for future tank draining which transformed site safety and maintenance requirements. Improved process energy efficiency was realised by the VPAs significant turn down capacity together with VPA™ Cyclonic Pulse™ technology which enabled enhanced dissolved oxygen control during aerobic and anoxic periods. Since commissioning, no unplanned maintenance or non-compliance issues were encountered demonstrating the reliable nature of VPA™ technology. In summary, the upgrade resulted in a 41% saving in specific energy consumption, equal to an emissions reduction of 8,900 kg$CO_{2\text{-}Eguiv}$ per annum, and is projected to lower maintenance costs by 80% at the facility. In aggregate, a 32% reduction in total lifecycle costs is expected at the facility over 35 years.

Introduction

Overview and Challenges

The secondary biological treatment process of a municipal wastewater treatment plant (WWTP) in Ireland was upgraded in 2021 to include a new aeration system with Vortech's Vortex Powered Aeration™ (VPA™) technology. The WWTP had a design capacity population equivalent (PE) of 3,333 with an average PE of 1,752. The plant's effluent discharge requirements (emission limit values) were 25 mg/L BOD_5, 125 mg/L COD, 25 mg/L TSS, 1.3 mg/L PO_4-P, 2.5 mg/L NH_4-N and 6.9 pH.

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The facility has five stages in the treatment process:

1. Preliminary treatment (screening/grit removal).
2. Chemical dosing (for phosphorus removal).
3. Secondary treatment (activated sludge treatment).
4. Clarification (separation of treated effluent and mixed liquor).
5. Tertiary treatment (constructed wetlands).

Before the upgrade, the facility's aeration system consisted of fine bubble diffused aeration (FBDA) as outlined in Figure 1. The FBDA system was driven by three 11 kW Aerzen blowers (duty, assist, standby) and a 4.1 kW mixer. The activated sludge reactor operated aerobically and anoxically to achieve nitrification and denitrification within the same reactor.

The Vortech upgrade was part of an early commercial demonstration of the VPA™ technology at the water utility. Although the plant's existing diffused aeration system maintained compliance with the site's emission limit values (ELVs), it couldn't operate efficiently under the plant's widely fluctuating loads due to poor control which resulted in high energy costs. The control inefficiencies were compounded by the fouling of diffusers, which reduced their effectiveness over time. The diffusers would also eventually require costly maintenance such as cleaning or replacement.

(a)  (b) 

Figure 1: (a) Aeration tank with diffused aeration operational before VPA-S3022 installation and (b) image of fouled floor mounted diffusers with solids accumulation evident around the diffuser mounts.

Solution Overview

The VPA-S commercial demonstration included the installation of a single VPA-S3022 model (rated power of 22 kW) in the reactor (see Figure 2). The VPA-S3022 model was installed over the existing FBDA system (see Figure 3) in the reactor, enabling ease of operational transition between both technologies for commercial demonstration purposes. The VPA-S3022 unit negated the need

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for the site's existing compact mixer which was deactivated along with the existing FBDA system when the VPA™ unit was commissioned.

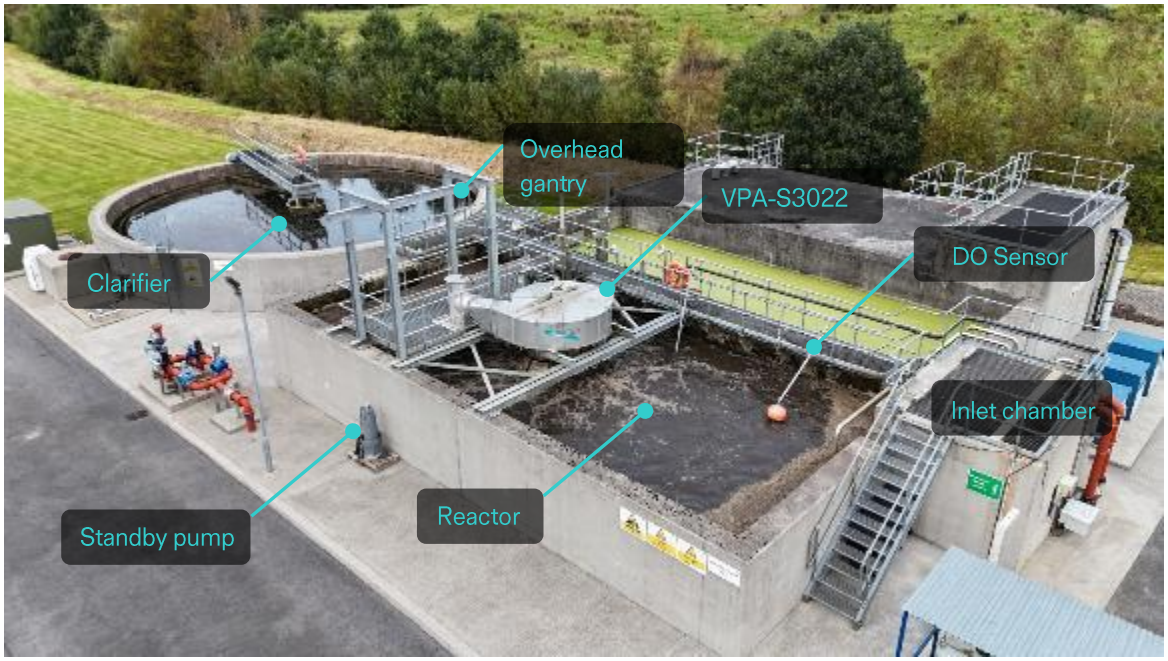

Figure 2: Annotated aerial image of the secondary treatment process including the VPA-S3022 system installed and operational in the aeration tank.

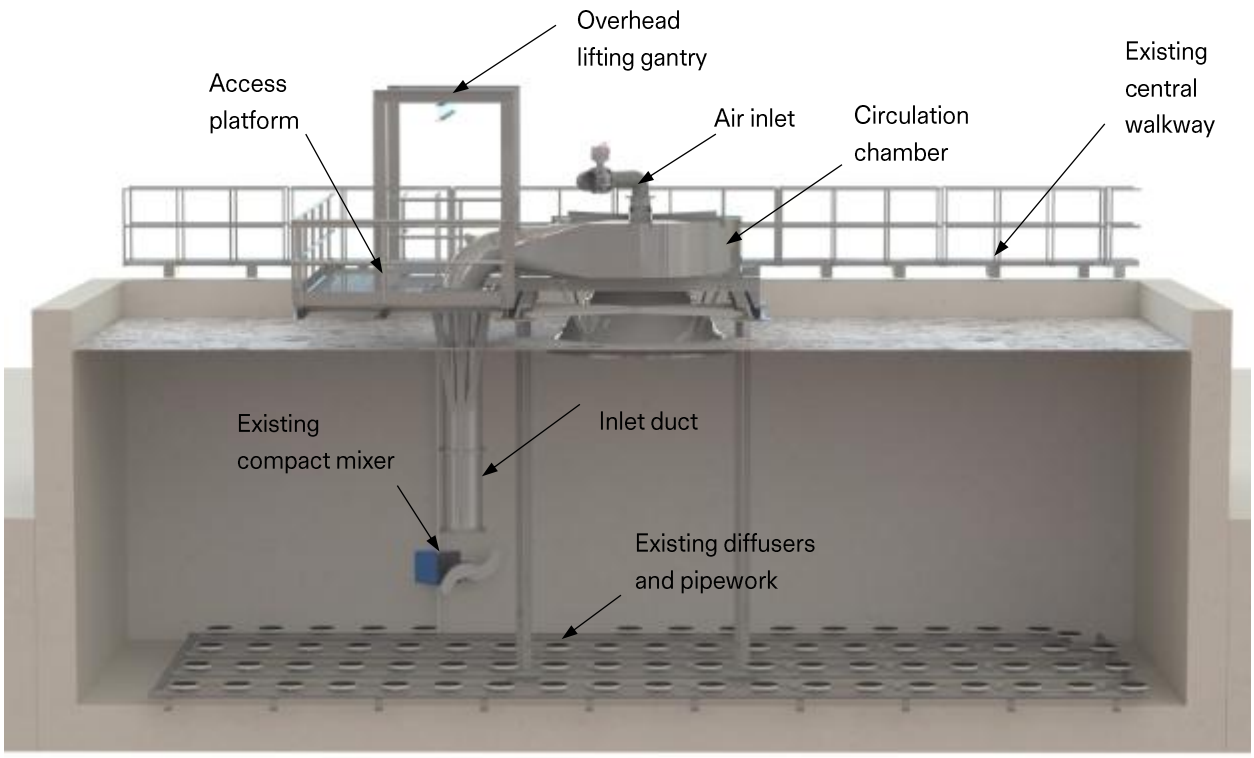

Figure 3: Annotated cross-section of the VPA-S3022 system in the aeration tank.

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Installation

Design for Manufacture and Assembly (DfMA)

Vortech adopted a “Design for Manufacture and Assembly” (DfMA) approach when delivering VPA™ aeration and mixing equipment. A Vortech intelligent motor control centre (MCC), VPA-S3022 unit and a support and access platform were all delivered as one pack, ready for on-site assembly (see Figure 4 and Figure 5). The VPA-S3022 unit and support platform were installed in three days. No civil works were required. All equipment was assembled outside the tank, requiring minimal lifts to install all mechanical equipment. The Vortech intelligent MCC was installed in the existing control room and connected to the network for data communications, remote monitoring, and control.



Figure 4: Vortech intelligent MCC and HMI control platform.



Figure 5: VPA-S pack stored at the facility ready for installation.

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Reporting Methodology

Several Key Performance Indicators (KPIs), typically used in industry and literature[1], such as the specific energy consumption, were selected to report on the performance of the VPA™ installation. The specific energy consumption metrics quantify the amount of energy expended per volume of water treated (kWh/m^3 treated), mass of contaminant loaded (kWh/kgBOD_5 influent), and mass of contaminant removed (kWh/kgBOD_5 removed), or energy consumption per capita required for treatment (kWh/PE/annum). Absolute energy (total site and aeration) was also logged (see Figure 6). Additional process performance KPIs monitored were the effluent concentrations relative to the site Emission Limit Values (ELVs), the pollutant removal efficiency (%), the sludge volume index (SVI) and activated sludge biological health to assess any effects on sludge floc and the pollutant removal efficiency (%).

Different sampling and monitoring resolutions (hydraulic, energy, and biochemical) were adopted, including diurnal, daily, and weekly (including quality control samples obtained from an independent laboratory). During each approach, combinations of the following parameters were monitored and assessed:

- BOD_5
- Chemical Oxygen Demand (COD)
- Suspended Solids
- Total Nitrogen (TN)
- Ammonium nitrogen (NH_4-N)
- Nitrate (NO_3-N)
- Nitrite (NO_2-N)
- Total Oxidised Nitrogen (TON)
- Total Phosphorus (TP)
- Orthophosphate (PO_4-P)
- pH
- Temperature

The total site energy, aeration energy, and hydraulic flow to the aeration basin were recorded daily. Energy meters were used to record the site energy for the baseline and after the commissioning of the VPA™ system. The energy meters used throughout the study were as follows:

- The site's total energy monitor was a Diris Socomec COUNTIS E50 installed in the primary site MCC.
- The FBDA energy was monitored using Efergy and Fluke 1732 meters (see Figure 6 below).
- The VPA™ energy was monitored by a Sifam Tinsley AP35-3RJ12 energy monitor installed in the Vortech MCC.

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Figure 6: Efergy and Fluke energy meter installed on the blowers during monitoring setup.

Two annual data sets were gathered for FBDA (pre-intervention) and VPA™ (post-intervention) to evaluate treatment process performance for both technologies under varying seasonal demands. The above parameters allowed the team to assess the treatment plant's performance in removal rates, mass removals, and specific energy removal rates for VPA™ and FBDA during separate 12-month comparison periods.

Fluid Dynamics and Mixing Performance

The VPA-S3022 can circulate up to 446 l/s of mixed liquor. During operation, the vortex generated in the circulation chamber produces a stable annular jet, which plunges into the aeration tank to drive air entrainment and mixing. This, in turn, triggers additional air flow rates of up to 1,238 l/s without the need for blowers. The hydraulic assessment of the VPA-S3022 unit was carried out by pressure and flow rate measurements, drone videos, and computational fluid dynamics (CFD) simulations. Some examples are provided below in Figure 7 and Figure 8 which outline velocity contour plots on the water surface and streamline distributions around the reactor, respectively. In general, the simulations indicated well-mixed conditions as confirmed by site observations and mixed liquor probe measurements.

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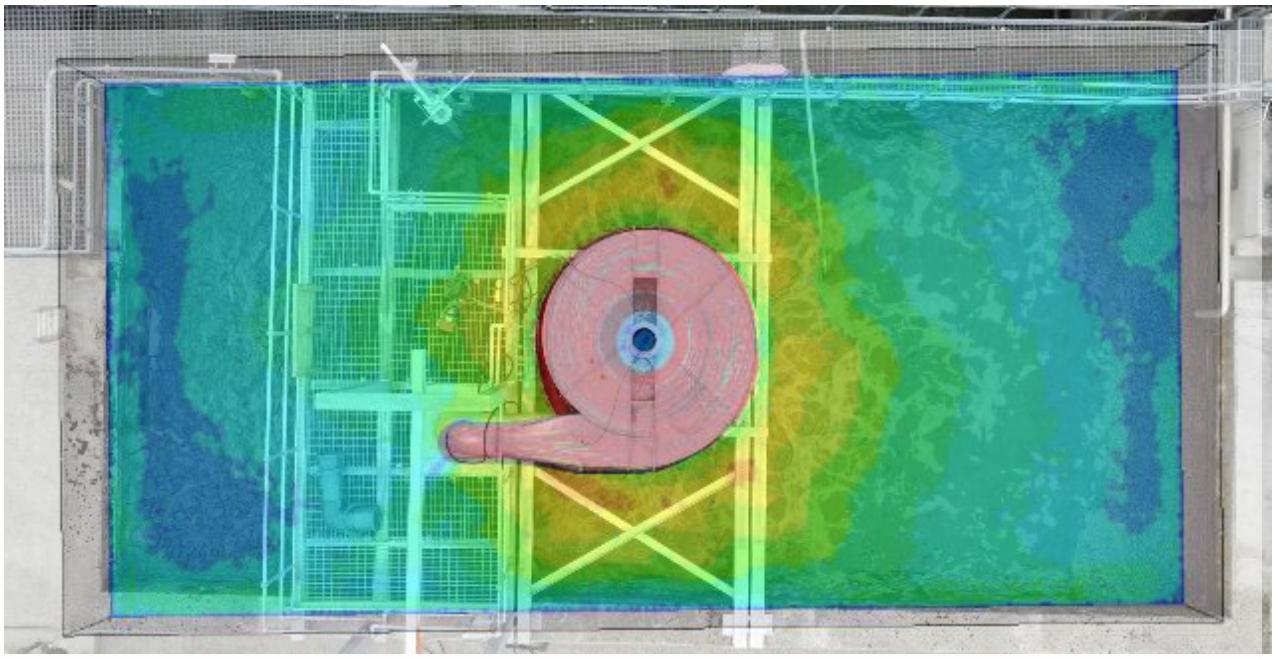

Figure 7: Surface velocity contour plots overlayed on the actual aeration tank.

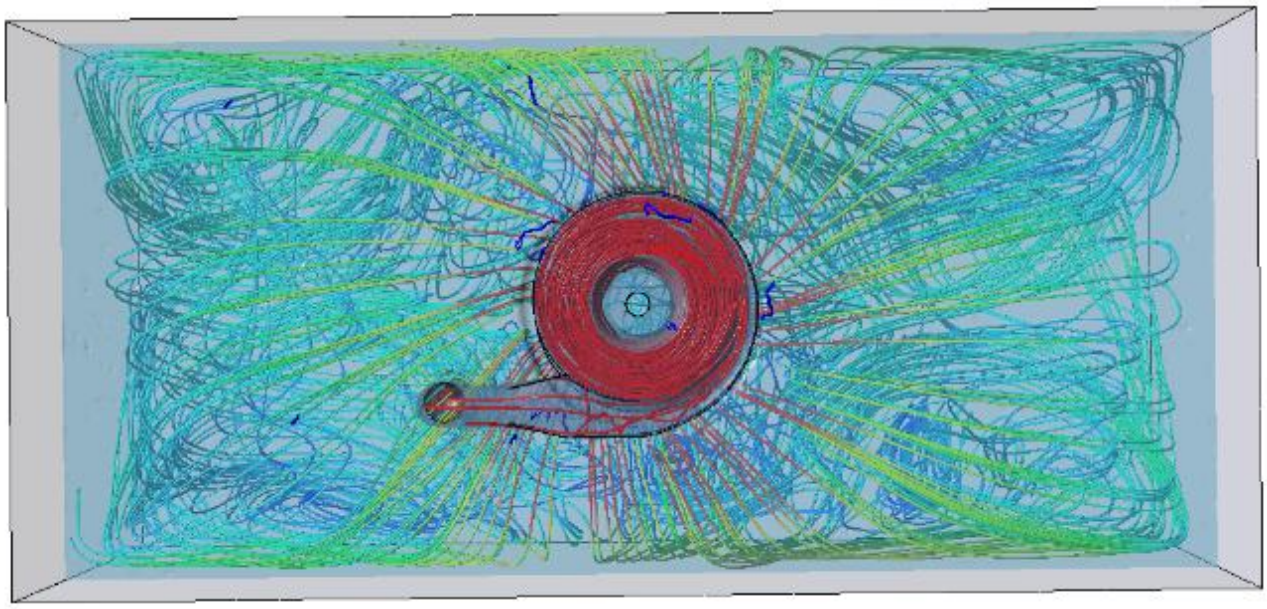

Figure 8: Plan view of three-dimensional velocity streamline distributions in the reactor.

An MLSS sensor was used to check solids concentrations at the tank corners at various power inputs. As supported by the CFD results above, the negligible variation in MLSS values at the bottom and top water levels indicated a low coefficient of variance (COV) and thus good mixing of activated sludge exhibiting no dead spots or MLSS settlement.

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Vortech's novel Cyclonic Pulsed™ aeration technique was also deployed and tested. This mixing mode operates by turning the VPA-S unit on at a low power every 15 minutes for 2.5 minutes to mix the tank under anoxic conditions. This significantly reduced mixing power in the reactor to between 1 – 2 W/m^3 resulting in an 85% energy reduction during denitrification.

Process Performance

General Observations

An average PE of 1,752 with a 95th percentile PE of 3,872 was recorded throughout the VPA™ monitoring period (October 2021 to October 2022). This represented an increase in average loading to the facility over previous years, with average annual PEs for 2019, 2020 and 2021 of 1,143, 1,158 and 1,536, respectively (35%, 34% and 13% lower than the monitoring period of this report respectively as outlined in Table 1). The plant operator noted that local wastewater and stormwater catchment conditions had changed in 2021 due to modifications to the drainage network, which was likely responsible for the increases in loads experienced. The facility also received "shock" loads sporadically throughout the year, including oil infiltration and potential illegal dumping in the local network. For example, on one occasion, very high instantaneous COD concentrations (over 10,000 mg/L) were observed at the inlet works from grab samples, including high volumes of inorganic heavy solids, which clogged screens and resulted in by-pass of rags and fibres to the aeration tank. Such influent characteristics enabled a review of VPA™ performance and reliability in a challenging real-world wastewater treatment environment.

Table 1: WWTP variation in BOD_5 load and PE from 2019 to the VPA demonstration monitoring period.

Parameter	2019		2020		2021		Monitoring Period	
	Average	95th percentile	Average	95th percentile	Average	95th percentile	Average	95th percentile
BOD Load (kg/day)	68.6	144.6	69.5	182.3	92.2	227.3	106.8	232.1
PE	1,143	2,410	1,158	3,038	1,536	3,788	1,752	3,873

Removal Efficiencies

The plant performance at the facility for contaminant removal has been closely monitored throughout the demonstration, with average removal efficiencies of 98%, 92% and 95% for BOD_5, COD and total suspended solids recorded respectively. Figure 9 exhibits BOD_5 concentrations throughout the demonstration period, and Figure 10 displays the daily flow of the plant since the beginning of the project. Average mass removals at the WWTP during the monitoring period for

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BOD_5, COD and Suspended Solids (SS) have been 103.9 kg BOD_5/day, 212.2 kg COD/day and 173.5 kg SS/day, respectively, with all effluent results well below the site's ELVs at all stages since commissioning. The average effluent ammonium was 0.6 mg/L (ELV of 2.5 mg/L) during the monitoring period.

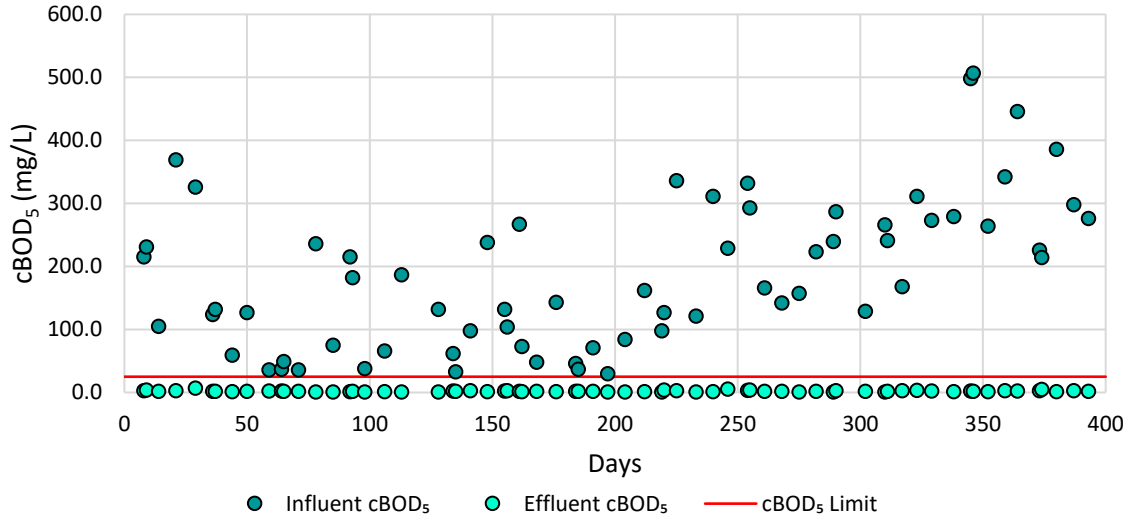

Figure 9: Influent and effluent ammonium concentrations at the facility.

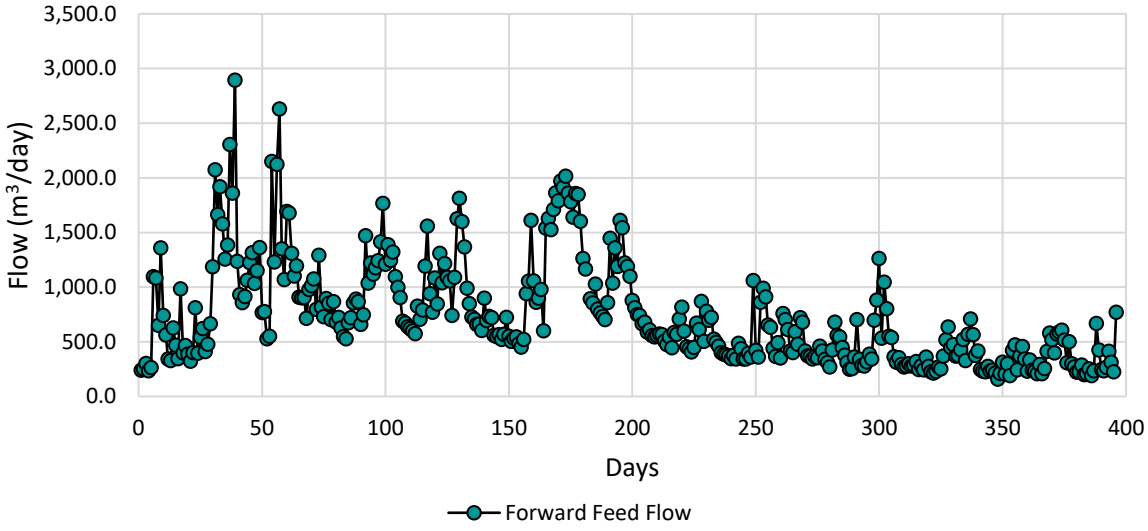

Figure 10: Flow rates at the WWTP from September 2021 - October 2022.

Activated Sludge Biology

One of the key concerns that the operators and utility raised during early engagements on the project was the potential effect of the VPA™ aeration process on activated sludge floc formation and settlement. In any activated sludge system, the balance of microorganisms (bacteria, protozoa,

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metazoan, filamentous bacteria, algae, fungi) present in the sludge indicates the overall health and ability of the system to carry out treatment and provide insight into the settling characteristics of the activated sludge. Investigations on the activated sludge were undertaken frequently before and after installation. Figure 11 exhibits the quality of the sludge before the installation of the VPA™ system.

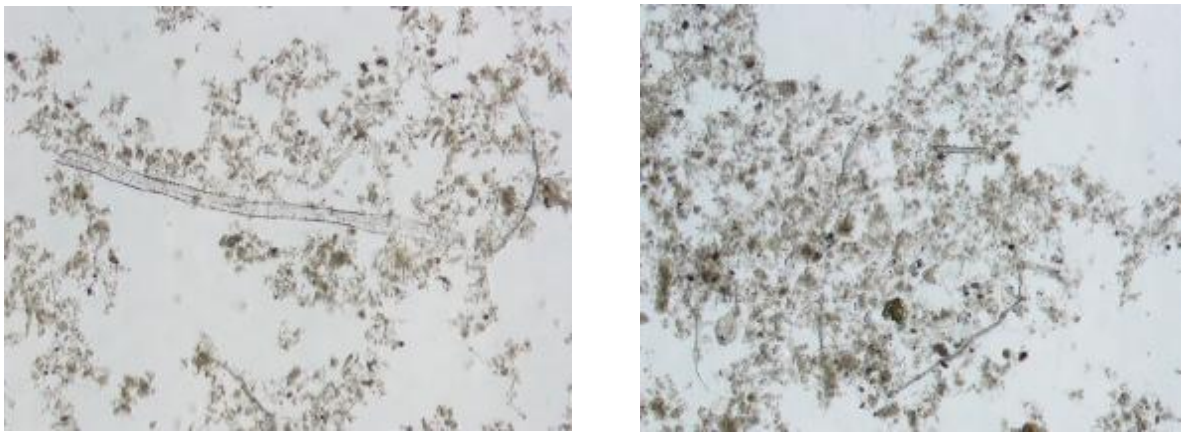

Figure 11: Activated sludge microbiology during FBDA operation.

VPA™ aeration positively affected the sludge health and promoted good settlement, with an average settled volume index (SVI) of 100.4 mL/g. After installation, the control of DO was more tightly regulated, reducing over-oxidation and notably denser flocs were observed (see Figure 12). This also appeared to bring about the dominance of more favourable organisms, such as crawling and stalked ciliates. Prior to the VPA™ installation, the sludge was observed to be of good quality, with a suitable number of rotifers and some ciliates present. After VPA™ operation, the flocs became more compact, and ciliates were more abundant in the sludge. This generally indicated a healthy biological system[2].

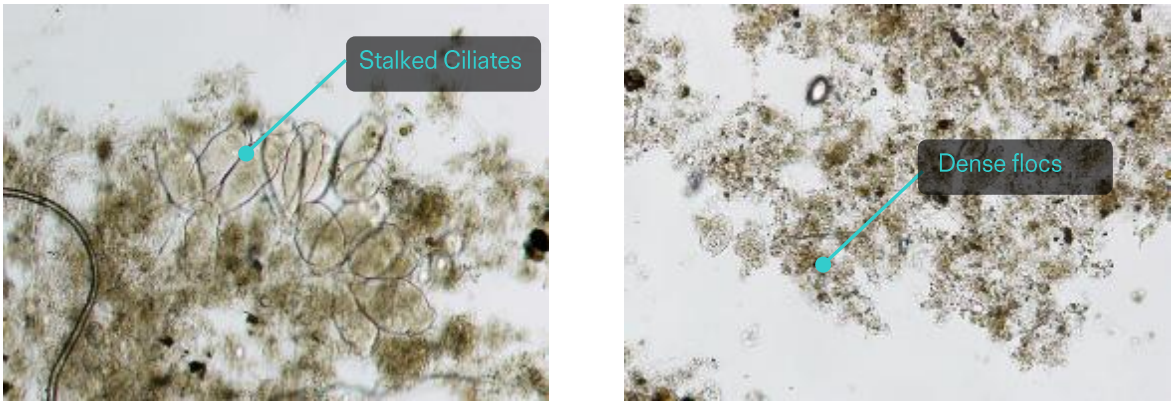

Figure 12: Activated sludge microbiology after commissioning of the VPA™.

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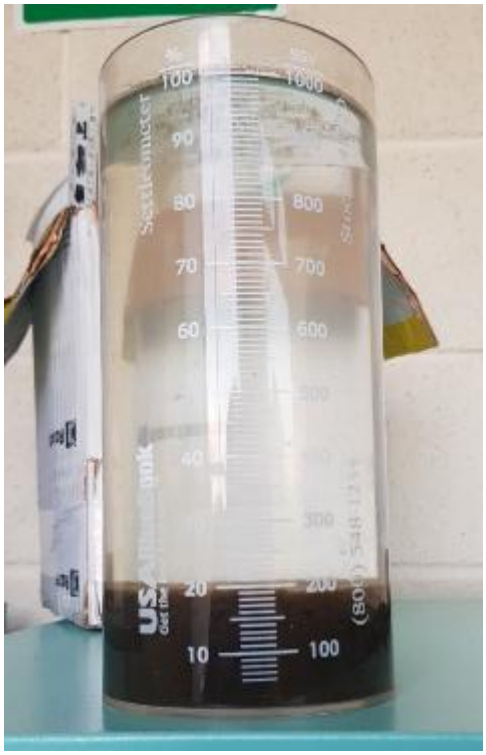
The clarity of the effluent since operation was excellent, as demonstrated in Figure 13, which outlines the SVI settlement test and the final effluent in the beaker. This reflects the low suspended solids concentrations measured in the effluent (average of 9 mg TSS/L) and further indicates that the VPA™ positively impacts activated sludge floc formation during operation.

(a)



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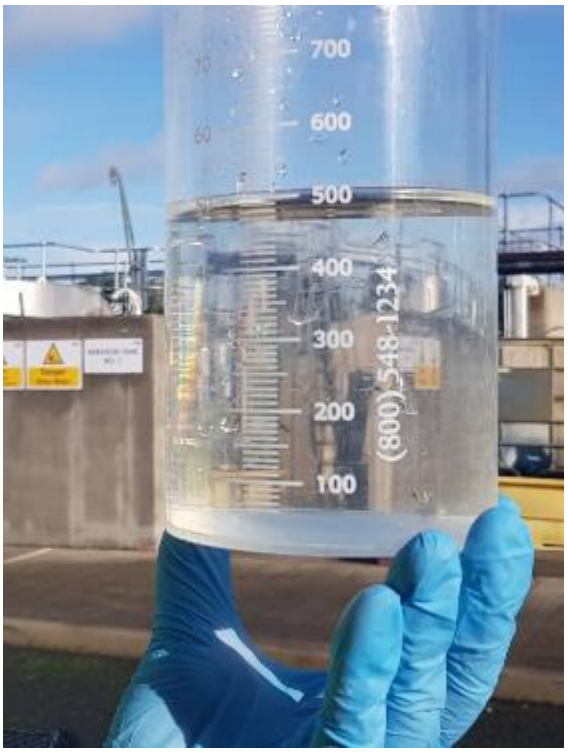

Figure 13: (a) Final settled volume in the SVI test and (b) effluent clarity obtained from the clarifier.

Energy Insights

This section provides an overview of the energy KPIs throughout the VPA™ commercial demonstration. As mentioned, the organic loading to the treatment facility in 2021 increased significantly. Despite this, the total energy consumption at the treatment plant decreased during VPA™ operation. Figure 14 outlines the annual energy trend throughout the monitoring period, showing relative savings to the average FBDA daily energy demand. The hotter, drier late spring and summer periods between days 225 and 375 experienced a temperature rise and an increase in COD concentrations, which are known to cause increased energy consumption in activated sludge systems (as exhibited in Figure 14) due to higher endogenous respiration rates and surfactant content. During this period, fouling of ORP and DO probes was also more prevalent, which often caused a false negative for increased energy requirements at the site.

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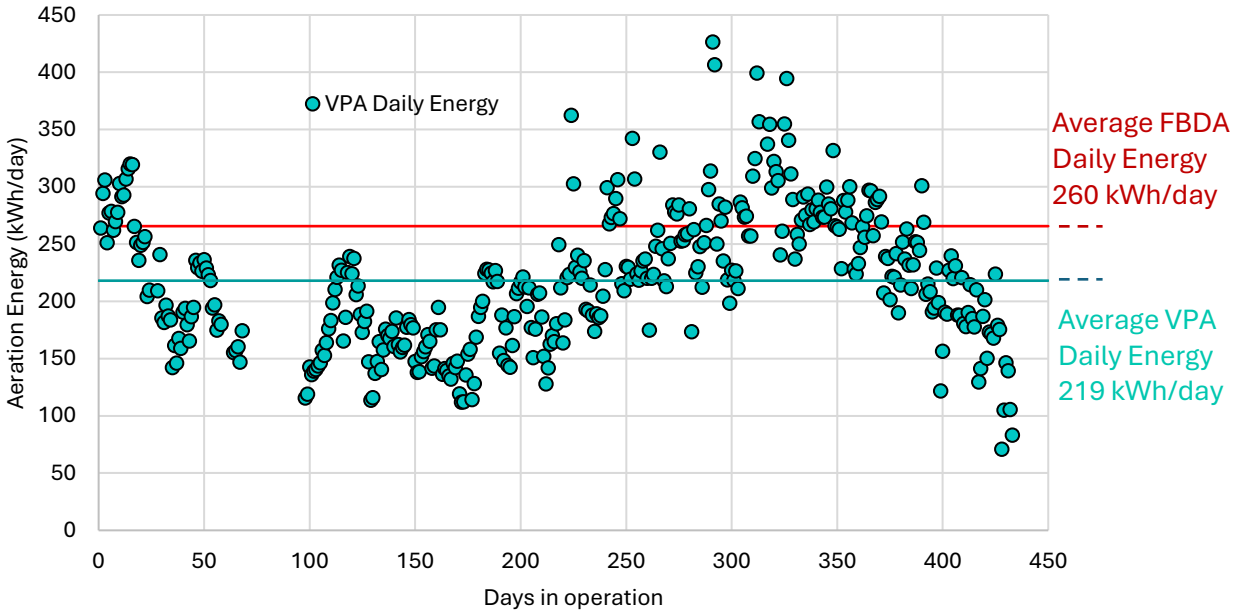

Figure 14: Aeration energy consumption by VPA-S3022 at the WWTP throughout the monitoring period.

At the end of the demonstration monitoring period (October 2022), the FBDA system was turned on again for two weeks in November 2022 to evaluate its energy consumption under similar loading conditions. The total site power was also monitored. As outlined in Figure 15, an immediate increase in electricity consumption was noted regarding aeration and total site power. During operation, the dissolved oxygen levels in the tank were not efficiently controlled, resulting in over-aeration of the activated sludge.

After two weeks, the aeration system was switched from FBDA back to VPA™, and the site's total energy consumption returned to normal levels (where VPA™ energy was circa 130 kWh/day immediately before and after the FBDA operational period). The loading remained relatively similar during the FBDA operational period and on the date that the VPA™ system was reactivated. The decrease in daily energy observed was circa 160 kWh/day representing a 55% reduction during this period.

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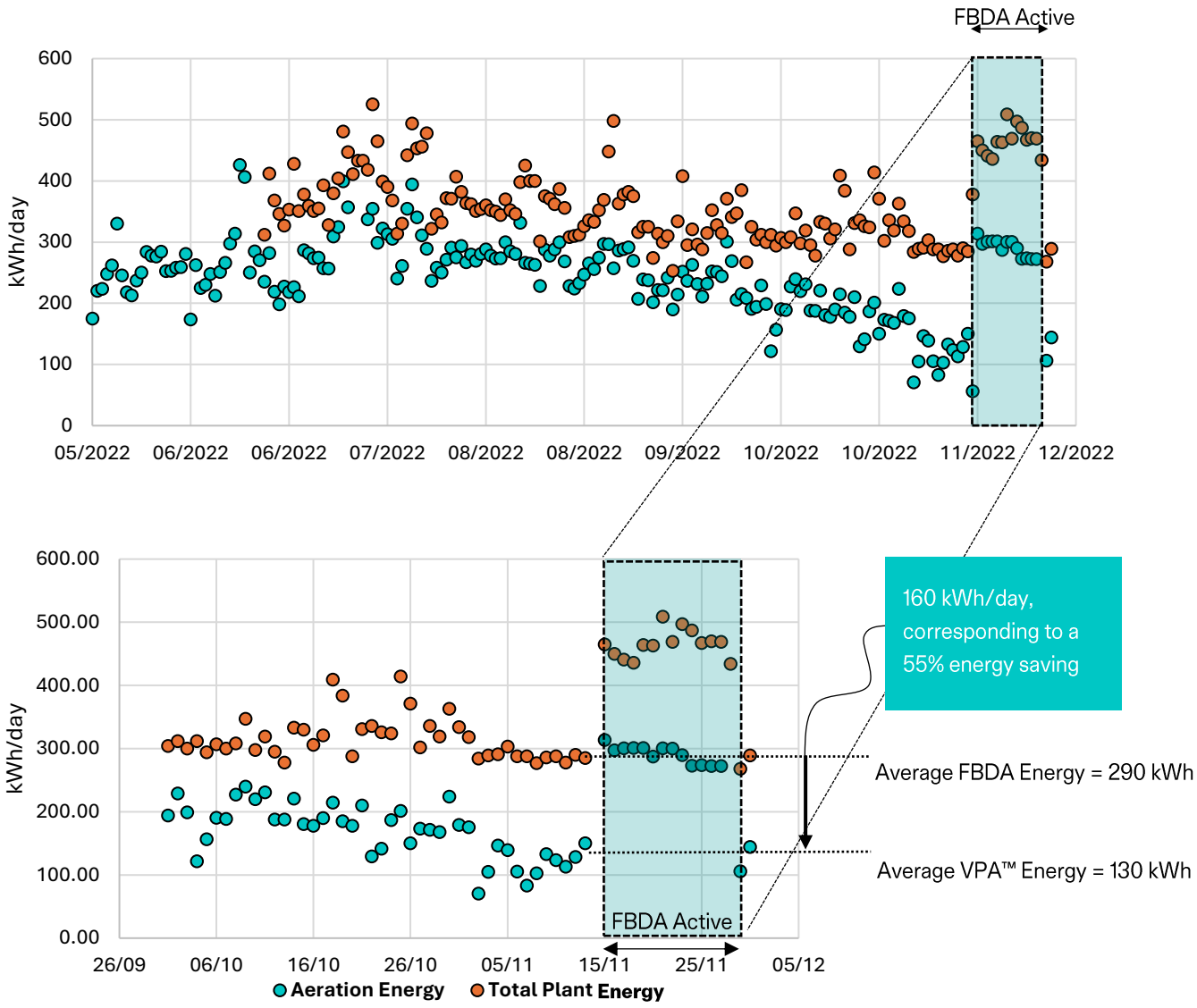

Figure 15: Aeration energy consumption by VPA-S3022 at the WWTP throughout the monitoring period.

The efficiency improvement is further demonstrated in terms of Specific Energy Consumption as described previously, namely, the energy required per kgBOD_5 removed or per capita treated. The comparison is also presented in Table 2.

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Table 2: Total plant energy consumption for 2020, 2021 and the monitoring period (October 2021 to October 2022)

Parameter	FBDA (June 2020 – June 2021)	VPA™ (October 2021 – October 2022)
Average Hydraulic Specific Energy Consumption (Total Site) (kWh/m^3)	0.42	0.43
Average Hydraulic Specific Energy Consumption (Aeration) (kWh/m^3)	0.3	0.27
Average Loading Specific Energy Consumption (kWh/kgBOD_5influent)	3.10	1.83
Average Loading Specific Energy Consumption (kWh/kgBOD_5removed)	3.15	1.86
kWh/PE/Annum (BOD_5 based)	68	40

The KPIs of specific energy consumption were also evaluated for the FBDA (from June 2020 to June 2021 using the average FBDA energy as a function of total energy) and the VPA™ demonstration period data sets (October 2021 to October 2022).

The average specific energy determined throughout the VPA™ demonstration was 1.86 kWh/kgBOD_5 removed and 40 kWh/PE/Annum. The lowest specific energy consumption value observed was 15.25 kWh/PE/annum. When compared to the FBDA baseline values of 3.15 kWh/kgBOD_5 removed and 68 kWh/PE/Annum, this reflects a reduction in specific energy of 41% during the demonstration monitoring period. Generally, the statistical data sets for VPA™ specific energy consumption align with the 25th percentile of typical treatment facilities of this size in Europe[1]. A summary of the specific energy consumption values for the baseline FBDA and VPA™ data set is illustrated in Figure 16.

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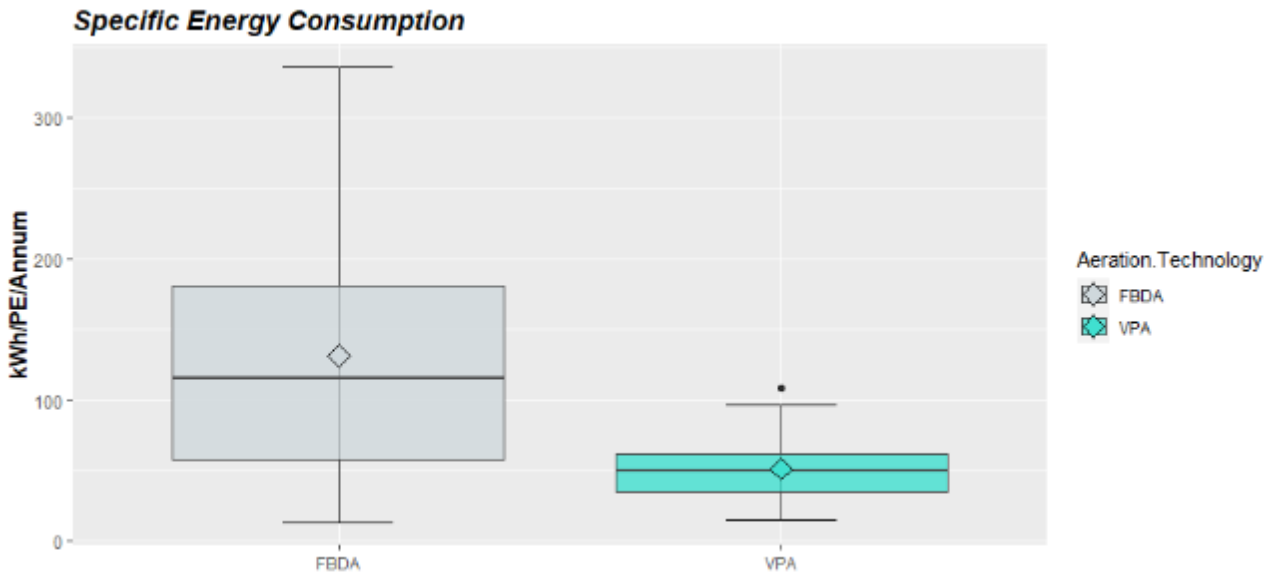

Figure 16: Specific energy use at the WWTP

Figure 17 and Figure 18 show a distribution of the specific energy data throughout the monitoring period for FBDA and VPA™, respectively.

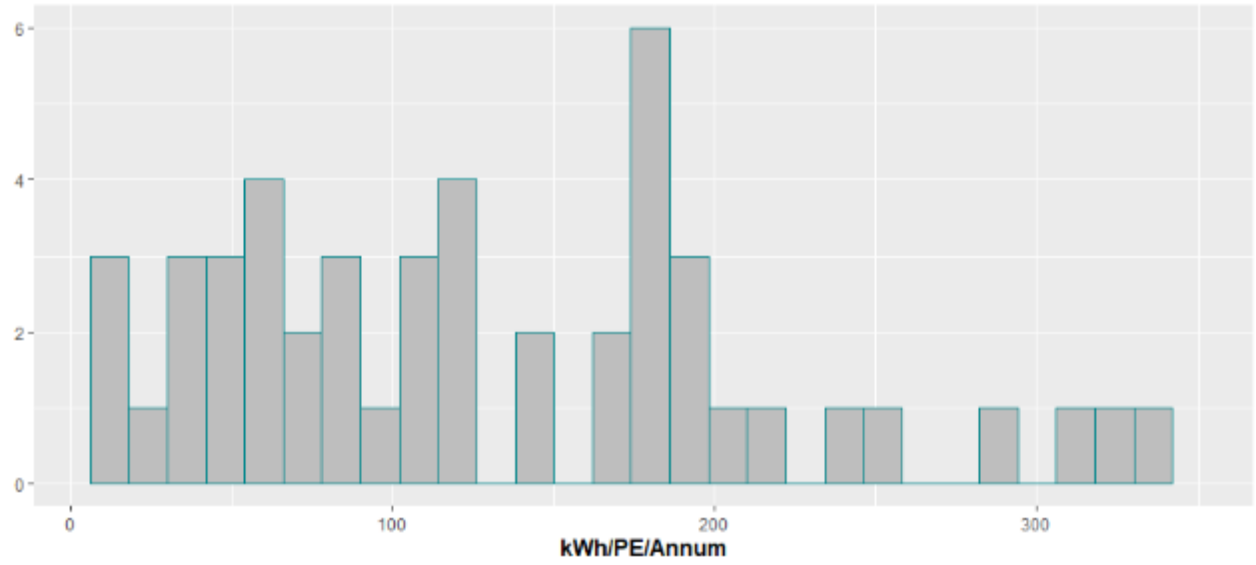

Figure 17: Histogram of FBDA specific energy during the baseline period

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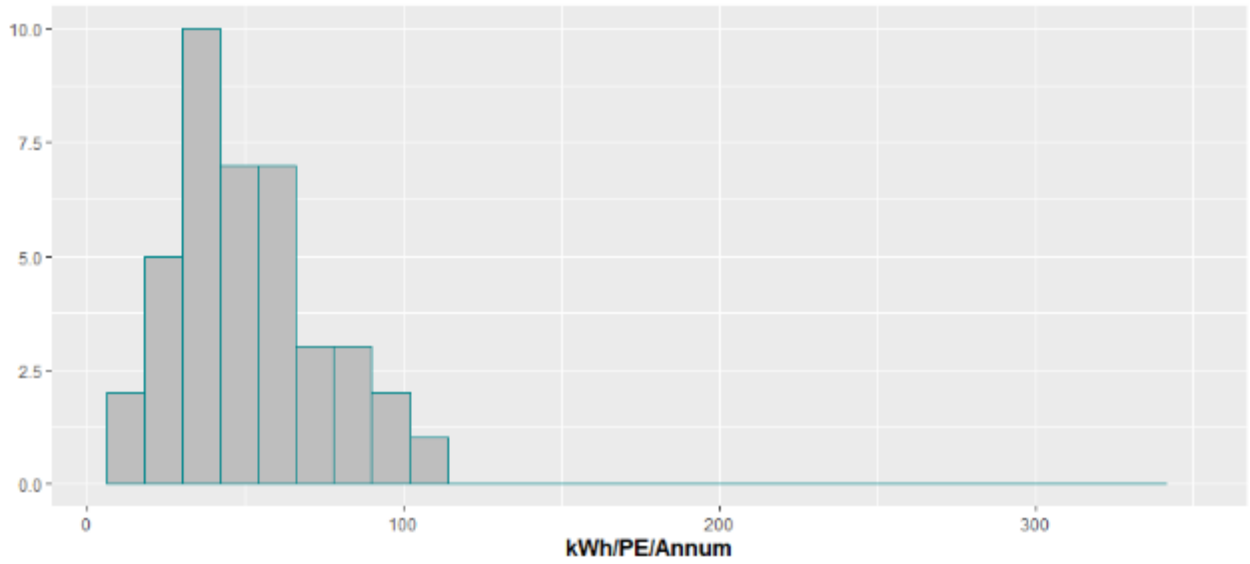

Figure 18: Histogram of VPA™ specific energy during the monitoring period

When comparing Figure 17 and Figure 18, it becomes clear that controllability is significantly improved with the VPA™ system. The ability of the control system to regulate the VPA™ power to deliver oxygen, only as required, results in a Gaussian distribution of the specific energy values exhibiting good performance under a range of loads and flows. In contrast, the FBDA distribution doesn't show this pattern, indicating a lack of controllability (i.e., the energy required for treatment of 50 kgBOD_5/day is similar to the energy required when the load is 80 kgBOD_5/day).

Noise and Aerosols

No observations of aerosol generation were recorded during the demonstration monitoring period. Vortech conducted a noise survey to quantify differences between both technologies, the results of which are outlined in Figure 19.

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Position	FBDA (dB)	VPA (dB)
1	50.9	51.0
2	71.5	53.2
3	59.9	65.0
4	53.4	48.0
5	48.3	49.7
6	32.1	32.1

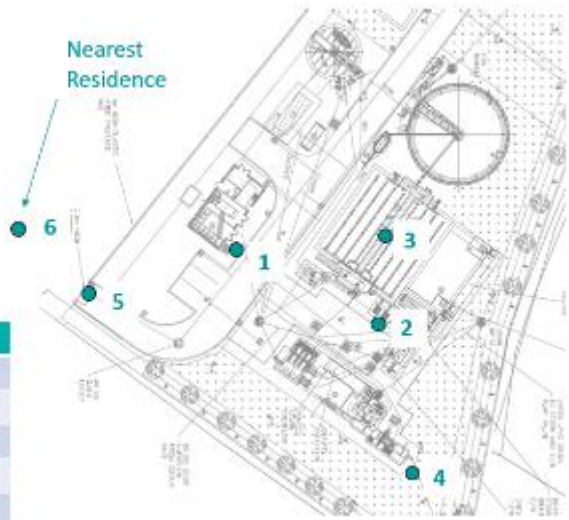

Figure 19: Overview of results from a noise survey carried out for different locations throughout the site for both FBDA and VPA operation.

Maintenance

Over 28 million tonnes of activated sludge have been circulated through the unit with no unplanned downtime since commissioning (3.6 years at the time this report was prepared). The pump was lifted and inspected three times by Vortech (to evaluate potential ragging), and no clogs or solid build-up was observed on the pump. These observations verify that the pump's backwash sequence and self-cleaning N-technology have effectively conveyed rags and fibrous material through the pumping system. The fibrous material can accumulate on loose cables and chains but has a negligible effect on system operation when it occurs. The overall maintenance time for the operator to gain access to the pump was recorded to be approximately 30 minutes. A standby pump is readily available on-site within reach of the overhead hoist and can be fitted within 1 to 2 hours.

Impact and Conclusion

A municipal wastewater treatment plant in Ireland faced challenges of rising load variability and aged aeration process equipment. The facility's diffused aeration system struggled to efficiently manage fluctuating loads which resulted in increased energy costs. Compounding these issues, ongoing blower maintenance and diffuser fouling progressively reduced system performance. The aeration facility was upgraded in 2021 with Vortech's Vortex Powered Aeration (VPA™) technology as part of an innovation demonstration project with the utility. The retrofit resulted in 41% energy savings for every kilogram of BOD_5 removed, significantly reducing energy costs. The upgrade improved the plant's capability to meet environmental regulations whilst reducing carbon

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emissions by 8,900 kg of CO_2 annually. In addition, the VPA™ dramatically reduced maintenance requirements, with a projected cost reduction of 80%. Noise levels at the site also reduced considerably. In summary, a 32% reduction in total lifecycle costs is expected over a 35 year period. Figure 20 illustrates the key metrics measured as compared to the site's original aeration system.

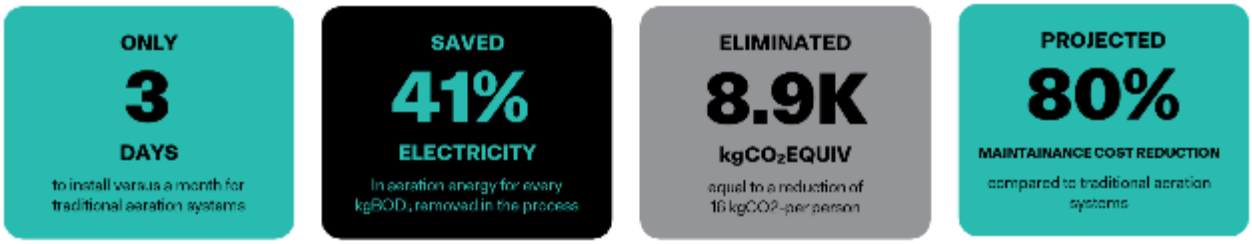

Figure 20: Infographic outlining the impact of the VPA™ activated sludge system at the site.

Acknowledgements

The Vortech team would like to acknowledge the client's (including their management and operators) support in developing this report.

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