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Start Up of a UASB Treating Malted Ingredient Manufacturing Wastewater

Ryland Cairns (Corresponding author)
Fontus Environmental, Thirsk, North Yorkshire, England
Email: Ryland@fontusenvironmental.com

Paul Mead
Muntons, Cedar Maltings, Stowmarket, Suffolk, England
E-mail: Paul.Mead@muntons.com

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Abstract

With a greater push to achieve waste management and renewable energy targets technologies such as anaerobic digestion (AD) have increased in popularity. One such technology option is the Upflow Anaerobic Sludge Blanket (UASB) reactor, these have been shown to be a particularly robust option for high strength organic wastewaters, such as those generated by the malted ingredient manufacturing industry. Despite their effectiveness they are reported to have lengthy and complex start ups due to the range of physiochemical and biological interactions influencing sludge blanket stability. This process can be sped up by seeding the plant from sludge from similar plants, however this is not always possible. This paper aims to investigate the start up of a full-scale mesophilic UASB treating malted ingredient wastewater that was initially seeded with a granular sludge treating dairy wastewater. Operational performance during the first 75 days of start up was comparable to that of a fully established plant with a COD removal efficiency in excess of 81.89% and a biogas methane concentration greater than 57.24%. During this period the plant remained operationally robust with the Organic Loading Rates (OLR) exuding the greatest influence on plant performance. Similar to operations during stable conditions key operational parameters such as HRT times, temperatures and pH did not exert a strong influence on the plant.

Keywords: Anaerobic Digestion, Start up, UASB, Malt, Wastewater, Trade effluent

1. Introduction

Anaerobic digestion (AD) is a technology that has gained popularity in recent years for its effective treatment of organic waste streams (ADBA, 2016). It holds significant benefits over aerobic treatment due to its low construction costs, low operational footprint, low sludge production, and green energy production through the production of biogas (Singh *et al*., 2013). From an operational perspective it is considered robust in terms of Chemical Oxygen Demand (COD) removal (Conceição *et al*., 2013), pH stability and recovery time (Hernández and Rodríguez, 2013) as well as relatively simple operation and management of plant (Singh *et al*., 2013). This has led to organisations constructing AD plants to achieve various waste management targets and renewable energy goals (Bekkering *et al*., 2016)

A popular form of treatment for medium to high strength effluents is Upflow Anaerobic Sludge Blankets (UASBs) (Musee *et al*., 2016), which have demonstrated high reliability both in terms of their COD removal efficiencies (typically >80%) and biogas CH_4 concentrations (typically >50%) (Latif *et al*., 2011). This performance has been documented in a number of studies treating a wide range of wastewaters including: Palm oil mill effluent (Siang, 2006); Paper mill wastewater (Kamali *et al*., 2016); Distillery wastewater (Musee *et al*., 2016); dairy wastewater (Tawfik *et al*., 2008); fishery wastewater (Huang *et al*., 2009); slaughterhouse wastewater (Chavez *et al*., 2005); Piggery effluent (Huang *et al*., 2005) municipal wastewater (Rivzi *et al*., 2015), malting's steep water (Borzacconi *et al*., 2006) and malt ingredients factory wastewater (Cairns and Mead, 2017).

Despite the robust operational performance, UASBs are reported as complex to start up with long start up times (Rivzi *et al*., 2015). The length of this start up procedure is governed by a number of complex and interrelated factors which influence the development of the sludge blanket such as wastewater characterisation, the sludge used to seed the plant, pH, nutrient ratio, inhibitory compounds, hydraulic and organic loading rates, up flow velocity, mixing effectiveness and reactor design (Zhang *et al*., 2012).

The stabilisation of the sludge blanket within a newly seeded plant can be influenced by a range of operational factors associated with both the new plant and the plant that the sludge originated from including wastewater composition, type of reactor, sludge temperature nutrient content and pH (Singh *et al*., 1997). When sludge conditions of a UASB closely match those of where the sludge seed originates from start up can be achieved in less than a week (Wolmarans and Villiers, 2002). Although, when wastewater, reactor design and temperature are different from where the sludge seed originates it has been shown to take up to 17 weeks for the plant to effectively start up (Rizvi *et al*., 2014).

Due to the cost and lack of availability of granular biomass, self seeding is a potential option. Previous studies indicating start up times of 6 to 17 weeks (Lettinga *et al*.,1993; Kalago and Verstraete, 2001; Yu *et al*., 2001; Alvarez, *et al*., 2006). with effectiveness influenced by a number of physiochemical and biological interactions (Schmidt and Ahring, 1996).

It has been demonstrated that UASBs are a suitable technology option for the treatment of wastewater generated by the malted ingredient (MI) manufacturing industry (Cairns and

Mead, 2017). However the potential lack of sludge from similar plants is likely to make start up of new reactors challenging. Additionally, the lack of literature relating to the start up of UASBs treating MI wastewater could potentially reduce the uptake of this technology as a treatment option for this type wastewater.

The present study investigates the start up of a mesophilic UASB treating a MI manufacturing wastewater that has been seeded with a mesophilic granular sludge from a UASB treating dairy wastewater. Trends in the treated effluent quality in relation to UASB process parameters over the first 150 days are to be presented as well as the impact of the Organic Loading Rate on COD removal and methane production.

2. Materials and Methods

2.1 Plant Layout

This paper investigates the start-up of a UASB reactor at a UK based Malted Ingredients Factory. The reactor had featured in a previous study which covered its performance under stable operational conditions (Cairns and Mead, 2017). The processes of producing liquid and dried malt extract ingredients (evaporator, band drier, spray drier, ultra filter and canning) from malted barley grain generates a variety of wastewaters that constitute the feed in to the reactor. The volume, temperature and concentration of the wastewater will naturally vary depending on process equipment being used even though the organic material originates from malt. A full process description is provided alongside a process flow diagram for the AD plant (Figure 1) and plant design parameters (Table 1), as covered in Cairns and Mead (2017).

Table 1. Process Design

Parameter	Units	Design Value
Flow (Q)	m^3/d	200 (280max)
Chemical Oxygen Demand (COD)	mg/L	40,000
Hydraulic Retention Time (HRT)	days	10 (7 min)
Organic Loading Rate (OLR)	Kg $COD/m^3/day$	4 (5.6 max)
Organic Nitrogen (TKN)	mg/L	110
Ammonia (NH_3)	mg/L	16
Total Phosphorus (P)	mg/L	230
Total Suspended Solids (TSS)	mg/L	2,000
Sulphate (SO_4^{2-})	mg/L	380

From the MI factory the raw wastewater passes through a 1mm drum screen to remove coarse solids and in to a 650m^3 buffer tank to aid with flow balancing. Wastewater is pumped from the buffer tank and in to a conditioning tank (64m^3) where temperature is regulated via a chiller unit which is automatically controlled to ensure the effluents is with the mesophilic digestion range (35℃-38°C). The conditioned wastewater is pumped in to the 2047m^3 Enprotech UASB where it percolates up through the sludge blanket comprising granular biomass. The plant was seeded by 10T of biomass that originated from a mesophilic UASB reactor treating dairy wastewater. Mixing within the reactor is hydraulic in nature with a homogenous blend being achieved via the sequenced opening/closing of actuator valves to regulate flows to different parts of the reactor. A three phase separator is used at the top of the reactor to separate the wastewater, biomass and biogas. Biogas from the reactor is collected within a 400m^3 Biodome prior to it being passed through to a Combined Heat and Power unit with a 499kW MAN engine. Treated effluent goes on for further treatment via conventional activated sludge treatment prior to it being discharged under an Environmental Permit to a local watercourse. The Waste Activated Sludge from this biological aerobic treatment is dewatered and send to local farm land to provide agricultural benefit. Due to the close proximity of the AD plant to the activated sludge plant off-gas from the UASB reactor can be treated aerobically by feeding it through the activated sludge reactor to reduce foul smells, this forms part of the plants odour management plan. The separated biomass is retained within the reactor and settles out in the sludge blanket.

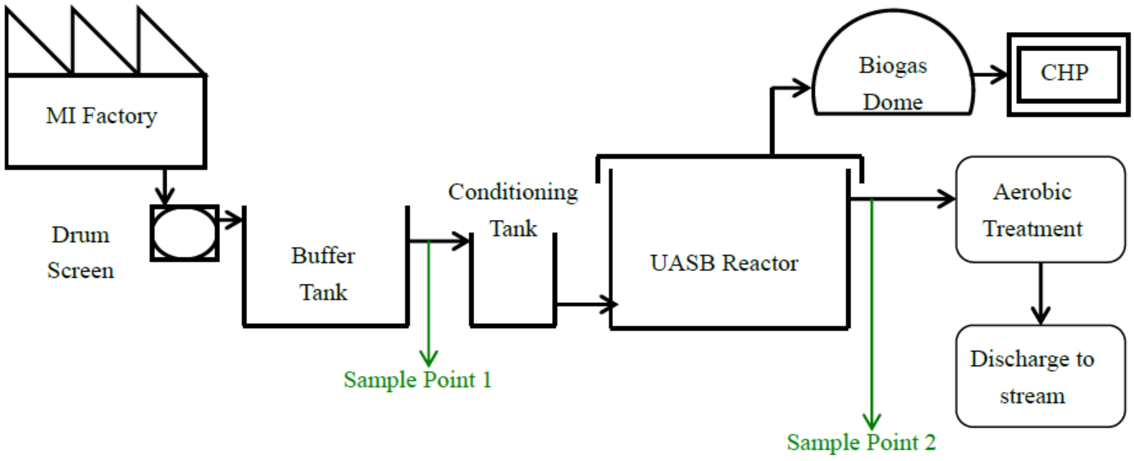


Figure 1. Basic layout of the AD plant (Cairns and Mead, 2017)

2.2 Characterization of MI Wastewater and Treated Wastewater

Composition of wastewaters from the MI production process varies considerably (Cairns and Mead, 2017) as a result of incoming wastewater streams from different production processes (such as band drier, spray drier, ultra-filtration, canning operations). çTo ensure testing was representative of the actual feed to the UASB plant samples were collected daily from the outlet of the buffer tank (Figure 1; Sample Point 1). A daily sample of the treated wastewater was taken directly after the UASB reactor (Figure 1; Sample Point 2) to demonstrate plant performance during start up. The analysis in this study represents the initial 150 days of operation between 02/04/2015 and 01/08/2015.

Standard methods for the examination of water and wastewater (APHA *et al*., 2012) were used to determine the physiochemical properties of both the treated and untreated wastewater. Analysis was performed by trained technicians within the in-house laboratory and included tests for the following: Chemical Oxygen Demand, total Kjeldahl Nitrogen, Ammonia, Total Phosphorus, Total Suspended Solids (TSS), pH and sulphate.

Due to various snagging the plant lacked a gas analyser and gas production meter during start up. A gas usage meter was in place however due to engine availability this did not provide a clear indication of plant performance in to the amount or composition of the biogas produced.

3. Results and Discussion

3.1 Characterization of Untreated Wastewater

Table 2 shows the composition of the raw wastewater over the 150 day start up period which includes the range of daily figures as well as means and standard deviation.

Influent COD concentration ranged from 15,619mg/L to 44,684 mg/L with an associated mean of 26,837mg/L (STD ±6,124); organic nitrogen levels ranged from 132mg/L to 561mg/L (mean 372mg/L) and phosphorus from 3.58mg/L to 180mg/L (mean of 106.9mg/L) This results in a mean CNP ratio of roughly 250:3:1 during the start up period. This is similar the mean CNP ratio recorded over the subsequent 600 days at a ratio of 234:3:1 (Cairns and Mead, 2017). From a macronutrient perspective it has been highlighted that for optimum CH_4 yield a CNP ratio of 100:3:1 is desired. For the current wastewater a CNP of 234:3:1 was apparent, this high C to NP ratio could lead to a deficiency in the process with a poor buffering capacity (Rajeshwari *et al*., 2000) and as such pH should be monitored closely.

Both ammonia and sulphate were at levels that would not inhibit the start up procedure with ammonia concentration ranging from of 1.28mg/L to 73.80mg/L (mean 10.41mg/L STD ±13.06) giving a mean COD:NH3 ratio of 2578:1, whilst Sulphate ranged from 136mg/L to 919mg/L with a mean of 465.15mg/L (STD ±143.49) giving a mean COD:SO_4 ratio of 58:1. This is in excess of the design limit which has states the maximum concentration value as 380mg/L. Total Suspended Solids (TSS) were also found to be in excess of their design limit with a mean value of 2,104mg/L (STD ±1,112) being compared to the 2000mg/L maximum concentration.

Table 2. Untreated MI Wastewater Composition

Parameter	Range	Mean
Chemical Oxygen Demand (COD) (mg/L)	15,619 - 44,684	26,837 ± 6,124
Organic Nitrogen (TKN) (mg/L)	132.00 - 561.00	233.51 ± 83.06
Ammonia (mg/L)	1.28 - 73.80	10.41 ± 13.06
Phosphorus (mg/L)	3.58 - 180.00	106.09 ± 39.25
Total Suspended Solids (TSS) (mg/L)	682 - 9,828	2,104 ± 1,112
pH	3.15 - 11.83	4.50 ± 1.88
Sulphate (mg/L)	136.00 - 919.00	465.15 ± 143.49

Predominantly the pH of the wastewater was acidic with a mean of 4.05 (STD ±1.14) and a range of 8.49 (spanning form 3.15 to 11.83). This large range was a result of caustic cleans of the processing equipment with the factory that pushed the pH in excess of 7.00 for a total of 10 days (6.66% of sampling period).

The characterisation of the wastewater presented in Table 2 is similar to the results observed in Cairns and Mead (2017) which carries on to state that although the values of these parameters are typical of results obtained from UASBs treating different effluents types there were no similar characterization profiles even amongst other industries involved in the processing of grains (Erashin *et al*., 2011; Rajeshwari *et al*., 2000 and Latif *et al*., 2011). Considering different MI processing equipment is expected to influence both the volume and strength of the wastewater future studies should examine the constituent inputs that make up the final raw wastewater.

3.2 Start-up: Reactor Conditions

A number of conditions were measured during the start up the reactor including flow, COD, temperature, pH, volatile fatty acids and the organic loading rates. Daily trends are show in Figures 2– 7 whilst mean figures for 30 day periods are shown in table 4.

Feed to the UASB was gradually increased from 22m^3/d to 215m^3/d by the 30th day (Figure 2). Between the 30th and 75th day flow fluctuated greatly between 113m^3/d to 265 m^3/d with the greatest difference in flow between being 134m^3/d. After this the flow in to the plant stabilised at 214 m^3/d (STD ±29.5). Table 4 shows that after the initial 60 days mean flow was in excess of operational design value of 200 m^3/d for the remainder of the start up. Despite this being under the maximum design limit it was in excess of the expected operational conditions.

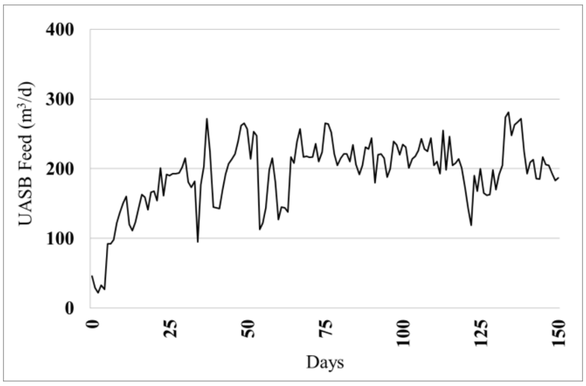


Figure 2. Feed to UASB (m^3/d)

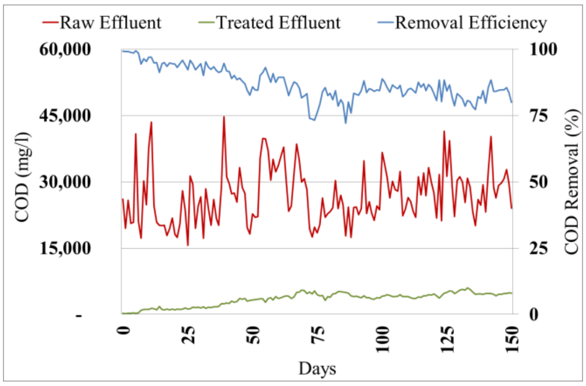


Figure 3. COD concentration and removal

These great differences in flow were due to operators responding to the daily fluctuations in COD concentrations from the incoming wastewater (Figure 3) and attempting to gradually step up the organic loading rate (OLR) until conditions had stabilised (Figure 4). Previous studies (Alphenaar, 1994) had indicated that large fluctuations in OLR prior to system stabilization could have a deleterious impact on plant performance. For this reason after the initial 75 days of start up OLR was maintained at a mean of 2.92 Kg COD/m^3/day (STD ±0.64), this effective control aided in keeping COD removal efficiencies in excess of 72% for the duration of the start up. Mean organic loading rates (table 4) were well within the design limit of 5.60 Kg COD/m^3/day and below the expected operational level of 4 Kg COD/m^3/day for all periods, with the highest mean being seen between days 90 – 120 at an OLR of 2.98 Kg COD/m^3/day (STD ±0.54).

Optimal mesophillic conditions of 35 ℃-38°C (Bolzonella *et al.*, 2012) were achieved within the first 9 days of operation due to the high temperature of the incoming effluent. After the 66th day temperatures were in excess of this optimum range on all but 1 day and reaching a maximum of 42.1°C. Although outside of the optimum levels conditions were within the range of mesophilic digestion and showed no noticeable decrease in reactor performance in terms of COD removal. This finding is in accordance with long term performance trends shown in Cairns & Mead (2017) which showed that the plant remained robust when operating at higher than optimum temperatures.

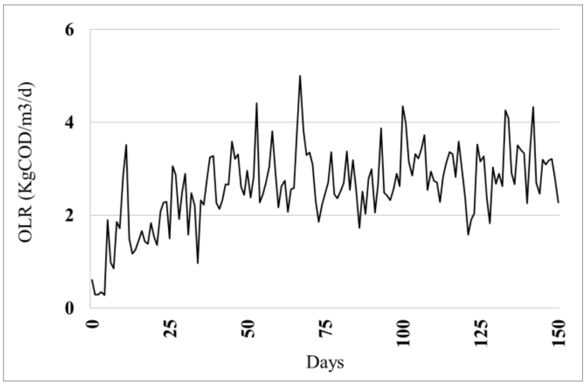


Figure 4. Organic Loading Rate (KgCOD/m^3/d)

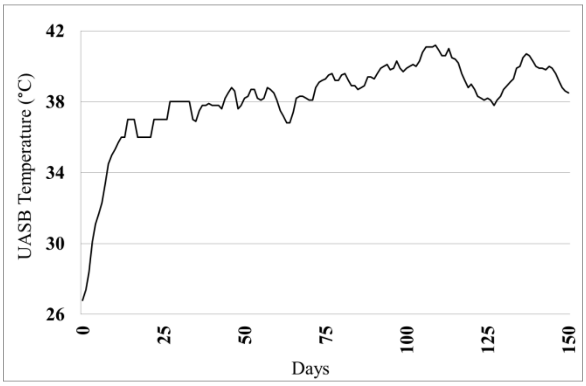


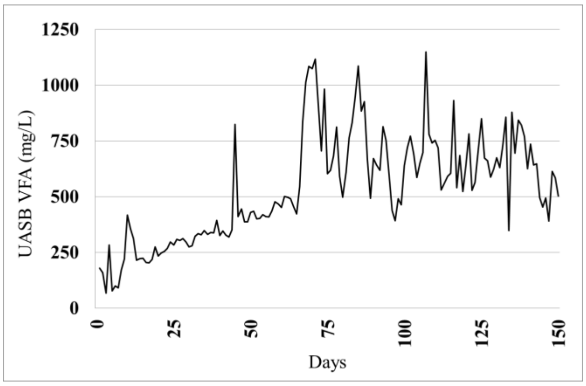
Figure 5. UASB effluent temperature (°C)

Volatile Fatty Acid concentration steadily increased inline with the OLR however a large spike on 67th day which saw the OLR double to 5.00 KgCOD/m^3/d and was followed by a large spike in VFAs two days later and continued to fluctuate around the mean of 696mg/L (STD ±172mg/L). A VFA profile was not conducted as part of this study although this could have helped provide insight in to whether the plant was performing under optimum, normal or stressed conditions (Horan et al., 2011). A understanding of the VFA ratios could be used to aid fine tune the digester by optimising key plant operating parameters such as hydraulic retention time and organic loading rate.

Table 3. Process Parameters

Parameter	0-30days	30-60days	60-90days	90-120days	120-150 days
Flow (m^3/d) ±STD	135.39±56.95	193.39±48.14	213.77±34.33	217.19±20.35	201.74±39.52
HRT (days) ±STD	22.14±21.20	10.99±3.27	9.57±2.00	9.20±0.90	10.19±2.05
V_{up} (m/s) ±STD	0.03±0.01	0.04±0.01	0.04±0.01	0.04±0.01	0.04±0.01
OLR (KgCOD/m^3/day) ±STD	1.660.86	2.68±0.65	2.77±0.67	2.98±0.54	2.91±0.68
Temperature (°C) ±STD	34.89±3.18	38.06±0.48	38.63±0.82	40.16±0.64	39.19±0.86
pH ±STD	6.89±0.17	7.16±0.13	7.16±0.11	7.61±0.21	7.75±0.08
VFA (mg/l) ±STD	235.52±82.13	391.61±96.75	734.32±221.01	656.90±148.74	646.00±135.72
COD Removal (%) ±STD	95.46±2.26	89.82±3.22	81.89±4.84	85.05±1.65	82.76±3.03

Treated effluent pH was also seen to steadily increase (Figure. 7) from a mean of 6.89 (STD ±0.17) in the first 30 days to 7.75 (STD ±0.7) in the last 30 days (table 3). This rise occurred without any chemical addition despite wide variations in incoming pH (3.15 - 11.83).



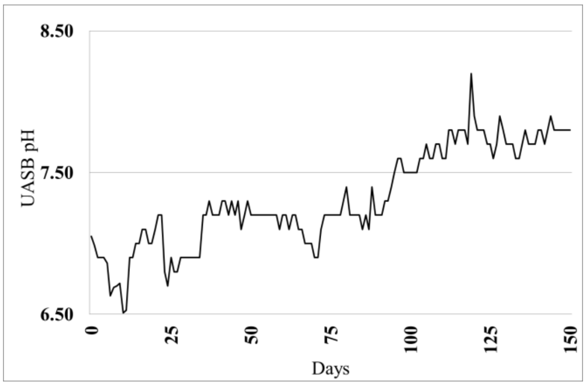


Figure 6. Volatile Fatty Acids (mg/l)

Figure 7. Reactor pH

3.3 Start Up: Treated Water

Over the 150 day start up sampling period the treated effluent had a COD concentration increase from 1029mg/L (STD±758) in the first 30 days to 4828 mg/L (STD±484) in the last 30 days. A similar increasing trend in N and P was witnessed increasing from 31.79mg/L (STD±9.45) and 27.62mg/L (STD±14.55) in the first 30 days to 171.25 mg/L (STD±484) and 102.3mg/L (STD±48.50) in the last 30 days respectively. This leads to a mean treated effluent CNP ratio ranging from of roughly 37:1:1 in the first 30 days to 48: 2:1 in the last 30 days. This could therefore cause issues with downstream aerobic process where a CNP ratio of 100:5:1 is desired (Ammary, 2004). Increases in the OLR has been shown to not only have a deleterious impact on overall residual COD (Figure 8) but also on COD removal efficiency (Figure 9).

Sulphate continued to be relatively low compared to COD increasing from a mean concentration of 146.61mg/L (STD±22.22) during the first thirty days to 538.39mg/L (STD±78.53), this results COD:SO_4 ratio ranging from 7:1 at the beginning of the start up to 9:1 at the end of the start up. This is comparable to COD:SO_4 ratio of 8.5:1 during long term operations (Cairns and Mead, 2017).

Table 4. Treated Wastewater Composition

Parameter	0-30days	30-60days	60-90days	90-120days	120-150days
COD (mg/L)	1029±465	2790±808	4476±604	4010±296	4828±484
TKN (mg/L)	31.79±9.45	99.60±41.50	137.80±33.97	175.50±43.62	171.25±49.74
P (mg/L)	27.62±14.55	77.34±8.08	87.22±8.63	82.33±1.14	102.30±48.50
TSS (mg/L)	610.73±786.39	1420.84±443.91	1965.03±292.57	1672.74±257.01	2606.00±465.92
SO_4 (mg/L)	146.61±22.22	349.79±130.09	413.58±143.25	360.55±56.59	538.39±78.53

Due to technical issues with gas meters, accurate data pertaining total biogas gas production, total methane production and Biological Methane Potential (BMP) was not possible. Under higher OLRs it was noticed that the plant became less efficient with regards to the % methane concentration of the biogas (Figure 9), which is comparable to post start up conditions (Cairns & Mead, 2017) with mean methane concentrations of 57.24% (STD±4.29) and 58.08 (STD±2.96) respectively.

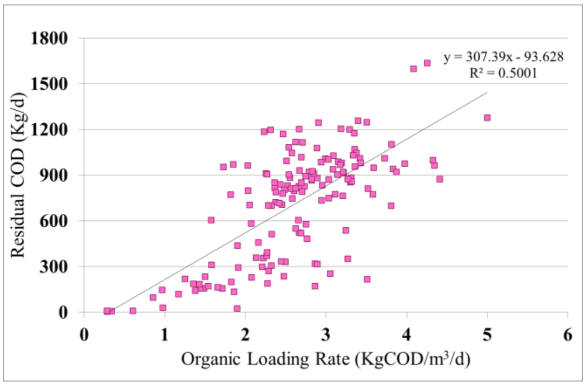


Figure 8. The impact of OLR on residual COD

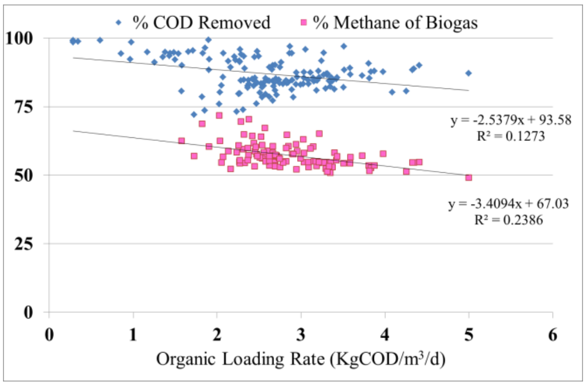


Figure 9. Impact of OLR on % COD removal and % Methane in biogas

4. Conclusion

In this paper it was demonstrated that an Upflow Anaerobic Sludge Blanket under mesophilic conditions treating a high strength effluent (15,619 - 44,684mg/L COD) from a malted ingredients factory could be started effectively within a period 75 days.

Despite previously reported difficulties with plant start ups, operational performance in terms COD removal efficiency (>81.89% ±4.84) and the percentage methane content of biogas (57.24% ± 4.29) was achieved at a level comparable to a fully established plant. Further work is required to determine if total biogas volumes are also comparable.

Operational performance was considered robust with the main factor limiting COD removal efficiency and biogas methane concentration being the organic loading rate. Typically key operational parameters such as HRT times, temperatures and pH were outside ideal plant operating parameters but did no exert a strong influence on plant performance. It would be beneficial to conduct a profile of the VFA to be able to get a better insight in to the plant operating conditions as well as understanding the micronutrient composition of the incoming wastewater.

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Glossary

AD: Anaerobic Digestion

ADBA: The Anaerobic Digestion and Bioresources Association

CH_4: Methane

COD: Chemical Oxygen Demand

HRT: Hydraulic Retention Time

MI: Malt Ingredients

NH_3: Ammonia

OLR: Organic Loading Rate

TKN: Total kjeldahl (Organic) Nitrogen

TSS: Total Suspended Solids

UASB: Upflow Anaerobic Sludge Blanket

VFA: Volatile Fatty Acids

V_{up}: Upflow Velocity

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