Evaluation of the Performance of Combine Primary Settling and Anaerobic Digestion for the Treatment of Yeast Wastewater

John Kabuba[1] and Mumsy Thloloe[2]

***Abstract*—**Thes aim of this study is to evaluate the performance of combined primary settling and anaerobic digestion as a treatment option for Yeast wastewater and to obtain consistent data to be applied in confirmation of the design of the full-scale anaerobic digestion plant. The study included the use of a clarifier for total suspended solids (TSS) removal from yeast factory effluent followed by anaerobic digestion for biogas production. A 2.7 m^3 clarifier was used to settle the solids in the wastewater before treatment in the anaerobic digester (AD). The clarifier inlet flowrate is the operating parameter investigated and varied to determine the best conditions for the clarifier. The anaerobic digester used is an up-flow anaerobic sludge blanket (UASB) type with dimensions of 1 m diameter and 6 m high. The optimal operation conditions for the anaerobic digester is a maxi-mum organic loading rate (OLR) of 4.5 kg chemical oxygen demand (COD)/m^3.d, and the COD reduction of 65% is achieved. A high vola-tile fatty acids (VFA) /alkalinity ratio of 0.5 is observed at COD loading of 18 kg/d, corresponding to an OLR of 4.5 kg COD/m^3.d which is above the recommended value of below 0.4. This observation is used as a precaution not to exceed the OLR of 4.5 kg COD/m^3.d because of a possible digester failure or reduced efficiency. The digester loading rate of 18 kg COD/d produced the highest biogas at approximately 2000 L/d. The nearly constant gas production indicated that the reactor is stable at this COD loading. This is supported by a nearly constant VFA/alkalinity ration during this period. The results indicated that anaerobic digestion of baker's yeast can and is a viable method for wastewater treatment.

***Keywords*—**Evaluation, Performance, Primary settling, Anaerobic digestion, Yeast wastewater

I. Introduction

YEAST production generates wastewater stream with high chemical oxygen demand (COD) of approximately 30,000 mg/L which is contributed largely by diluted spent molasses. The effluent also contains residual yeast which, together with the spent molasses, contributes to high total suspended solids (TSS) concentration of about 9,000 mg/L. The effluent generated by Anchor Yeast is currently discharged at the sea outfall in Durban without any treatment. This is a potential source of environmental pollution despite the high initial dilution at the outfall diffusers. Anchor Yeast is concerned about the potential pollution from its operations and is committed to research to find a possible wastewater treatment technology for handling the effluent. Anaerobic digestion, which is the degradation of organic compounds by microorganisms in the absence of molecular oxygen, has been applied in the treatment of yeast effluent due to its advantage in producing biogas which is a renewable energy source [1]. However, low performance has been observed when using anaerobic digestion in treating yeast effluent due to the inhibition by the high TSS originating from the residual yeast cells and molasses. Due to this reason, methods of reducing the residual yeast or TSS content of the effluent prior to anaerobic digestion need to be researched. The proposed work focused on the feasibility study of using anaerobic digestion for the reduction of organic content of Anchor Yeast wastewater. The efficiency of anaerobic digestion was improved by initially removing the residual bio-recalcitrant yeast through settling using a clarifier. The optimum operating conditions for pre-settling and anaerobic digestion was determined in a pilot plant scale. The methane rich biogas generated from the anaerobic digestion of wastewater can be used to generate steam from a biogas boiler, which can ultimately be used in the yeast production process with the potential of reducing operation costs. The biogas potential of the Anchor Yeast effluent was determined in this study. Based on the findings of this study, Anchor Yeast considered installation of a full-scale anaerobic digester for energy recovery and wastewater management.

John Kabuba[1] is with the Department of Chemical and Metallurgical Engineering, Vaal University of Technology, Vanderbijlpark, South Africa

Mumsy Thloloe[2] is with the Department of Chemical and Metallurgical Engineering, Vaal University of Technology, Vanderbijlpark, South Africa

II. Methodology

A. Equipment setup and Procedure

The study investigated the use of a clarifier for TSS removal from yeast factory effluent followed by anaerobic digestion for biogas production. A 2.7 m^3 clarifier was used to settle the solids in the wastewater before treatment in the anaerobic digester (AD). The operating parameters in the clarifier were varied to determine the best conditions. The anaerobic digester used was an Up-flow Anaerobic Sludge Blanket type with dimensions of 1 m diameter and 6 m high. The clarifier and the UASB digester pilot plants were fabricated, installed and operated at the Anchor Yeast production site located at Heartlands Estate, Umbogintwini Durban.

https://doi.org/10.17758/IICBE6.C1124205

The pilot plant is divided into two sections: a clarifier pilot and an anaerobic digester pilot. The set up for the pre-settling (clarifier) unit in Figure 1 was fed from a diversion of the effluent line of the factory and the flow is controlled by valve BAV2 and monitored by magnetic flow meter FE101, which allows for flow trending. The wastewater flows into the clarifier where the suspended solids are settled and then removed as underflow. The clarifier flow rate was varied between 200 L/h to 1000 L/h. Samples were collected from the inlet, underflow and clarified effluent outlet. Sampling was done on a regular basis and the rate of solid removal determined for evaluation of the system performance; the clarifier set up is shown in Figure 2. The sludge was drained into an existing sump for disposal while the overflow was fed by gravity to the ensued anaerobic digestion system via an equalization (EQ) tank (T-103). The equalization tank had a capacity of 1m^3 and it was fitted with a mixer to ensure homogeneity of the effluent prior to feeding into the anaerobic digester. The flow rate to the EQ tank was controlled by valve BAV6. Excess overflow was channeled to an existing effluent sump. The sludge and overflow streams ware sampled by opening valve BAV3 and BAV5, respectively.

The AD was inoculated using a mixture of equal volumes of sludge sourced from anaerobic digester treating breweries wastewater and sludge from anaerobic digester treating municipal wastewater, the total inoculum volume was 1.5 m^3. The AD was then fed from the EQ tank by gravity at a flow rate of between 5 L/h to 35 L/h, varied stepwise over a period of four months. The feed and the recycle stream were fed into the digester at a sufficient flow rate to achieve the recommended-up flow velocity of between 0.6 to 1 m/h through the distributor manifold in the digester. The distributer/diffuser was made of a 1 m long pipe fitted on the floor of the digester with five staggered alternating holes each at 120^{o}C from the digester floor, the holes were 143 mm apart.

Fig. 1 Clarifier set up

Fig. 2 Anaerobic Digester set up

B. Laboratory Analysis

COD was measured using the colorimetric method after digesting the samples at 150^{o}C for two hours. TSS and VSS were measured using the gravimetric method using 1 mm filter paper. VFA was measured through the reflux and two-point titrimetric method using 0.1 M NaOH and 0.1 M HCL. Calcium, sulphur and magnesium were measured using ion chromatography. Yeast cells in the effluent were determined using the cell culture and count method. FTIR analysis was used to determine the functional groups in the raw material and effluent. The energy content of the settled solids were determined using a bomb calorimeter.

C. Experimental Design

One at a time experimental design was used to evaluate the performance of the clarifier and the AD unit in treating yeast effluent. The parameters investigated for the clarifier were feed flow and rise velocity. The feed flow rates studied ranged between 200 L/h to 1000 L/h corresponding to rise velocity of between 0.1 m/h to 0.5 m/h. For the AD unit the effect of OLR and HRT on biogas production was investigated. The parameters used to analyze the performance of the clarifier were TSS removal, while for the AD the parameters were COD removal, VSS distribution, biogas production and methane composition of the biogas. The amount of methane produced was used to predict the amount of energy in terms of steam that can be produced by the yeast factory effluent when a full-scale anaerobic digester is installed. The potential of steam production through anaerobic digestion was compared with the steam consumption of the yeast factory.

III. Results and Discussion

A. Characteristics of Yeast effluent

Baker's yeast, used in the preparation of bread, is manufactured through aerobic fermentation of molasses using bacterial strains of Saccharomyces cerevisiae. Various chemicals are added in different stages of fermentation and cleaning of equipment, some of the chemicals used are sulphuric acid, phosphoric acid, mono ammonium phosphate, ammonium hydroxide, sodium hydroxide, sodium hypochlorite [2]. Therefore, baker's yeast effluent contains substantial amounts of organic and inorganic compounds. The characteristics of the yeast effluent studied is shown in Table I. The organic constituents come from molasses which are the main raw materials, with the inorganic constituents originating from the chemicals added. Molasses also contains potassium, calcium and sodium [3].

TABLE I
CHARACTERISTICS OF YEAST PLANT EFFLUENT

Parameter	Unit	Mean value
Chemical Oxygen Demand (Total)	mg O_2/L	31500
Electrical Conductivity	mS/m	1360
Salinity	mg/L	24
Suspended solids	mg/L	5600
Volatile suspended solids	%	72
Calcium	mg/L	610
Magnesium	mg/L	340
Potassium	mg/L	2450
Sodium	mg/L	1380

Monitoring the daily COD of anchor yeast effluent for a period of seven weeks showed that the highest COD was about 63000 mg/L and the average value of the COD over that period was about 31000 mg/L. Because of the high fluctuations in the effluent COD, an equalization tank is necessary prior to anaerobic digestion to ensure homogeneity of the digester effluent to prevent any possible shock loading that can reduce the digester efficiency. Corresponding values for total suspended solids (TSS) during the same period showed that in some occasions the TSS in the effluent was above 8000 mg/L while average TSS was about 5000 mg/L. Determination of the daily TSS load in the effluent could help to estimate the amount of solid waste to handle if a settler is used as an application to remove the TSS prior to subjecting the effluent to anaerobic digestion. The amount of TSS load per day is shown in Figure 3, the average load was found to be 12 ton TSS/day depending on the characteristics of the solids that could be incinerated to produce energy. This aspect was investigated in this study.

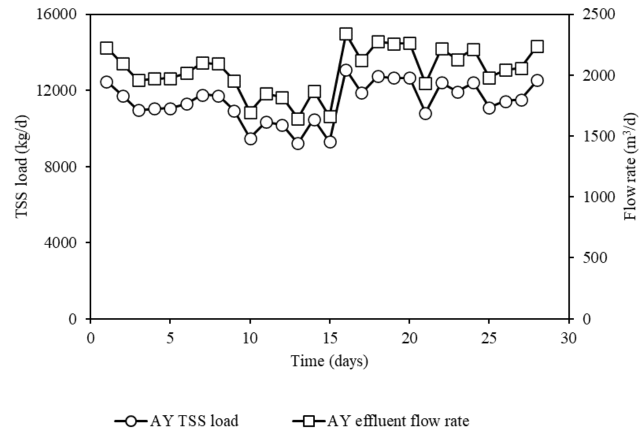

Fig. 3 Daily flow rate and TSS load of Anchor Yeast effluent

Normally the high TSS in baker's yeast affect the performance of anaerobic digesters by accumulating in the digester and forming a hard mass of solid after some period [2], which necessitates the removal of the TSS prior to anaerobic digestion. The TSS could be from residual yeast or from the molasses raw material. The settleability of the TSS was determined using the Imhoff cone and it was found that a substantial amount of the solids are settleable as presented in Figure 4. Further characterization of the suspended solids in the yeast effluent was carried out to estimate the presence of yeast cells on both the settleable solids and fluffy solids that could not settle. If too much yeast in the effluent is not settleable, this could mean that most residual yeast cells may be in the feed to the anaerobic digester which could reduce the efficiency of the anaerobic digestion owing to the fact that yeast cells are not easily biodegradable due to their proteinaceous cell walls.

Fig. 4 Determination of settleable suspended solids in baker's yeast effluent

B. Characterization of solids in yeast factory effluent

Yeast in the effluent is difficult to settle due to its poor settling ability. To ascertain the amount of yeast in the

https://doi.org/10.17758/IICBEE6.C1124205

effluent and their distribution, yeast count and FTIR analysis was carried out. The FTIR analysis and yeast count were conducted on the effluent supernatant and on the suspended solid cake to establish yeast distribution. The effluent was centrifuged at 10000 rpm to separate the yeast that can settle from the yeast that is difficult to settle out. The yeast in the settleable solids and in the supernatant were cultured followed by a cell count on the resulting cells (Figure 5) aided with a microscope.

Fig. 4 Results of heat fixed smear of yeast cells stained with methylene blue

Figure 5 shows the yeast count in the supernatant and suspended solids expressed in counts/ml and counts/g, respectively. The samples analyzed were collected from the factory effluent for six consecutive days.

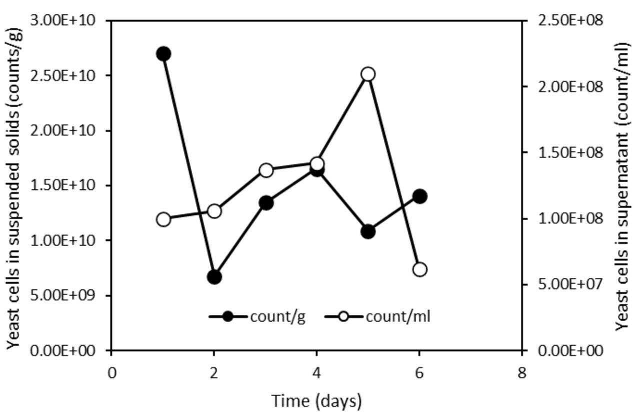

Fig. 5 Amount of yeast cells in un-settleable and settleable solids

There were more yeast cells in the effluent solids than in the supernatant. This indicates that more residual yeast cells from the factory production line could be removed using the clarifier. However, the supernatant also had a substantial amount of yeast cells. The number of cells in the supernatant shows the amount of yeast which could not be easily separated by settling. The source of the suspended solids in the yeast effluent are likely from the molasses raw material and the residual yeast. A comparative analysis of raw material used in the production of yeast (molasses) and yeast factory effluent was carried out using FTIR analysis to determine any similarity which will help to further ascertain the source of the suspended solids. Figure 6 shows that there was similarity of the FTIR of yeast factory effluent supernatant and that of the effluent suspended solids indicating similarities in their composition. The FTIR spectrum of molasses showed bands majorly at 3400 cm^{-1} due to stretching vibration of OH and NH_2 bonds, at 2850 cm^{-1} due to CH stretching vibration, 1640 cm^{-1} due to CO-NH [4]-[5].

The similarities of some functional groups of molasses supernatant and factory effluent indicate that the molasses raw material was not fully degraded during the fermentation process. Molasses contains dark brown organic compounds called melanoidins which are bio-recalcitrant and often constitute the wastewater in a molasses-based yeast fermentation process [8].

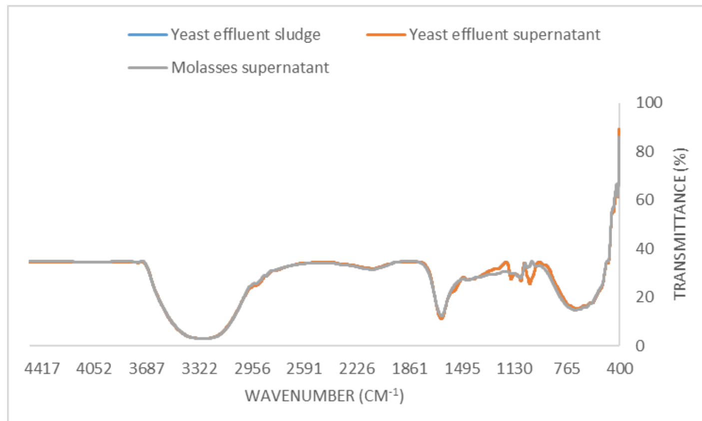

Fig. 6 FTIR analysis of the molasses raw material and yeast factory effluent

The FTIR analysis was further used to determine whether the solids in the yeast factory effluent originated from the raw material or from the fermentation process. Comparing the peaks for the suspended solids in the effluent and that of the suspended solids in the molasses, molasses sludge obtained after centrifugation, (Figure 7), a remarkable difference was noted. This shows that part of the solids in the effluent do not originate from the suspended solids in the raw material (molasses) but are most likely generated during the fermentation process. This is supported by the large number of yeast cells in the effluent.

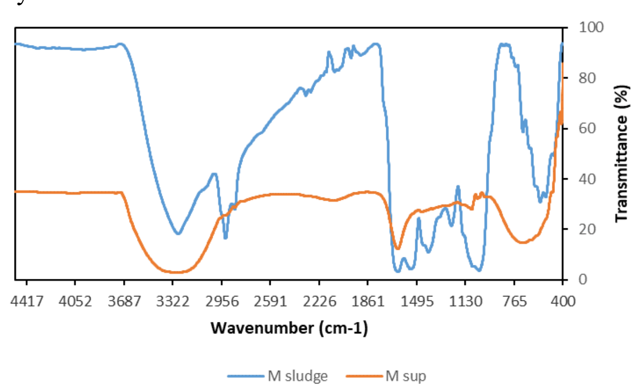

Fig. 7 FTIR analysis of the molasses sludge and molasses supernatant

C. Application of clarifier for pre-treatment of Yeast effluent

The Yeast effluent has suspended solids ranging between 2000 to 10000 mg/L with an average of 4300 mg/L. The solid concentration is high for effective anaerobic digestion for biogas recovery. Therefore, it is necessary to separate the solids prior to anaerobic digestion. A primary clarifier was used to achieve solid separation. The separation efficiency of the clarifier was determined at different influent velocities. The flow rates were varied from 0.4 to 1 $m^{3/}$h. Due to the variation in the TSS concentration of industrial wastewater, different runs were carried out to capture the fluctuations in the clarifier feed. Five runs were carried out at a feed velocity of 0.4 m^3/h in a day when the TSS in the wastewater varied between 5340 to 13250 mg/L. Figure 8 shows that irrespective of the inlet TSS concentration, the clarifier removed the TSS to about 3800 mg TSS/L. The amount of TSS below 3800 mg/L could not be removed most likely due to their poor settleability.

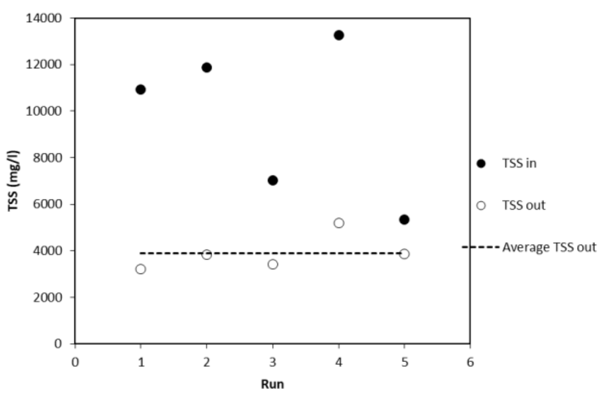

Fig. 8 Performance of clarifier at varied feed concentration at a flow rate of 0.4 m^3/h

A corresponding TSS removal efficiency at 0.4 m^3/h is shown in Figure 9. It was observed that high percentage removal of the TSS is mostly achieved at high feed TSS concentration. The highest TSS removal was 71% when the feed TSS concentration was 10900 mg/L while the least removal was 28% when feed TSS concentration was 5300 mg/L. These observations show that the clarifier is mostly affected by the characteristic of the solids to be removed than the amount of the solids in the effluent. However, with high solids concentration frequent discharge of the settled sludge was practiced during the clarifier operation.

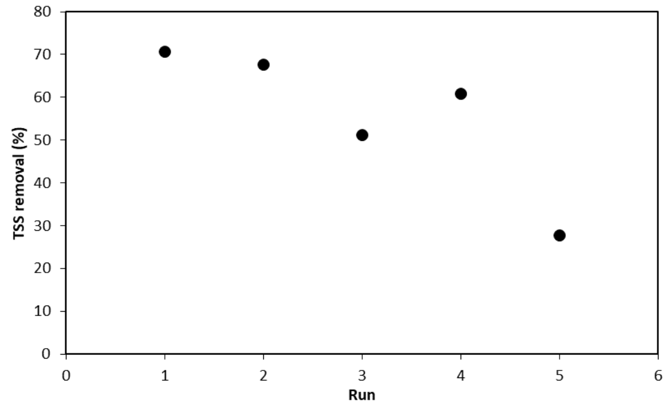

Fig. 9 TSS removal efficiency at feed flow rate of 0.4 m3/h

Increasing the feed rate to 0.7 m^3/h (Figure 10) shows that the TSS could be removed to about 2000 mg/L irrespective of the feed concentration. This further confirms that there is a minimum TSS in yeast effluent with poor settleability and this could depend on processes used in production, production conditions and raw material quality which could vary widely or on daily basis.

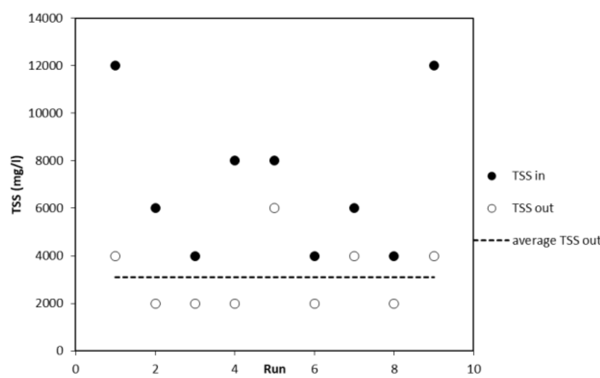

Fig. 10 Performance of clarifier at varied feed concentrations at a flow rate of 0.7 m3/h

Similarly, the TSS removal efficiency at 0.7 m^3/h appeared to increase with an increase in the feed concentration as was the case at 0.4 m^3/h. The efficiency of removal of TSS at both 0.4 and 0.7 m^3/d at high concentration of above 10000 mg/L was averagely 70%. From this observation, it is not economical to operate the clarifier at low flow rate of 0.4 m^3/h when the TSS is high since the TSS removal efficiency is nearly similar to that at 0.7m^3/h.

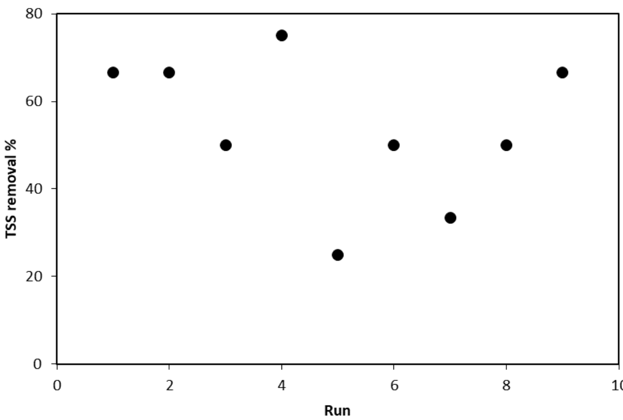

Fig. 11 TSS removal efficiency at feed flow rate of 0.7 m^3/h

Due to the relatively low solid removal efficiency at feed TSS concentration of below 4000 mg/L and being a fact that there is a high possibility of daily discharge of wastewater with TSS between 4000 mg/L and 3000 mg/L as shown in Figure 11, a study of TSS removal at these feed TSS concentration ranges was carried out. It was shown that at a nearly constant feed TSS concentration of approximately 3300 mg/L, the TSS removal was highest (51%) at low feed flow rate and least (12%) at the highest flow rate of 1 m^3/h. It is, therefore, beneficial to operate the clarifier at low flow rate when the feed TSS concentration is less than 4000 mg/L. This is to increase the residence time of the wastewater in the clarifier to increase settling of solids. This will affect the rise rate which is very significant for effective solids settling.

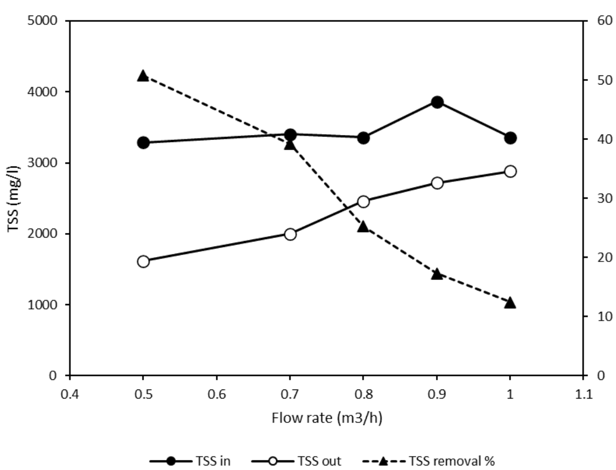

Fig. 12 Effect of feed flow rate at constant feed concentration

D.Effect of settleable solids on clarifier performance

Settleable solids are that portion of the suspended solids which are of sufficient size and weight to settle in a given period of time, usually one hour. These are those suspended solids which settle in an Imhoff cone in one hour and are measured in ml/l, this is referred to as sludge volume (SV).

The effect of the settleable solids composition of the yeast factory effluent on the removal of TSS is shown in Figure 13. It was observed that there was nearly a direct relationship between the amount of TSS and settleable solids in yeast effluent and in the settled wastewater.

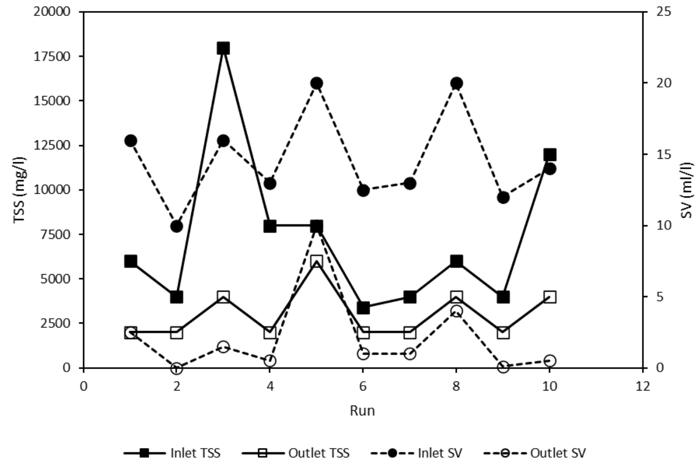

Fig. 13 Effect of settleable solids on clarifier performance

The removal efficiency of the settleable solids and total suspended solids also had a direct relationship as shown in Figure 14. Settleable solids were effectively removed by the clarifier with removal efficiency often greater than 85%. Under similar conditions, the TSS removal efficiency was scarcely above 50% indicating that substantial amount of the total suspended solids could not be adequately settled in the clarifier. This indicates that the suspended solids could consists of residual yeast as confirmed by yeast count and FTIR analysis in Figures 14 and 15, respectively. Residual yeast cells in yeast plant effluent have been reported to be fluffy and very difficult to be removed through settling.

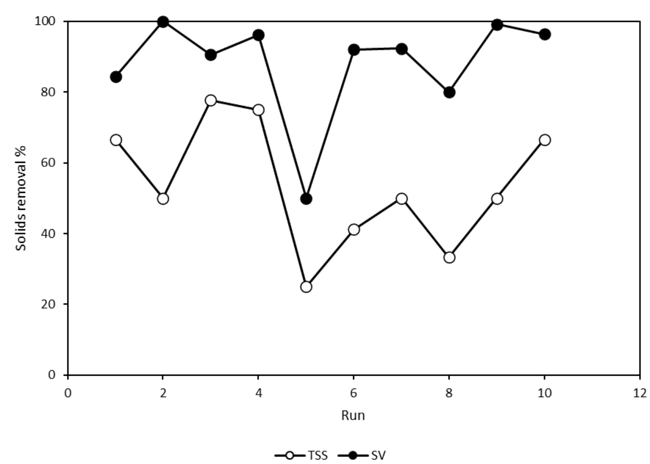

Fig. 14 Removal efficiency of settleable solids and TSS

E. Effect of rise rate on clarifier efficiency

Determination of the rise rate of the pilot plant can be used as a design parameter for scaled up industrial clarifier. Varying the rise rate of the clarifier was carried out for a period of 30 days in a continuous feed mode, the effluent was treated as received without any dilution. During this period, the rise rate was stepped up sequentially from 0.2 m/h to 0.6 m/h. Irrespective of the rise rate, the clarifier effluent TSS was treated to approximately 2000 mg/L (Figure 15).

Under the range of rising velocities studied, the settling velocity of most of the suspended solids in the clarifier were much higher than the rising velocity, this led to adequate TSS removal, especially when the effluent TSS was greater than 400 mg/L. However, some residual TSS could not be removed even at low rise rate because they were light in weight and were well dispersed in the liquid thus could not settle within the rise rate studied.

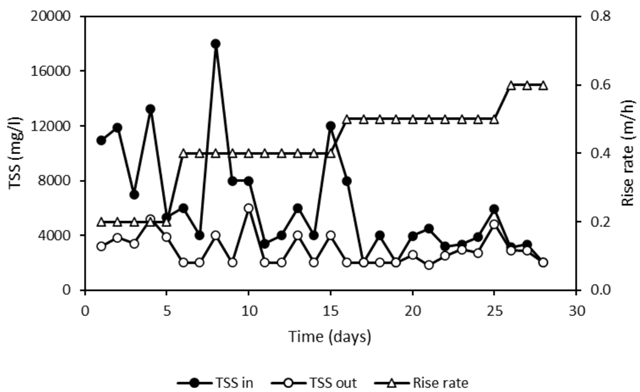

Fig. 15 Effect of varying rise rate when treating raw effluent

F. *Effect of solids loading rate*

Solid loading rate is the amount in kilograms of TSS fed into the clarifier per available surface area per unit time. The loading rate of a pilot plant clarifier can also provide a valuable data necessary to design an industrial scale clarifier treating similar waste.

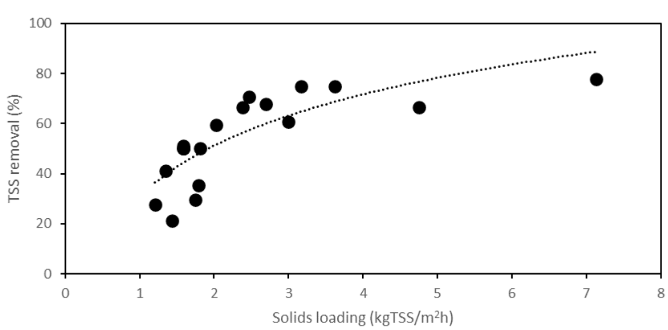

Fig. 16 Effect of solid loading rate on clarifier performance

Solids loading rate of between 1.2 and 7 kg TSS/m^{2}h was studied. In Figure 17 more solids were removed at high solids loading rate, however, the quality of clarifier effluent is superior at loading rates below 3.6 kg/m2h as shown in Figure 17. For better effluent quality, owing to the wide variation in the TSS concentration, it is advisable that a sump/an equalizer be installed before the clarifier to harmonize the wastewater to avoid extremely high TSS peaks. This may ensure that the feed to the clarifier has a fairly low amount of TSS that can be adequately removed by the clarifier to values approximately 200 mg/L.

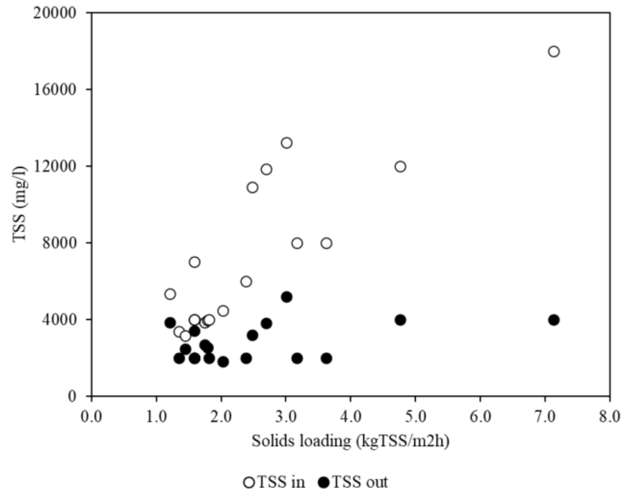

Fig. 17 Effect of solids loading rate on clarifier performance

IV. Anaerobic Digestion of Pre-Settled Yeast Factory Effluent

Anaerobic digestion of pre-settled yeast factory effluent was carried out in a pilot UASB reactor. The aim of the anaerobic digestion was to investigate the efficiency of the process in COD reduction. Additionally, kinetic analysis of the pilot plant was carried out to predict the performance of a full-scale bio-methane plant. Further, the bioenergy production potential of the pilot UASB was used to determine if bioenergy from a full-scale plant can be used to supplement the energy requirement of the yeast plant.

A. *Performance evaluation of anaerobic digestion*

The balance between VFAs, alkalinity and pH in an anaerobic digester is used as a measure for bio-digester stability [7]. A stable reactor operates at a pH range of 6.7-8, the total alkalinity should be sufficiently higher than the VFA for adequate buffering in the digester. The pH of the plant was automatically regulated using a caustic and sulfuric acid dosing pump. The VFA of the digester increased in the first two weeks when the feed was introduced in the digester because of increased acid production through the initial acidogenesis and acetogenesis processes [8]. During the same period, the alkalinity of the digester dropped due to the production of the VFAs. During the initial stages of feeding an anaerobic digester hydrolysis and acidogenesis processes proceed faster than methanogenesis leading to generation of VFAs which consumes the alkalinity. As feeding continued, the VFA and the alkalinity remained relatively stable when the COD loading was increased from 0.8 to 4 kg/d showing that the alkalinity in the digester was sufficient to neutralize the effect of VFAs in the digester. The VFA raised above alkalinity which could lead to reactor failure. To restore normal operation, the reactor feed pump was stopped for the subsequent three days for the methanogens to convert the generated simple organic acids into biogas. A good response was obtained after the three days break and the VFA reduced from 1737 to 1175 mg/L. A corresponding increase in alkalinity was observed when the VFA concentration had reduced. Once the loading was resumed the alkalinity continued to rise above the VFA concentration even when the loading was increased gradually from 6 to 18 kg COD/d. This was an indication that the reactor was stable and had a good buffering capacity due to adequate alkalinity. Normally, VFA/Alkalinity ratio is used to evaluate reactor stability, with a ratio below 0.4 considered most suitable [7]. The VFA/Alkalinity ratio was mostly below 0.4 but it increased to above 0.5 from 16th January due to a possible organic overloading. A subsequent halt on reactor feeding restored the VFA/alkalinity ratio. However, at some instances, after resuming normalcy, the VFA/alkalinity ratio was above 0.4. This could be due to the complex nature of industrial effluent and operation of a reactor at pilot plant scale. For example, the yeast effluent contains substantial amounts of ammonia and sulfates. The sulfates generate H2S in the reactor that contributes to acidity. The production of H2S was confirmed by scrubbing the walls of the mixing tank in the AD system where deposits of H2S was discovered alongside deposition of calcium and magnesium. Volatile suspended solids in a digester are used to monitor biomass growth (Aziz et al., 2011). Figure 18 shows that over a period of more than one month the amount of VSS in the reactor, which directly correlates with the biomass growth, increased from 4 kg to 18 kg. The increase in VSS in the digester over the feeding period evidenced conducive environment for biomass growth. Biomass growth flourishes when there is no shock loading which results in high VFA generation and compromises the buffering capacity or the alkalinity of the digester. Performance of a UASB digester significantly depends on the nature and distribution of sludge granules in the digester. The sludge granules are formed as a result of flocculation and ultimate granulation of biomass that effectively degrade the organic pollutants into methane. The nature of the sludge and its distribution is affected by extrinsic factors such as up flow velocity, VFA and alkalinity [9]. The effect of VFA on sludge volume which is an indicator of sludge development in the digester. An increase in VFA resulted in a reduction in the sludge volume. This could be explained by the granulation process in which the initiation of granules starts from the microorganisms' adhesion that forms aggregations of bacterial cells surrounded by extracellular polymer (ECP) and other components in spherical shapes. The filaments of Methanosaeta species, a methanogen, are responsible for granulation phenomenon [9]. The methanogens are more sensitive to changes in VFA concentration in the digester than the acidogenic bacteria [8]. At high VFA concentration, acidogenic bacteria growth is favoured while the growth of methanogenic bacteria is suppressed, subsequently low granulation is observed [10]. The distribution of sludge in the digester was evaluated by measuring the axial concentration of TSS and VSS. Figure 18 shows that the solids were fairly distributed in the reactor from the bottom- most section sampled at sample point 1 (SP1) to the top- most section of the digester sampled at SP7. The even distribution showed that the upward velocity applied was adequate and ensured that there was no accumulation of biomass rich granules at the bottom of the digester. Also, there was a general increase in the concentration of solids in the reactor from week 1 to week 11. This could be due to growth of biomass which formed the solid granules. Biomass growth corresponded to an increase in OLR which subsequently leads to an increase in the available food for the microorganisms. Low OLR of < 1.5 kg/m^{3}d often causes acute mass transfer limitation leading to disintegration of the larger granules, an OLR of 2 – 4.5 kg/m^{3}d has been recommended for developing good granular sludge (Tiwari et al., 2006). There was a slight decrease in the TSS concentration towards the top of the digester likely due to the increased biomass terminal velocity resulting from increased mass due to growth. This also ensured that there was minimal sludge washout.

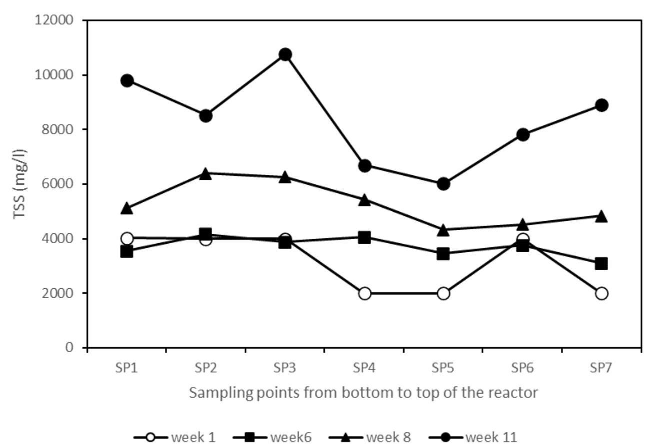

Fig. 18 Axial solid concentration in the digester

The solid biomass material (granules) can consist of inorganic materials, microorganisms' cells and extracellular polymers (ECP). A measure of the VSS of the solids gives their approximated biomass fraction. Figure 19 shows that the VSS fraction of the solids ranged mainly between 65% and 78% axially along the digester for all the weeks tested, except for week one when it was 60% at the bottom section of the digester. The low VSS at the bottom of the digester in week one cloud means that there was fluffy sludge which could easily be carried up the digester due to their poor settling ability/low weight. There was a general increase in the VSS composition of the solids from the bottom of the digester to the top. This could suggest that the solids with more organic constituents were lighter and could sufficiently be suspended by the applied up- flow velocity. The solids toward the bottom could be rich in inorganic components like calcium, magnesium and potassium which is present in yeast effluent in significant amounts. It has been reported that the inorganic components in granules can range from 10 to 90% and depends on the wastewater contents and the operational conditions. A relationship between density and ash content of granules contributed by calcium, potassium, sodium and iron indicated that an increase of density is mainly attributed by ash increase in granules [9].

Fig. 19 VSS composition of the TSS

There was a general increase in the VSS composition of the solids from the bottom of the digester to the top. This could suggest that the solids with more organic constituents were lighter and could sufficiently be suspended by the applied up-flow velocity. The solids toward the bottom could be rich in inorganic components like calcium, magnesium and potassium which is present in yeast effluent in significant amounts. It has been reported that the inorganic components in granules can range from 10 to 90% and depends on the wastewater contents and the operational conditions. A relationship between density and ash content of granules contributed by calcium, potassium, sodium and iron indicated that an increase of density is mainly attributed by ash increase in granules [9].

V. Conclusion

The optimal clarifier operation condition to achieve best solids removal was at loading rates below 3.6 kg/m^{2}h, since the results indicated that the quality of clarifier effluent was superior at these loading rates, even though more solids were removed at high solids loading rates.

The clarifier rise rate was stepped up sequentially from 0.2 to 0.6 m/h. Irrespective of the rise rate between 0.2 to 0.6 m/h, the clarifier effluent TSS was treated to approximately 2000 mg/L. Under the range of rising velocities studied, the settling velocity of most of the suspended solids in the clarifier were much higher than the rising velocity, this led to adequate TSS removal, especially when the effluent TSS was greater than 4000 mg/L. This effluent TSS removal will minimize the possibility of TSS deposits on the seabed and avoid destruction of the aquatic habitat.

The optimal operation conditions for the anaerobic digester was a maximum OLR of 4.5 kg COD/m^3.d, in which the COD reduction of 65% was achieved. This COD reduction will minimize the probability of dissolved oxygen depletion in the marine environment due to microbial activity. A high VFA/alkalinity ratio of 0.5 was observed at COD loading of 18 kg/d, corresponding to an OLR of 4.5 kg COD/m^3.d was above the recommended value of below 0.4. This observation was used as a precaution not to exceed the OLR of 4.5 kg COD/m^3.d because of a possible digester failure or reduced efficiency. Digester loading rate of 18 kg COD/d produced highest biogas at approximately 2000 L/d. The nearly constant gas production indicated that the reactor was stable at this COD loading. This was supported by a nearly constant VFA/alkalinity ration during this period.

The energy produced from the AD increased from 20000 to 99000 kJ/d as the OLR was increased from 0.4 to 4.5 kg/m^{3}d, based on methane heating value of 35800 kJ/m^3. It was therefore advantageous to operate the AD at high OLR, however at OLR above 4.5 kg/m^{3}d there is a risk of VFA accumulation which can lead to digester failure. The predicted amount of steam production varied from 1000 to 9000 kg/h with the highest distribution between 4000 and 6000 kg/h. Thus, amount of steam that could be recovered from the wastewater was approximately equal to the amount needed for yeast production. This was an indication that anaerobic digestion of baker’s yeast can and was a viable method for wastewater treatment including primary settling of the wastewater and resource recovery that can lead to significant cost reduction in energy expenditure.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Y. Vögeli, C. Riu, A. Gallardo, S. Diener, C. Zurbrügg “Anaerobic Digestion of Biowaste in Developing Countries”, 2024

[2] Y. Arhan, I Ozttirk “Settling and Dewatering Characteristics of sludge from baker’s yeast production wastewater treatment.” *Water Sci. Tech.* Vol. 34, pp. 459-467, 1996. https://doi.org/10.2166/wst.1996.0464

[3] Y. Satyawali, M. Balakrishman. “Wastewater Treatment in molasses-bsed alcohol distilleries for COD and color removal: a review.” *J. Environ. Man.* vol. 86, pp. 481-497, pp.2008. https://doi.org/10.1016/j.jenvman.2006.12.024

[4] R. Dolphen, P. Thiravetyan. “Adsorption of melanoidins by chitin nanofibers.” *Chem. Eng. J.* vol. 166, pp. 890-895, 2011. https://doi.org/10.1016/j.cej.2010.11.063

[5] D.N. Olennikov, LM. Tankhaeva “Physicochemical characteristics and antioxidant activity of melanoidin pigment from the fermented leaves of Orthosiphon stamineus” *Brazilian J. Pharmacogn.,* vol. 22, pp. 284-290, 2012. https://doi.org/10.1590/S0102-695X2011005000194

[6] U. Hampannavar, C. Shivayogimath. “Anaerobic treatment of sugar industry wastewater by upflow anaerobic.” Int. J. Environ. vol. 1, pp. 631-639, pp. 2010.

[7] B.S. Moraes, M. Zaiat, A. Bonomi “Anaerobic digestion of vinasse from sugarcane ethanol production in Brazil: Challenges and perspectives” *Renew. Sustain. Energy Rev*. vol. 44, pp. 888-903, 2015. https://doi.org/10.1016/j.rser.2015.01.023

[8] A. Aziz, A. Latiff, A. Hussein, Z. Daud “A review on granules initiation and development inside UASB Reactor and the main factors affecting granules formation process.” *Int. J. Energy Environ*., vol. 2, pp. 311-320, 2011.

[9] M.K. Tiwari, S. Guha, CS Harendranath, S. Tripathi. “Influence of extrinsic factors on granulation in UASB reactor”, *Appl Microbiol Biotechnol*. vol. 71, pp. 145-154, 2006.

John Kabuba is a Professor and Faculty Research Ethics Chairperson in the Faculty of Engineering and Technology, Vaal University Technology. He has more than 19 years’ experience in academia which he gained at University of Johannesburg and Vaal University of Technology. He is a recipient of several awards and scholarships for academic excellence.

Mumsy Thloloe is a Postgraduate student in the Department of Chemical and Metallurgical Engineering in the Faculty of Engineering and Technology, Vaal University Technology.