Co-Generation Opportunities Utilizing Sugar Industry Wastewater Through the Use of Biological Treatment Systems

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In 2000, a major sugar central milling company, Central Azucarera de Tarlac ("CAT") requested waste-to-energy expert, Philippine Bio-Sciences ("PhilBIO"), to review all of its waste streams to identify energy-laden waste. After an initial study, PhilBIO concluded that distillery slops, which contain ethanol, are readily available to convert into biogas via advanced anaerobic digestion systems.

CAT agreed to have PhilBIO undertake a feasibility study on the distillery slops to energy concept. This study, funded by PhilBIO, included the technical design work of *Waste Solutions, Ltd. of New Zealand.* The study concluded favorably that a project could be designed that would succeed in utilizing the **U**pflow **A**naerobic **S**ludge **B**lanket ("UASB") high rate digester technology, but would need to proceed through a pilot plant to address some key constraints to the technical design, the most important of which is higher concentrations of sulfates in the wastewater. Sulfates have been known to cause tremendous problems with anaerobic digesters. But there are solutions.

With the assistance of the New Zealand AID, PhilBIO, CAT and Waste Solutions, with other local partners, are in the midst of the pilot plant phase. The pilot plant is innovative in design. It is a fully enclosed system in a 40-foot cargo container that can be installed and operated easily.

The pilot plant phase will provide the final design solutions to optimize wastewater treatment and methane gas recovery while limiting the impact of sulfates on the physical structure of the plant. PhilBIO and partners will set up a **p**roject **o**perating **c**ompany ("POC") on a build-operate-own-transfer (BOOT) basis. 100% of the biogas will be utilized for electric power. CAT and the POC will negotiate a long-term Power Purchase Agreement ("PPA").

PhilBIO has engaged in discussions with *GE Jenbacher of Austria ("Jenbacher")* to provide a 2 to 2.5 mW electric power plant, utilizing the biogas recovered from the distillery slops. Jenbacher maintains the largest market share globally for co-Generation plants utilizing 'special gases' such as biogas and landfill gas ("LFG").

PhilBIO, Local Experts, International Expertise

PhilBIO engineers, installs and operates digesters that are of the highest workmanship, utilizing lower-cost, durable materials. Gas impermeable ISO 9001 HDPE (*HUITEX* brand) is used wherever possible for applications such as in food processing wastewater treatment.

In 2001, a sister company of PhilBIO, CleanTHAI, constructed the largest anaerobic digester ever in Asia, the PhilBIO **A**naerobic **B**affled **R**eactor ("ABR"). The ABR is a fully lined vessel with a high strength HDPE floating cover. It utilizes separate loading and unloading cells on a continuous feed basis. This ABR design with a storage volume of over 100,000 cubic meters, reduces the land requirement to treat the same wastewater (300 liters per minute at average flow rates) by 50 hectares. The reason: The ABR reduces BOD by over 95% and COD by over 60%. This effective wastewater treatment also provides substantial energy: A total available mechanical energy of 9 mW. A 3 mW Jenbacher engine generator power plant is being installed this month.

Our engineering team proved that through the biological treatment of the wastestream, the client would be able to take a negative, the heavily polluted wastewater, and convert it into a positive, an on site energy source to substitute for heavy fuel oil for its four (4) boilers at a reduced cost to fuel oil, and over 50% of its electric power needs from the Jenbacher power plant. The project has been so successful that we now have twelve additional cassava processing plants interested in the ABR under similar BOOT Agreements.

The ABR is proven to provide effective wastewater treatment, fuel substitution and electricity. This may be beneficial enough except for the fact that in these times of global warming, the developed world must regulate carbon emissions into the atmosphere. Under the United Nations and its 1997 Kyoto Protocol, a mechanism exists to provide financial incentives to developing nations to reduce carbons. Termed the Clean Development Mechanism (or CDM), the mechanism is used to provide additional capital for environmental projects such as PhilBIO's that have proven carbon abatement. For the Thai ABR project, PhilBIO fulfilled the requirements to ensure that this project would be designated a 'CDM' project, the first of its kind in Asia. Our carbon advisors concluded that there were *375,000 tons per year of carbons* abated by this one ABR digester. Last month, we signed a letter of intent with the Netherlands Government to buy at least 220,000 tons of carbon credits per year for seven years at a rate of Euro 3 per ton. This fairly low price on a fairly low priced biogas system means that the project economics work on the carbon credit value alone.

The combination of effective wastewater treatment, methane gas recovery and utilization and carbon credits means that for this time, biological treatment may be the answer to your environmental challenges, especially for all types of 'wet waste'. For the sugar industry, these includes filter cake, sugar milling wastewater and sugar scum, as well as distillery wastewater. You can turn around the term, pollution, and look at a highly pollutive source, as an energy source. PhilBIO is in the business of helping the sugar industry do just that. And the interesting thing about waste-to-energy is that the fuel and electric power savings go right to the bottom line.

Anaerobic Treatment of Distillery Slops at CAT

For CAT, PhilBIO has patiently worked through the issue of sulfates and suspended solids in the wastewater. We have done extensive study on the wastewater, through simulation in our laboratories on a small-scale digester. The conclusion is that through the proper management of the distillery slops, a high rate digester such as the Upflow Anaerobic Sludge Blanket or UASB, is an appropriate and economical biological treatment of this high COD (upwards of 100,000 mg/liter) waste source.

Anaerobic treatment has been applied to a wide variety of solid and liquid organic wastes, including waste from food and beverage producing industry (sugar, soft-drink, potato, vegetable, distillery and brewery wastes), meat, pulp and paper processing industry, dairy and wool processing industry, and even pharmaceutical and chemical industry. Their main purpose is to remove the **B**iochemical **O**xygen **D**emand (**BOD**) from the wastewater.

The recent popularity of anaerobic processes in Europe and the United States can be attributed to a number of important advantages in comparison with conventional aerobic and physico-chemical treatment processes:

- No aeration needed and thus low in energy demand
- Production of energy-rich biogas
- Very low production of residual surplus sludge for final disposal
- General low demand of chemicals and nutrients
- Very high loading rates in terms of BOD removal per unit installed reactor volume per day
- Stable process performance under irregular load conditions
- Suitable for seasonal operations as the anaerobic bacteria remain viable during extended periods of plant shut-down
- Containment of malodor as the processes take place in closed tanks
- Compatible with aerobic post-treatment processes designed for nitrogen and phosphorus removal or composting.

An energy comparison between traditional aerobic treatment methods such as activated sludge treatment and anaerobic treatment such as the UASB illustrates a major point. Complete oxidation of 1 kg of BOD requires 1.2 kg of oxygen and 1 kWh or 3.6 MJ of aeration energy. 0.6 kg of additional sludge bacteria is produced as new waste under aerobic conditions.

Under anaerobic conditions 0.35 m^3 of methane is produced with an energy value of 12.9 MJ. Waste sludge production is much lower, typically 1/10 of the amount produced under aerobic conditions. The conclusion: Wherever feasible anaerobic systems avoid added costs of wastewater treatment while supplying fuel and nutrient recovery.

Digester Fundamentals

Anaerobic digestion processes take place in a closed tank, generally called a *digester* or *reactor*. The reactor is equipped with an inlet and an outlet port, and a mixing device. Mixing can be done by mechanical means or by gas recirculation. A gas outlet at the top of the reactor removes gas, produced during the digestion process. Often a reactor of this type is heated (e.g. by combustion of the produced biogas or via cogeneration to produce electricity and heat), for which heat exchangers are used in the reactor (not shown in Fig.3) and heat insulation to prevent heat losses. However, in recent times it has been established that anaerobic digesters can also be effectively operated at ambient temperatures (15 - 20 ^oC) without heating provided that reactor conditions are adequate to prevent washout of the methane bacteria.

In the case of thermophilic processing (under temperatures in excess of 42 degrees C) of hot distillery slops, digester heating is not required and cooling of the hot slops prior to digestion becomes an important consideration.

In some reactors, such as the **C**ontinuously **S**tirred **T**ank **R**eactor ("CSTR"), contents contain a mixture of fresh material and fully digested material. Typical examples for CSTR systems are sewage sludge digesters or well-mixed anaerobic treatment ponds.

Each day, some fresh waste is fed into the digester, which means that an equal quantity of digester contents must be discharged. This mixture is only well degraded (or stabilized) when the waste material has been retained sufficiently long in the reactor so that the bacteria would have had enough time to act upon the discharged material. This, indicated by the **H**ydraulic **R**esidence **T**ime ("HRT"), is an important parameter for digester operation.

In a completely mixed reactor it cannot be avoided that some bacteria are lost with the treated end product as they are mixed with the reactor content and "swimming" in the reactor. These are 'water-loving bacteria'. Usually, this loss of bacteria will not be a problem, if the bacteria in the tank grow fast enough to maintain sufficient cell numbers to compensate for the losses.

The slowest growing bacteria in the process are methane bacteria and acetogenic bacteria. These bacteria double every 7-10 days under mesophilic conditions and every 2 – 3 days under thermophilic conditions. It can be calculated that in order not to lose these slow growing bacteria from the reactor a hydraulic retention time of at least 10-15 days or 3 – 5 days is preferred under mesophilic and thermophilic conditions respectively.

Generally, growing the bacteria in a complete mix environment is not a problem. The problem is the HRT. To illustrate by way of example: A factory discharging 1,000 m^3 of effluent on a daily basis would require a 15,000 - 20,000 m^3 reactor if a mesophilic CSTR type process would be used. This, of course, would make a treatment plant prohibitively expensive.

So, in order to reduce reactor size and costs (by reducing the hydraulic residence times) it would be necessary to retain the bacteria in the tank, while the wastewater is pumped through it. This principle is called cell retention. A number of different methods and processes have been investigated and developed over the last 20 years with some being more successful than others. The main principles used are both gravity (viz. retention by sedimentation as in case of the UASB process) and biofilm growth (retention by attachment to the surface of support material e.g. plastic used in anaerobic filters).

Cell retention is the first important key to support the UASB for CAT.

The second key design issue for PhilBIO at CAT is the *"space loading rate"* or *"organic loading rate"* (kg BOD m^{-3} day^{-1}). This measure determines *"how much food"* the bacteria in a reactor can digest to methane before they are lost by washout from the digester. Typically, a thermophilic CSTR without cell retention can achieve 90 % BOD removal at an organic loading rate of 5 –7 kg BOD m^{-3} day^{-1}. However, systems with effective cell retention measures can handle 2 –3 times the load.

Therefore, the reactor (digester tank) for a given load can be 2 – 3 times reduced if cell retention technology is used in anaerobic digestion such as in **U**pflow **A**naerobic **S**ludge **B**lanket (UASB) digesters.

One of the most successful processes for anaerobic wastewater treatment that uses cell retention to the maximum is the UASB process. The UASB process promotes and utilizes the attachment of the anaerobic bacteria in the reactor to themselves which results in the formation of well settling "living granular sludge" similar in size to coarse sand. Because of their size, the self-attached bacteria settle and are thus effectively retained in the anaerobic reactor.

Upflow Anaerobic Sludge Blanket

The Upflow Anaerobic Sludge Blanket (UASB) process was developed in the late seventies in the Netherlands and has become increasingly popular since then with many applications (mainly in the food industry) all over the world.

The UASB process received its popularity because of its effectiveness and short hydraulic residence times. The key to its success has been the spontaneous formation of small 'granular' bacterial pellets (= granules) in the reactor. These pellets settle readily to the bottom of the reactor. Thus wastewater can be pumped relatively quickly through this reactor without loss of bacterial granules. Therefore smaller reactors can be used that **cost less than standard anaerobic digesters and treat effectively large volumes** of wastewater.

In terms of the organic loading rate that can be applied to UASB reactors (kg BODm $^{-3}{}_{reactor}$), they excel over every other anaerobic digester technology by a large margin because of the enhanced amount of active bacteria that are retained in the reactor. For example, granular UASB systems at mesophilic temperatures (30 – 40°C) treating wastewaters with soluble and readily degradable BOD can be loaded up to 15 – 20 kg BOD/$m^3{}_{reactor}$ day^{-1}. CSTR systems for the same wastewater would struggle at loading rates in excess of 6 –7 kg BOD $m^{-3}{}_{reactor}$/day. UASB systems have therefore a 2-3 fold advantage over non-UASB anaerobic digester designs. Thermophilic UASB systems have an even larger advantage due to the 2-3 times increased digestion rates and growth rates when compared with mesophilic UASB systems.

UASB systems at thermophilic temperatures (50 – 70°C) can be loaded up to 40 – 80 kg BOD $m^{-3}{}_{reactor}$ day^{-1} when treating wastewaters with soluble and readily degradable BOD. Thus hot waste waters such as distillery slops are ideally treated with thermophilic UASB systems which can be even smaller and thus less expensive than respective systems operated at mesophilic conditions for a given wastewater flow.

However, if the wastewater contains inhibitory constituents as in the case of CAT, then the loading rate to thermophilic digesters needs to be accordingly reduced to provide an operational safety margin if occasional shock loads of inhibitory compounds enter the digester. Rather than accepting this fact, PhilBIO will be using the pilot plant to effectively map out how we will adapt the UASB to its full potential, even with the presence of inhibiting sulfates.

Distilleries that utilize UASB for wastewater treatment include the large scale sugar cane fermentation industry in Brazil, which makes extensive use of UASB technology for its effluent treatment needs.

A UASB reactor is usually equipped with a gas collection system (often referred to as **G**as **S**olids **S**eparator, or “GSS”) at the top. The separator also performs the function of settling and internally recirculating sludge pellets that may have lifted to the top with rising biogas bubbles. Clarified effluent is discharged at the top of the tank. HRT for full-scale granular UASB systems under thermophilic conditions can be as short as 4 hours. Thus, the UASB technology provides a very powerful tool to tailor-make anaerobic digestion systems for distillery slops.

A High Rate UASB at CAT

Extensive experience exists with the anaerobic treatment of distillery slops from sugar cane derived materials with very high concentrations of COD (60,000 – 160,000 mg/L). Despite expected toxicity problems arising from the high concentration of COD, sulfide and salts, anaerobic treatment of distillery effluent with the UASB process has proved to be successful[23]. However, certain problems may occur due to the typical composition of this wastewater. High potassium concentrations have been reported to be inhibitory to methanogenic sludge[24]. During anaerobic digestion, sulfate is converted to sulfide which is reported to be inhibitory at free H_2S concentrations of 50-250 mg/L[25].

While PhilBIO will test the ability to control sulfates through pre-treatment, the pilot plant is being set up to develop sulfide tolerant bacteria from distillery slop sludge from the source.

Table 1 illustrates the different analyses of sugar cane distillery wastes (slops). Typical distillery slops from molasses in the Philippines fall into a composition range that has been successfully treated with UASB systems at other sugar cane distilleries in the world. Its TSS and VSS content is comparatively low suggesting its suitability to UASB treatment by flocculant or granular sludge UASB systems.

Table 1: Comparison of the Chemical Composition of Distillery Slops (*Vinasse*)

Parameter	Unit	Brazil	India	Venezuela
Feedstock		Juice	Molasses	Molasses
COD_{total}	g/l	22	80-120	109
BOD	g/l	15	27-52	43
TS	g/l	-	50-140	117
VS	g/l	-	-	84
TSS	g/l	1.48	2-14	14
VSS	g/l	1.2	-	13
PH		3.5	3.4-4.5	3.4
N_{total}	g/l	0.4	0.33-1.73	1.2
NH_4^+-N	mg/l	5	55-900	600
Total SO_4	g/l	0.4	3-16	6.8
K^+	g/l	-	4-10	6.3
Na^+	g/l	-	-	-
Ca^{++}_{tot}	g/l	0.17	0.5-0.7	1.6

Table 2 below gives typical UASB treatment performance results on sugar cane molasses.

Table 2: UASB Performance on Sugar Cane Molasses

Parameter	Unit	Venezuela	India
COD removal	%	65-70	65-70
BOD removal	%	85-90	85
Biogas yield	m^3/ kg $COD_{removed}$	0.5	0.5
Loading rate	kg COD m^{-3} day^{-1}	16	10

An improved process design for the UASB plant in India at full scale (two reactors of 1875 m^3 each or 3750 m^3 UASB volume) led to operational results shown in Table 2. The active biomass in the reactor was not granular sludge but of a well settling floc type with more than 40 % ash (likely due to calcium carbonate precipitation). Up to 1995, six further similar UASB plants were constructed in India, and all are still in operation today.

In India, distilleries with a batch fermentation process generate 13-15 liters alcohol per liter of molasses. This is virtually identical to the performance and yield of the distillery at CAT. Therefore, based on the analyses presented in Tables 1 and 2 , it is likely that a full scale UASB digester at CAT loaded with 10 – 15 kg COD $m^{-3}_{reactor}$ day^{-1} will have BOD removal efficiencies in the vicinity of 85 % and COD removal efficiencies of 65 – 70 %.

The high sulfate content (4.3 g/l) at CAT is likely to reduce the biogas yield by about 10 % when compared on a BOD basis with wastewaters w/o sulfate. However, the data presented in Table 2 suggest that a biogas yield of 0.5 m^3/ kg $COD_{removed}$ can be expected at this sulfate content.

Due to different operation conditions and molasses (slops) composition, well settling granular sludge was formed in the example presented for Venezuela in Tables 1 and 2. This permitted a 1.6 times higher loading rate (16 kg COD) and a 40 % smaller UASB reactor tank. For a conservative reactor sizing for a thermophilic UASB treatment system at CAT, PhilBIO will err on the side of prudence, and limit the loading rate at CAT to 6.6 kg BOD $m^{-3}_{reactor}$ day^{-1} which corresponds to 16.5 COD $m^{-3}_{reactor}$ day^{-1}. The PhilBIO pilot plant testing will prove whether this more conservative approach can be surmounted by the ability to create sulfate-resistant granular bacteria from CAT's own activated pond sludge.

Biogas Production

Biogas formed in the UASB will be collected under the glass-lined steel roofing of the UASB and will be directly fed to a biogas holder. This arrangement controls potential odor problems from the biogas (H_2S, mercaptans etc.). The daily biogas production depends directly on the daily BOD load (short HRT in the UASB). Biogas production of at least 0.42 m^3/ kg BOD_{loaded} is expected. An average production of 17,400 m^3 biogas/ day is expected based on treatment of 770 m^3/day of distillery slops with a BOD content of 34 g/liter.

The PhilBIO UASB plant will go towards full utilization of biogas for electric power. That power can be used to fulfill the requirements of the plant and can be made available to substitute for the electric grid power throughout the sugar milling complex. One of the reasons for 100% electric power utilization is the current state of the electric power industry.

Jenbacher is the leading firm in co-Generation from special gases with current global market share of 53%, as well as a dominant share in Europe, the location of the largest installed base. PhilBIO projects that there will be sufficient biogas (at a heating value as indicated above) to generate power from a 2 to 2.5 mW power plant.

Toyota Tsucho has agreed to work with PhilBIO and its carbon financing partner, *EcoSecurities Ltd.* (Oxford, England), to complete the primary documentation for potential emission reductions. We anticipate that this project will be have more than 50,000 emission reduction per annum, available for sale to entities in Annex A countries.

Conclusion

With the slow implementation of electric power deregulation, and necessary closures of old **N**ational **P**ower **C**orporation ("NPC") plants from 2004 through 2007, shortages of grid power are forecasted throughout the country. The island of Panay (central Philippines) already suffers from shortages of available, reliable electric power. For some in the Capital, there are fears that 1992 may be revisited, and that sugar millers and other premium energy users, will pay upwards of 22 pesos per kWh to ensure power throughout the plants. Now, most millers can utilize bagasse to some extent, but this may not be enough to ensure self sufficiency. Diesel generator sets may be an easy solution, but even then, the cost of diesel and the inefficiencies of diesel generator sets may compromise overall plant efficiency, and cause operations and maintenance problems. The use of gen-sets is a stopgap measure, not a permanent energy solution.

If sugar millers take a look at their wastewater, as well as their solid waste from the processes, you will find the lasting solution. It is the energy value in your wastewater that we harvest. The advances in the UASB and other anaerobic treatment technologies, and our deeper understanding of how to optimize the biological treatment of wastewaters such as distillery slops, are available today.

PhilBIO and its investors know these biological treatment reactors will work very well for your operations, providing lower cost electric power or thermal power at reduced costs to other available treatment systems. We believe in our technology, our ability to harness the power of the energy in your wastewater, and are willing to provide our solutions through a BOT agreement with any interested food processing company.

PhilBIO hopes that through this discussion of the UASB and other technologies, that we have shown our dedication to providing the best available technology for each particular site, and the knowledgeable people to make these systems viable wastewater and energy options for the sugar millers of this country.

"Waste is Merely Natural Resources out-of-place."