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Date. June.2008.

The Renertech Biogas Process.
Coffee Waste Water to Energy.

Mk.4 ver.

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The Renertech process for making biogas from coffee waste waters, by a modified UASB, (Upflow Anaerobic Sludge Blanket) process was originally developed in Papua New Guinea, whilst the Author was Principal Research Scientist for Coffee Processing at the PNG CIC Coffee Research Institute. It is now under further development in Vietnam, at the Khe Sanh Coffee Factory in the Quang Tri Province. The project is funded by German Aid. This process avoids the problem of dealing with the indigestible mucilage which can clog up a normal solids digestion process. Apart from coffee waste waters, the process is good for handling large volumes of waste water containing medium levels of organic matter which can be fermented down to soluble organic acids, and processed into biogas at ambient temperatures in a matter of hours rather than days.

Do note that this process applies only to waste water where the digestible substrates are in total solution. Making biogas from coffee pulp solids is a totally different process and takes as many days, 12-20, as it takes hours to process soluble acetate salts in solution. More details on the coffee solids digestion processes are given in the 4th chapter of the text,

"The Microbiology of Coffee processing."

The Coffee production industry in the 'Third World' is, in general, not noted for its care of the environment. Our key word is a generated one, 'CLEMEG': Clean, Lean, Mean & Green. The underlying philosophy for developing this integrated system was to use only naturally available substances, and use them in the most economical way to allow for their use in remote underdeveloped areas with a minimum of infrastructure and supply..

The basis of the process was the discovery that starting from the traditional two stage/phase UASB process, a new second stage could be inserted, whereby a surplus of raw limestone or marble chips could be used to automatically buffer a solution of volatile fatty acid salts, largely acetates, at pH 6.1. That is, the pKa of carbonate/bicarbonate ions. At the same time, over a period of more than five years, a mix of psychrophylic methanogenic bacteria were isolated from acid coffee soils, to which had been added the gut contents of many cold blooded species of fish, reptiles and insects. As a result of prolonged enrichment techniques, we now have a septic strain of anaerobes which will gas freely on only coffee waste waters, at low pH and at ambient temperatures, usually 13-25^{O}C. This anaerobic sludge now constitutes a valuable resource for the global coffee industry. It is the intention of the discoverers not to patent this process in any way and to freely disclose any new developments that come to hand, so that the coffee industry of the third world may benefit. However, for those larger companies and institutions who want to short circuit the development period, supplies of the Renertech Sludge can be made available under a licensing agreement

The use of limestone chips as an acid neutralizer for a three stage UASB process creates two rock solid buffered points of acidity which gets around a lot of ‘digester sickness’ to do with bad or ‘hung up’ fermentation and digestion processes. It also provides the potential for reduction of carbon dioxide in the output of biogas by taking out half of the CO^2 at the fermentation stage. The traditionally understood overall reaction for production of biogas starts from acetic acid and produces equal amounts of methane and carbon dioxide.

$$\mathbf{CH_3COOH = CH^4 + CO^2}$$

However, neutralizing the acid first with raw limestone produces a molecule of carbon dioxide in the first stage, which can be got rid of before the effluent enters the biogas digester.

$$\mathbf{2CH_3COOH + CaCO_3 = Ca(CH_3COO)^2 + CO^2 + H_2O}$$

Then, in reacting the calcium acetate salt, there is only one molecule of free carbon dioxide as against two of methane. This makes for a raw biogas with a much higher energy level, albeit some loss of hydrogen. While this is of little gain to anyone aiming at a completely stripped natural gas, for a low cost ‘Village’ or ‘Institutional’ project operating with straight biogas ‘per se’, this is a considerable advantage in that it allows the gas to be fed directly into a diesel dual fuel engine without the necessity to strip the remaining carbon dioxide from it first.

$$\mathbf{Ca(CH_3COO)^2 + H_2O = 2CH^4 + CO^2 + CaCO_3}$$

The theorists will also ask what happens to the hydrogen from the acidogenesis section of the overall hydrolysis/acidogenesis/acetogenesis/methanogenesis reaction, and remark that we will ultimately get less methane. That point will be addressed later! The present method of describing this process is for Coffee Managers, not Scientists.

As the solubility product's of other calcium salts, principally phosphates, plus an ammonium/magnesium phosphate complex called 'Struvite',ie. the commercial 'MagAmp' fertilizer, are much less than that of calcium carbonate by several orders of magnitude, the above reaction never gets enough calcium ions left over to allow it to go to completion. What can be said however, is that the readiness of the calcium to precipitate in one form or another, does encourage the formation of relatively heavy sludge granules, which allow for a much faster rate of effluent flow through the digester without losing active material. This would encourage us to promote the EGSB process over the UASB, but formal trials have not yet been carried out.

The practical outcome nevertheless is that as well as biogas production, crystalline limestone or marble chips are transformed into a loose lime sludge containing interesting quantities of other fertilizers, and which can be reused as fertilizer. The wet gas is simply passed through a bed of metallic iron, the cheapest option, an oil drum full of bashed up old rusty tin cans, to strip out the sulphides and reduce the moisture levels. This iron sulphide process is completely self regenerating and very simple. It also produces a fertilizer grade of elemental sulphur that can be blended back in with the lime and struvite to give a fertilizer of wide configuration. Once one digester is working in a new area, the high output of granular sludge seed material, due to the struvite precipitation process, makes start up of further digesters only a matter of days instead of weeks.

24hr Turnaround:

To achieve a complete daily 24hour cycle of both coffee and wastes, within a factory, it is necessary to concentrate up the processing waste waters by intensive recycling. Every three to four hours during the pulping, a new tank or silo should be used to store the pulpage, (freshly pulped beans), and a fresh batch of water is used to restart the process. For the next period, that water, plus all the makeup water required, is recycled back through the pulpers and also used to pump the pulpage into an open tank or vertical silo. The water is allowed to drain down through the bottom of the tank before being recycled back to the machines. This causes the levels of sugars and enzymes to build up to the point where the water is heavily coloured and almost soupy. However, it also means that all of the pulpage, particularly that at the bottom of the tank, has received the same dose of concentrated pectolytic enzymes at a temperature several degrees above ambient, caused by the recycling water system. Then, what ever hour before midnight that that tank or silo has been turned off, fermentation will be complete and the coffee will be ready to be fully washed out the following morning, and left to soak in clean water for up to 8 hours, until the new cherry starts to come into the factory, and that tank is needed mid afternoon, to kick off a new cycle. For those factories that may like to start pulping as soon as the cherry starts coming in in the morning, the advice is to let the cherry continue to heat up in dry bulk for a few hours before beginning to pulp. Allowing bacterial activity ie. Temperature, to build up means that fermentation will be more than that much quicker. However, do not let the temperature on the bags rise above 40oC or damage to the coffee quality will result.

For those factories that are running a 'South American' semi washed type process, there will be a very significant lift in the final colour of the dried parchment and in the ultimate liquoring quality of the green bean, because this process ferments the remaining mucilage out of the centre cut of the beans and the short soak time gives a 'fully washed' output. It is on the colour of the center cut, exposed during the roasting process, that the 'Quality Control' people grade their coffee samples.

Acidification/Acetification:

The overall process includes a full environmentally friendly total clean up of wet factory waste waters. The Khe Sanh factory started off with a very high water usage system, circa 25 m^3/hr, using a pair of Pinhalense DC3/6 pulpers with close coupled demucilators, that is, in a semi washed process. This plant was converted into a fully washed process by recycling the factory water supply, pumping the demucilated coffee up into a pair of vertical stainless steel silos and draining the pulping water back to the machines for 4-6 hours of pulping. The actual water from the demucilators was discharged directly to the first stage fermenter or acid pond and fresh makeup water added to the pulper circuit to maintain correct levels. Every 4 hours, a silo was closed off with the coffee left under clean water, the pulping water was changed and the fresh coffee then pumped to another silo. The next morning, The silos were back flushed with water, both the water and coffee cycling through the pump to give good agitation, the water sent to waste and the coffee left to soak under clean water until the early afternoon when everything was sent on for drying as brilliant white parchment, and the 'decks' cleared for the mid afternoon arrival of the next picking of cherry.

The discharged soaking water 'may' then be used for beginning the next pulping session, if supplies are short, otherwise all that days water is sent down to the acid pond, a long narrow concrete tank of approx 200 cubic metres, sized to hold around one days throughput of heavily recycled wash water and mucilage, from pulping up to 200 tonnes of cherry. As well as the build up of mucilage, sugars and pectolytic enzymes in the recycled water, there was also as significant rise in temperature. To those who may be fearful of introducing rogue infections by such intensive recycling and concentration of wastes, one can only say that machine operators soon become quickly attuned to the appropriate times, smells and colours of normal processing. Any small change that occurs, is very quickly noticed, however rare it might be, and it is simply a matter of dumping that batch of water and continuing with a fresh batch of process water to claw back that particular batch of coffee, followed by a extra particular hose down for the next days batch. The human sense of smell is still the best judge of quality. The smell of acetone, the beginning of 'Fruity flavour', once sampled is never forgotten!

Handling the Solids:

The wastes from the pulpers are put through a rough filter which extracts the pulps and skins etc. which are usually stock piled somewhere for further treatment. The water coming through this rough filter constitutes the waste water that is used to ferment and digest into biogas.

Placement of Ponds:

Because most coffee country tends to be from rolling 'downs' to the down right 'mountainous', the use of long thin ponds makes it easy to create them around the contour of a hill by simply digging into the side of a rise and placing all the spoil down hill! Indeed if the rise is long enough one can dig a series of ponds accross the slope with the direction of flow alternating from left to right as one descends down the hillside. Just don't make them too close together, or it will be hard to recover raked off solids etc!

Acid pond:

By the time that the dirty water has flowed down the full length of the fermentation or acid pond, around 15-20 hours, the pH has dropped to 3.8, a pKa buffer point for formic/formate ions, and all the mucilage oligo-saccharides have come out of solution and float as a thick orange scum which is allowed to build up on the surface for several days, to turn into a thick black solid crust, which can be raked off periodically and deposited with the screened pulp solids for composting. At the far end of the acid pond, beyond a baffle placed to hold back floating solids, there will be a clear middle layer of yellow acid water, under the mucilage and over the settled solids. This is then pumped on to the next stage for neutralisation. Acidification/Acetogenesis can be speeded up considerably by bleeding off a small percentage of this acid water and feeding it back into the intake of the acid pond. If any hydrogen is indeed evolved at this stage of acid breakdown and reduction, then it is lost under the bed of floating mucilage. However, further developments at this stage could be the recovering of the fresh mucilage, for conversion to 'medicinal soluble dietary fibre', and the so called 'dark' hydrogen taken along with it for reinsertion at the methanation stage, or for other use.

Neutralising tank:

Use was made of an old 25,000 litre ex wartime steel fuel tank, which was three quarters filled with screened 2-5mm limestone chips. Acidified and clarified wash waters are pumped into the bottom of the tank through a manifold and up through about 1 to 1.5 metres depth of chips, with a minimum residence time of around 2 hours. Once again, the surface is covered with a foam of CO^2 generated solids, mucilage remnants and a finely divided black material, which is considered to be condensed tannins and polyphenolic precipitates, which have proved in the past to seriously restrict the efficiency of the biogas sludge if they are not removed. Tannins are natures protection chemistry infection by bacteria and yeasts etc. The tannin locks up the enzymes of attacking microbial species just as caffeine reacts against animals and insects.

Once again, the clear solution from over the limestone and under the foam layer , now at a pH of precisely 6.1, buffered by the pka of carbonate/bicarbonate ions, can be drawn off and used for the next stage and the floating layer periodically raked off and transferred to the pulp solids for compost. It is important to have available facilities to flush this tank and stir up the limestone bed sufficiently to strip off the surplus biological film from the chips. This film will slowly choke off the flow rate over a period of 2-3 weeks. A faster rate of flow and agitation of the bed will strip off most of the biological film which can be raked off with the rest of the solids. At this present level of technology, the froth and dark polyphenolics scum could be removed more easily by raking off the floating material up onto the bank of a long low rather than a high round trough. Once again this can be easily dug into the hillside. However a plastic liner will be needed to seal the bottom, whereas the pectin content of the acid pond/trough is largely self sealing.

The Biogas Digester:

Once again, in Vietnam, we have gone through the enrichment process, with a mix from every possible local source of psychrophyllic, acidogenic, methanogenic bacteria, and have derived a strain, which appears under the microscope to be mostly 4 lobed clumps of Methano-Sarcina species. However, every possible shape and size may be seen. It would have to be called a 'good brew' or a good heavy sludge, which settles very well. There are problems with the buildup of struvite encrustations on the outlet pipes, but we have developed mechanical fixes to this problem. Gas production levels are around twice the volume of gas per litres of waste water feedstock but vary a lot, depending on the amount of recycling of the pulper water.

The digester itself is a 50,000 litre ferrocent tank dug into the ground. Over the inlet manifold in the bottom of the tank is a layer of more limestone chips about 350mms deep. Above that is the sludge layer which can be up to 1.5 metres deep when inactive, but fluffs up and granulates to make a 2 metres plus deep bed of activated sludge. This sludge will settle and remain quiescent for up to 12 months at a time. However at the beginning of the next season it will fully reactivate in about a week. The top portion of the tank contains the gas/solids/liquids separator about 500mms under the surface of the discharge water. It is believed that the EGSB process, using a taller digester would be a logical progression over the present system, but this has not been tried yet. With the great variation in effluent strengths, cherry is the only real measure of inputs into the system for practical evaluation. At the present moment we are running 6-7000 litres of raw biogas, that is, about 3-4,000 litres of methane per tonne of cherry into the factory.

Gas from the digester is stripped of sulphide and stored in a large bag, from where it can be reticulated for only short distances at a pressure of 400mms WG. Further development in this area would be a modified commercial single stage air compressor to take the pressure up to around 12bar, and push the raw biogas into the bottom of a vertical column of water in a 6 metre length of PVC pipe. The stripped gas, now 98% methane, comes off the top still at the same pressure, and the resulting pressurized solution of soda water, is continuously bled off the bottom of the pipe. This solution of carbon dioxide can be processed for sale, released inside a plastic green house for CO_2 enriched plant growth or into the bottom of an algae pond for production of Single Cell Protein etc. At a pH of around 4, the major growth is of Euglena species, which being Protista have protein instead of cellulose cell walls making for good animal feedstuff. However, with large supplies of enriched lime sludge available for raising the pH, Spirulina is another possibility.

Under this low pressure regime, small quantities of gas can be stored in Ex LPG cylinders at around 11bar, however, it is easily reticulated around the factory, and the dwellings of factory workers at reduced pressures in PVC water pipe, (Check local OSH Regulations), and used pretty much as quickly as it is made. CNG or compressed Natural Gas requires a much higher compression, to around 30 bar, and can be used for running motor vehicles etc. With the current volatility of petroleum stocks the economics of automotive CNG fueling is sure to escalate.

Aeration ponds:

At Khe Sanh, the major part of the neutralized wash water is presently discharged into a constructed wet land made in three sections.

The discharged effluent from the digester passes through a small settlement tank, mainly to collect and recycle escaping sludge, and then flows by gravity to the first pond. This pond should function as a facultative oxidation pond, growing lots of algae which may be recovered as SCP, and start to build up the oxygen levels. By maintaining a slightly acid pH It is possible to grow Euglena, a protozoa, as well as algae. Protozoa have cell walls of protein rather than cellulose, and make better animal feedstuff. Because Euglena species are flagellate and motile, they move up and down in the water with the sunshine. This allows a thin mat to be drag netted off the surface during the heat of the day, still leaving plenty to continue the multiplication process.

The second pond has been planted out with local varieties of hollow stemmed reeds and rushes. These plants use those hollow stems to actively pump enough oxygen down to not only their own roots but also the bacteria that reside on those roots, to allow them to survive in a highly anaerobic environment, and they are good reducers of both BOD and COD. The base of the pond is coarse gravel, into which the roots penetrate, and through which the water can slowly filter through as a 'hydroponics' filter bed. After the biogas digester, and the facultative pond, they constitute the third line of biological filtering. In colder climates much greater use would have to be made of the reeds and rushes because our forth stage is relative only to tropical climates.

Water Hyacinth Tertiary treatment:

The tertiary filter or 'water polishing' pond is much deeper, 1.5 metres, and is filled with floating water hyacinth, which as well as constituting a micro-filter will also take out the fertilizer salts, the nitrates, potassium, humate precusors etc, and any remaining phosphates. This fantastic filtration system comes not only from their filamentous root system but also the microbiological flora that cling to and live on those roots. The problem with a hyacinth pond however is that they grow and grow fast. They require a continuous thinning process by pulling out older plants and processing them. There are several options available to utilize the excess material, of which the easiest way is to chop them up and add them to the composting mix of coffee pulp and skins! This will effectively recycle all the fertilizer salts not taken out by the exported green bean. More biogas, literally farming the sunshine over the ponds, Animal Feedstuffs and Single Cell Protein are also possibilities. Once again all the bits that don't break down are made into compost for use not only as fertilizer, but long life soil carbon to return to the coffee trees. So, in between the treatment of both liquids and solids there is a 100% conversion of wastes to useful products, and no pollution of the environment.

Lots of research has been done on the utilization of water hyacinth as a means of farming solar energy to produce methane. The coffee season is the cool season, when hyacinth growth can be sustained on nutrients from the coffee effluent. However, during the hot season, when there is no coffee, the increased solar output could increase the growth of hyacinth to make up the difference, simply by recycling the biogas effluent made from its own biomass in the ponds. Any losses being made up from stored waste coffee pulp. This not only means that energy production could be sustained all year round, but also that just about everything is returned to the soil.

The big problem however, for the total cleanup of coffee waste waters is the anthocyanin colours from the cherry skins. In nature these polyphenolic chemicals get ultimately condensed into the brown colours of swamp water and end up as solid humus and more soil carbon. These compounds come through the biogas processes as a clear yellow colour in acid conditions and a very intense greenish black colour in neutral and alkaline conditions. This colour will stain waterways for tens of kilometers down stream of a coffee factory. So far, nobody has put up the finances to actively look at this problem. What we are doing is keeping abreast of developments in the olive processing and the red wine industry. When every olive grove around the Mediterranean has a hotel down on the beach at its drainage outlet, there is a lot more money to be spent there rather than here. What is presently being mooted there is the 'Electro-Fenton'process. That is presently too expensive for coffee.

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ADDITIONAL NOTE Added in 2006 on
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If it is true that sequestration of CO^2 and keeping methane out of the upper atmosphere is going to be worth money, then the system under development at Khe Sanh has all the potential to lead the coffee industry into a 'brave new world'! Control and combustion of any methane emissions is complete. The worst source of atmospheric methane emissions is heaps of old coffee pulp left out in the weather. As the acids are steadily leached out by rain, a brown intermediate layer is found between the black crust and the sticky red 'sourkrat' preserved pulp silage underneath. That is where the biogas bacteria reside, steadily working their way down through the heap.

It would not be at all difficult to also control most of the carbon dioxide by recycling it into more facultative algae ponds, and produce animal feedstuffs to go along with the ensiling of coffee fruit pulp under newly discovered simple biological processes, which can extract tannins and alkaloids and convert it into animal feedstuffs. Cattle feedlots are big business in Vietnam, and the Chinese are hungry for meat! Euglena and Spirulina also make very good poultry feedstuffs.

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