Reviewof the Operations of the Two Anaerobic Digesters (AD) in San Carlos Bioenergy, Incorporated (SCBI) using Vinasse from Cane Syrup & Molasses-Based Distillation

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ABSTRACT

This is a review of the performance of the additional two (2) Anaerobic Digesters (AD) in San Carlos Bioenergy, Incorporated (SCBI); producer of bioethanol using cane syrup and molasses as feedstocks. Using Continuous Stirred-Tank Reactor (CSTR) - type of AD technology; the facility was designed to handle distillery slops totaling to 1,000 cubic meters under mesophilic condition. Distillery slops also known as vinasseis one of the most challenging streams of wastewater to manage and considered a very significant contributor to environmental pollution. It is classified as a high strength wastewater characteristically dark-brown color, very acidic with pH range of 3.9-4.5, temperature range of 60-70 degreeswith Chemical Oxygen Demand (COD) concentrations from 100,000 - 160,000 mg/l; of which the latter is indicative of its suitability as substrate to produce a clean and renewable fuel resource commonly known as biogas. Biological start-up of the facility used the less concentrated seed sludge from effluent of the factory's old anaerobic digester. Short of five (5) months from start up, the factory now utilizes the biogas at an average hourly rate of 2,000 cubic meters. It replaces a bagasse-fuel equivalent of 4.2 tons bagasse per hour or fuel savings equivalent to Php 7.5 Million per month. Sustaining a stable performance, AD operation must consider good balance between the substrate and microbial activity to create an optimum physical and chemical environment in the digester. Daily monitoring of performance indicators was done including but not limited to pH, temperature, chemical oxygen demand, volatile organic acids and total suspended solids. Performance is evaluated and expressed in terms of daily biogas production per kilogram of COD removed. Comparison of the current and start up quantity of sludge was also reported expressed in kg COD removed per kilogram of solids; with the latter parameter representing the microbial biomass in the ADs.

Key words : anaerobic digestion, biogas, distillery slops, chemical oxygen demand, volatile fatty acids

INTRODUCTION

Anaerobic digestion is a series of complex microbial processes in which groups of microorganisms breakdown organic compounds into simpler forms in the absence of oxygen. The process produces biogas, primarily composed of methane (CH_4) and carbon dioxide (CO_2).*(Metcalf and Eddy, 2003)*Historical evidence indicates that this process is one of the oldest technologies and with various explorations made dating as far back as 16th century. Works of curious minds with the likes of Van Helmont, Volta in 1776, Bechamp in 1868, Omelianski in 1890s *(T. Abbasi et al., 2012)* and Buswell et al in 1930's *(Lusk, P. 1997)* paved in the industrialization and advancement of anaerobic digestion (AD) technology today.

San Carlos Bioenergy Incorporated (SCBI), is not new to this technology. Established in 2008, the factory started with one (1) unit of digester, designed to treat concentrated slops coming from the production of ethanol based on sugar cane syrup. Biogas is utilizedin the process. Over the years, this digester has evolved from a thermophilic to a mesophilic reactor or changes on the type and volume of substrateto adapt with the changing landscape of the business.As a response to the challenges brought by its operation, the factory commissioned for the construction of the two ADs.

SCBI commissioned for a Continuous Stirred Tank Reactor (CSTR)-type AD technology. It is designed to handle 1,000 m3 per day of distillery slops. Distillery slops has a characteristic dark brown color, very low pH ranging from 3.90 to 4.50, high temperature of 60 ^{o}C to 70 ^{o}C fromthe source and high chemical oxygen demand (COD) concentrations varying from 100,000 to 160,000 mg/l; making it one of the most difficult stream to handle. On the other hand, this high COD has high potential of returns withgeneration of biogas froman AD operating at optimum conditions and efficiency.Theoretically, 0.40 m3 of methane is produced per kilogram of COD removed from the anaerobic degradation at 35 ^{o}C.*(Metcalf and Eddy, 2003).*

Investing in an AD facility is capital intensive. In order to secure the best possible return on this investment, one must operate and manage the facility to attain optimal efficiency. Noting that AD is a biological process, it is important to understand the process' complexities in order to identify the suitable design and establish the key environmental and operational controls vital to maintain a balanced synergy among groups of microorganisms in the AD. Any disruptions to this environment may alter biological actions and most often, lead to upsets or system failures; posing significant loss of opportunities due to low biogas, prolonged re start-up, and/or other environment-associated risks.

METHODOLOGY

Scope of the Study

The paper reviewsthe operations of the twoand newCSTR anaerobic digesters in SCBI from commissioning up to its post guarantee test run. Thirty-week data of key environmental parameters including pH, temperature, COD, VFAand TSS were gathered from 23 November 2018 to 30 June2019. Reviewof these parameters were correlated to the digester's operational performance or efficiency.Operational performance in this context will refer on how well the ADs delivered its intended function based on its design capacity. The paper also takes into considerationthe economic benefits derived from its operation.

Overview ofa Continuous Stirred Tank Reactor (CSTR)-Type AD

The two units of CSTR-type ADsconstructed in SCBI have a total combined capacity of 1,000 m3 day input of distillery slops. It isoperatingunder mesophilic condition designed at 35 to 39 ^{o}C.The system has three (3) main unit processes namely: 1) pre-treatment, 2) anaerobic digestion; and 3) biogas handling. *Figure 1* illustrates the schematic flow in the CSTR system.

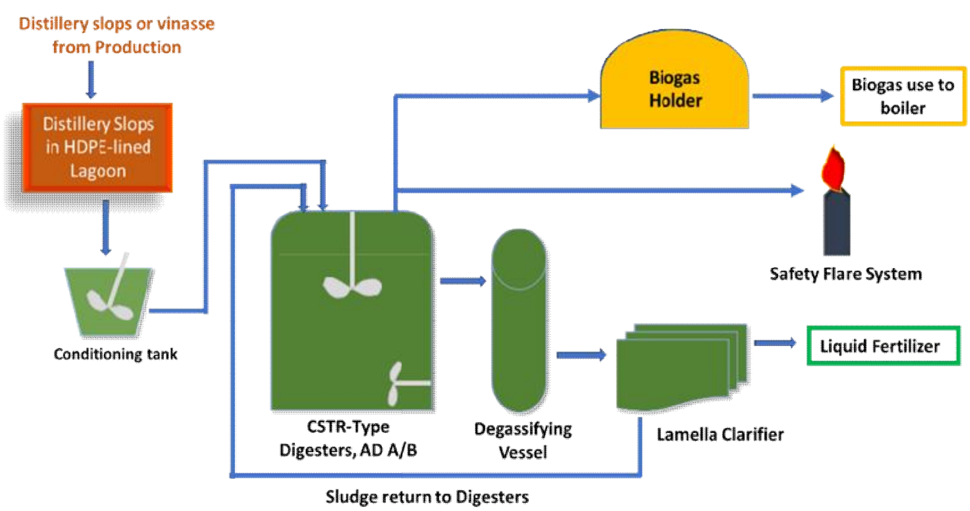

Figure 1. Schematic Process Flow of CSTR-Type of Anaerobic Digestion Technology

Conditioning of substrate is at Stage 1. Process parameters including pH, temperature and nutrients are adjusted or corrected at this stage. Noting the reactions and processes are biological in nature, these parameters arekey control points prior to feeding of substrate to AD. Conditioning may use milk of lime and bicarbonate-source for pH and di-ammonium phosphate for nutrients. This is foreseen during early start period, say 1 – 2 months.*Table 1* lists the designed process parameters.

Stage 2 is the anaerobic digestion processes. This is the stage where conversion of complex organic matter takes place to produce acids and biogas through the series of microbial actions under anoxic conditions. The digester tank is equipped with agitators to provide equalized distribution of pH, temperature, COD and VFA between microorganisms and substrates within the digesters' content.

The biogas is fired to the boiler using biogas blowers passing several condensate traps.

Table 1. Minimum set of parameters for the optimum operation of the ADs

Design Operating Parameters	Units	Value
No of Digesters		2
Digester Capacity	m3 per AD	500
Flowrate Total, Distillery Slops	m3/day	1,000
Inlet Distillery Slops		
pH		3.9 – 4.5
Temperature	°C	35 - 40
Chemical Oxygen Demand	mg/l	130,000 -150,000
Volatile Acids	mg/l	4,500 – 6,500
Digester (AD)		
pH		7.3 – 7.8
Temperature	°C	35 - 39
TSS	mg/l	25,000 – 35,000
COD Reduction	%	65%+/- 5%
Biogas Generation	m3 biogas/kg COD removed	0.50

Biological Start-up, Guarantee Test Run and Optimization Stage

Biological commissioning of AD-B was conducted, seven weeks ahead of AD-A with inclusive weeks illustrated in Figure 2, while Table 2 shows the actual characteristics of the distillery slops used as feedstock of AD.

In SCBI, regular monitoring of physical and chemical parameters was done including pH, temperature, VFA and COD while operational performance was measured based on COD removal efficiencies and biogas generation.

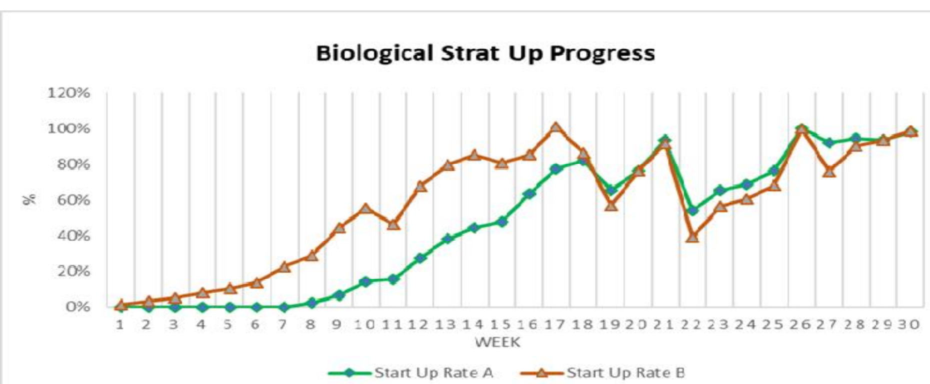

Figure 2. Biological process start-up of AD-B and AD-A

Table 2. Characteristics of distillery slops input to AD

Distillery Slops Characteristics, 30-week data					
Parameters	COD, mg/l	Input pH	Input Temp, degC	VFA, mg/l	TSS
Range Low	109,579	3.86	32.8	3,360.0	2,705
High	159,590	4.52	48.9	12,494.5	22,246
Average 30-wk	**136,011**	**4.14**	**41.6**	**6,064**	**8,916**

Daily analysis of above parameters was conducted in the factory's laboratory based on the Standard Methods for the Examinations of Water and Wastewater

RESULTS AND DISCUSSIONS

AD-B was first commissioned using the sludge from the effluent of factory's existing digester. Concentrations of total suspended solids (TSS) and volatile suspended solids (VSS) were given at 5,505 mg/l and 3,860 mg /l, respectively. Sludge cultured from manure with TSS of 3,270 mg/l and VSS of 2,285 mg/l was added totaling to a combined initial volume of 44.3 tons of TSS to start up AD-B. Further, laboratory analysis showed composition of 70% VSS, indicative of very good quality seed material.

AD-A was started up seven (7) weeks later; with initial seed sludgecalculated at 47.0 tons TSS.

Figure 3. Two CSTR-Type ADs B & A (L-R) and the Control Room. Photo taken after commissioning phase.

There is no absolute figure for quantity and quality of the sludge requirement. However, higher volume of good quality sludge may shorten the start-up period, given that all process operating parameters are at optimum design range. Anaerobic sludge of not less than 0.50 VSS to TSS ratio is ideal. This is expected to increase as the biological start-up progressed.

Progressive increases in organic load along with maintaining optimum physical and chemical environment at the inlet and in the ADs became the focus of the start-up. With the characteristic low pH, high COD concentration and high temperature of 60-70 ^{o}C*(see Table 1)* makes slops a challenge for anaerobic digestion. It is important to properly control this organic loading to establish the optimum environment in the ADs.
Figures 4 shows the COD loading progress for both AD A & B while *Figures 5*and *6* shows the resulting pH and VFA in the ADs

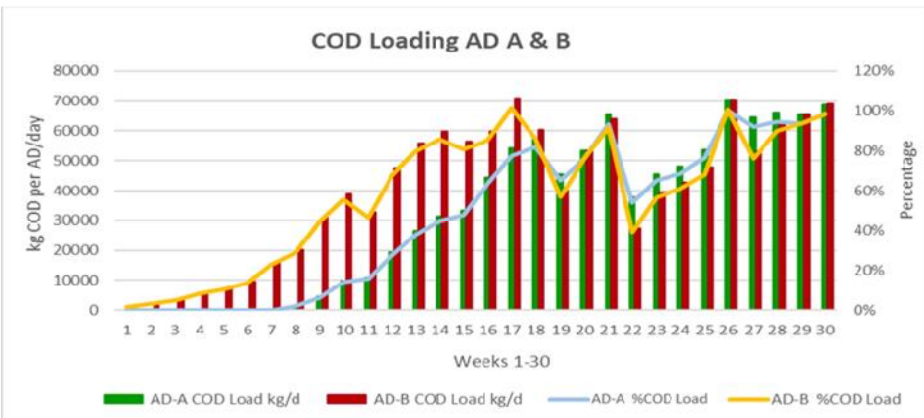

Figure 4. Graphical representation of progressive COD loading in AD A & B

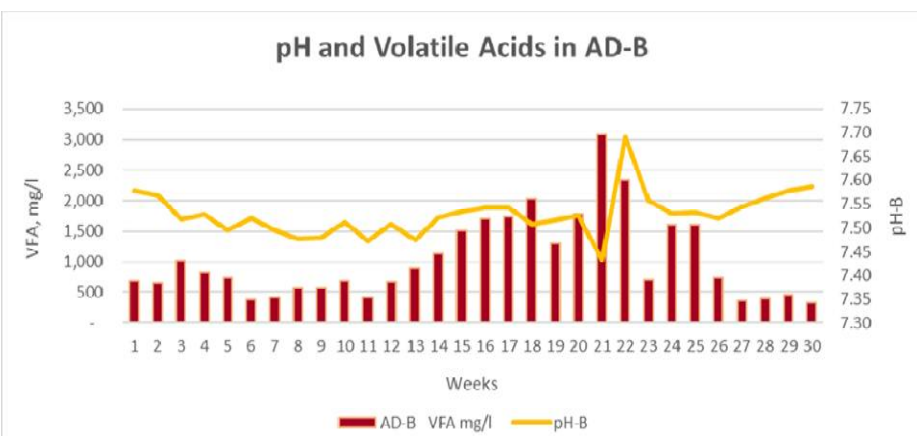

Figure 5. pH and Volatile Acid relationship in AD-B

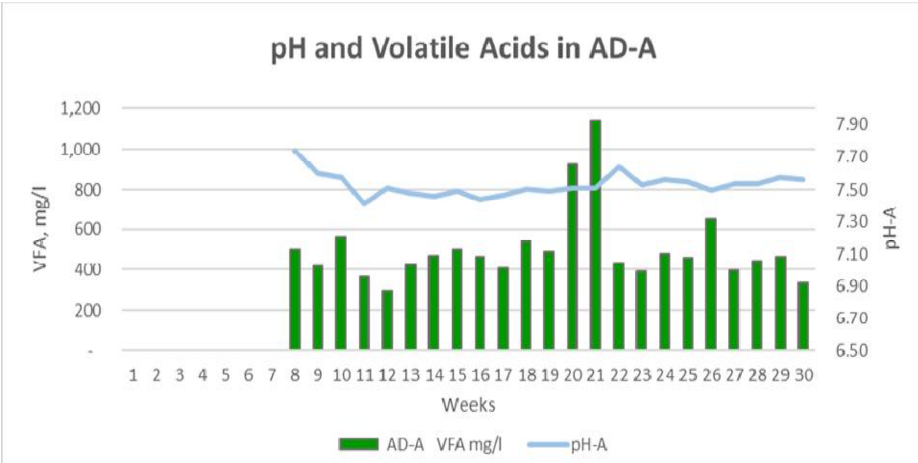

Figure 5. pH and Volatile Acid relationship in AD-B

Each AD is designed with COD load ranging from 65,000 kg -75,000 kgs COD per AD/day. Mean value is 70,000 kgs COD-AD/day.

Rapid increase in loadings on Weeks 19 to 21 has seen significant spikes or increasein the VFA concentrations in both AD A & B. More prominent in AD-B, there was a lowering pH trend observed with anincreasing VFA concentrationsinweeks 20 and 21. A57% increase in VFA-B concentration was recorded between those weeks.

Volatile fatty acids are produced from the fermentation of organic matter (=COD/BOD) byacid-forming microorganisms. The VFA serves as substrate for the methanogens to produce biogas.Accumulation of VFA as what has been observed in weeks 19 to 21 is indicative of imbalance in substrate utilization by these groups of microorganisms given the abrupt increases in the organic loads. This when left undetected, maylead to process upset.

Following Weeks 22 to 30 showed a recovered and stable AD conditions. Noticeably on Week 22, there were abrupt reductions in organic load by 53% in AD-B and 40% in AD-A; which aided in the immediate recovery of the system. Average VFA concentrations of 451 mg/l and 952 mg/l at average COD loadings of 96% and 92% for AD A and B, respectively. pH were maintained at 7.5 and temperature of 38-39^{o}C.

The 100% design organic capacity of the facility was reached on Week 26.

Biogas Production

Figure 6 shows the combined performance of AD A & B in terms of the volume of biogas generated per unit of COD removal from Week 21 to 30.

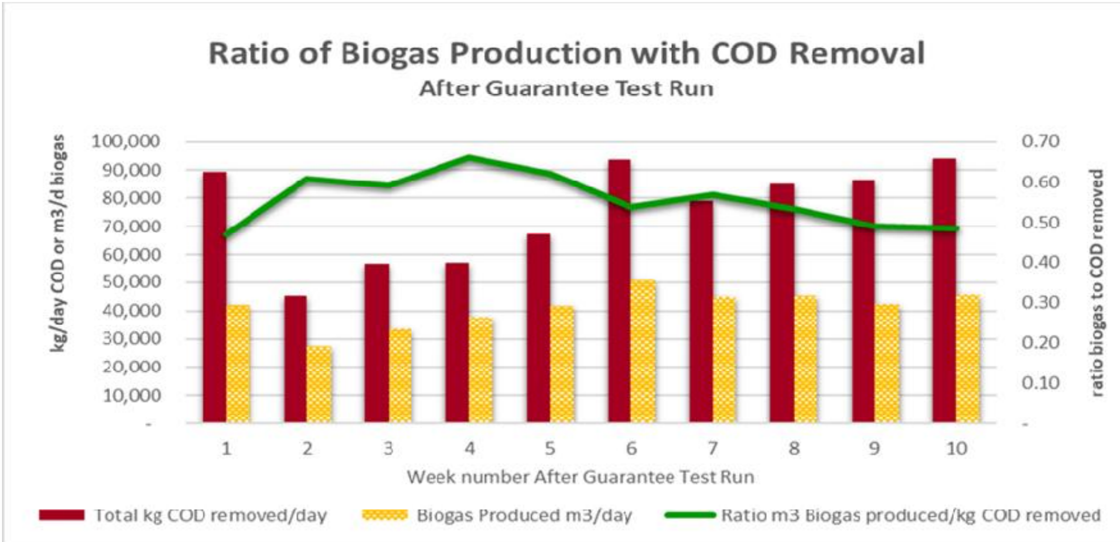

Figure 6. Ratio of biogas produced per kg COD removal

The factory started utilizing biogas on January 26, 2019 *(Week 10)*with average generated volume of 15,067 m3 biogas/day. Records ofbiogas yield at stable condition from Weeks 21 to 30 have an average ratio of 0.56 m3 of biogas per kg of COD removed per day.

Biogas has high calorific value that makes it a very viable energy resource.It is also clean and renewable. Laboratory showed that the actual sample of biogas from the facility contains50.2%methane and 46.3%carbon dioxide. With the digesters currently operating between 38^{o}C to 39 ^{o}C, the equivalent calorific value of the biogas is at 23 MJ/kg.

On Week 26 of this 30-week study, factory operations declared the highest bagasse displacement due biogas of 97 tons bagasse per day. With the current market price of biomass fuel, the monthly savings due fuel displacement is calculated at Php 7.28 Million.

Both digesters are operating at 100 percent of the factory's daily generation of distillery slops. All environmental parameters are within the limits for optimal performance. Biogas is produced an average hourly flowrate of 2,000 m3/hr and is continuously replacing an average bagasse-fuel equivalent of 4.2 tons per hour or fuel savings equivalent to Php 7.5 Million per month

CONCLUSION

The anaerobic digestion is a series of biological processes by groups of microorganisms acting on a specific substrate to produce acids and biogas; the latter considered as most valuable by-product of the process. Understanding this microbiology and their synergies to each of their metabolic by-products, lead in the identification ofvital control parameters for the operation of the AD.

It is important that these parameters or information are regularly monitored and evaluated to make timely decisions on how to operate the system and achieve optimal performance. Operating outside of the limits of the design may result to poor performance; worst, system upset. This condition may entail risks and costs the owners both environmentally and economically.

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