**AD review for Farms Systems for Professionals, Oct 2017**

**The process of AD mimics rumen biochemistry**

Anaerobic digestion (AD) mimics the biochemical & microbial digestion of organic feeds that occurs in animals with rumens: cattle, sheep, goats, etc.,. The AD process proceeds through two phases: aerobic digestion followed by anaerobic digestion. There are four steps in the AD process: hydrolysis, acidogenesis, acetogenesis & methanogenesis. In hydrolysis, material is broken down into biomolecules like proteins, amino acids, complex and simple carbohydrates and lipids. Acidogenesis converts these biomolecules into small organic acids of 2-6 carbons. Acetogenesis converts these organic acids into the acetic acid, the 2-carbon volatile fatty acid that is the direct precursor to methane. Methanogenesis converts the acetic acid to methane and carbon dioxide by two different pathways.

**Biogas harvests carbon**

Biogas is a combination of methane (55-75%), carbon dioxide (most of the remainder) and lesser amounts of water, ammonia, hydrosulfuric acid and hydrogen gas. Combustion of methane produces carbon dioxide and water and lowers the greenhouse gas potential of methane 27-fold.

**Nutrient levels aren’t changed**

While AD converts organic carbon to methane gas and lowers the carbon content of feedstock materials, levels of nitrogen, phosphorous and potassium nutrients (NPK) aren’t appreciably changed. When operated well, AD is a steady-state or equilibrium process so roughly the same amount of nutrients are used by create new bacteria as are released by dying bacteria.

**The form of nutrients is changed dramatically: organics are mineralized**

AD does dramatically alter the form of NPK: organics are mineralized. ‘Organic’ nutrients are large biomolecules with significant amounts of NPK: proteins, carbohydrates and fats. Organic nutrients are not immediately bioavailable to plants and must be broken down (metabolized) by microbes before they can be taken up by plants. Mineralized nutrients have been metabolized by microbes and are ionic and soluble or gaseous forms of the nutrients that are immediately bioavailable. AD converts nitrogen into ammonia (NH3) gas or, at pH below 8, water-soluble ammonium (NH4+1) salts. Phosphorous is converted to water-soluble phosphates (P2O5). Potassium becomes ionic and water-soluble.

**Mineralization of nutrients has advantages & disadvantages.**

Ammoniais immediately available to plants and very effectively boosts vegetative growth. However, ammonia is volatile & much of it is lost to the atmosphere unless it is injected or spread very close to the soil. Lowering the pH of effluent below 8.0 can convert ammonia (NH3) to ammonium (NH4+1), which is no longer volatile but is still quite bioavailable. pH can be lowered by: addition of strong acids; or sugars & fermentation to create lactic acid; or by addition of lactic acid extracts & biochar.

Phosphorous is more bioavailable to plants once mineralized to phosphate and contributes to growth, flowering and fruiting. Phosphate is negatively charged & associates with positively charged ions like magnesium and calcium. Phosphate will bind to iron ions that are sometimes added to digester feedstock to prevent formation of hydrosulfuric acid in biogas. Phosphorous ions and precipitates can associates and bind to solids, particularly smaller particles or fines: 20 – 600 μm.

**Nutrient bioavailability has pros and cons.**

Mineralized and bioavailable nutrients can be taken up by plants as soon as they are applied and may increase crop yield, though outcomes depend on the crop. At the college we estimate that crop yields have increased by one-third or more; we would like to spend time with this data. However, if AD effluent is not properly managed & applied, bioavailable nutrients could enter surface waters where their immediate bioavailability would result in algae growth & eutrophication. Finally, mineralization of nutrients makes it possible to separate, to a large extent, nitrogen from phosphorous.

**Are there best practices for application of liquid AD effluent?**

Of course, nutrient management planning with proper execution, record keeping and follow-though is essential. Since the predominant form of nitrogen is volatile ammonia, AD effluent should not be broadcast spread. Application close to the soil with immediate incorporation or injection will get more nitrogen to the crop. Some studies show that effluent can be applied to crops once they are growing because nutrients can be taken up immediately. Monitor crop yields and soil nutrient levels carefully to be sure that excess nutrients are not being applied.

**Separated solids are too valuable for bedding to be applied as fertilizer.**

Solids can be separated from raw or digested manure using a fan / screw-press auger separator. The separated ‘solids’ are roughly 35% total solids & 65% water. Solids still have high organic content & will compost & produce significant heat when stored in piles. Solids are probably the most valued AD product for dairy farmers as they make good bedding for dairy cattle. It is often said that one cow will produce two cows worth of bedding, but the amount of solids produced decreases with digester efficiency. Thus, bedding production is likely higher for plug flow than complete mix AD and will decrease with hydraulic retention time. Solids production depends on the solids content of feedstock.

High quality and abundant bedding increases cow health & comfort, and thus milk production. Traditional sawdust bedding has become less available & more expensive, largely due to wood pellet production. Sand bedding isn’t compatible with AD. Cattle can be bedded on raw manure solids or solids from anaerobic digesters. AD dramatically decreases pathogens in separated manure, and mastitis. However, mastitis will still occur on AD solids but can be managed. We’ve seen an organismal shift from *Klebsiella* on sawdust to a *Staph aureus* bacillus.

Separated solids are somewhat enriched in phosphorous: roughly 2.5 times as much phosphorous is found in separated solids than in the digestate they are separated from. Using solids for bedding parks some phosphorous under cows. Each time bedding is processed through AD it breaks down into fines that usually end up in liquid effluent, pulling some phosphorous into the liquid with them.

**Nutrient separation is a holy grail for dairy farming and AD.**

There are several successful, but expensive, approaches to separating much of the nitrogen and phosphorous in dairy manure and the mineralization caused by AD makes separation easier. Sadly, the costs of separation prohibit use of this technology on all but the largest farms in Vermont. Two AD vendors are now offering nutrient separation packages with their AD plants. To my knowledge, neither has been used in Vermont.

DVO, formerly GHD, installs plug flow digesters like most of those in Vermont. Their nutrient separation strategy begins by aerating effluent & heating it with engine exhaust to 160F (70C) to release & vaporize NH3, CO2 and other gases. The gases are sent to a stripping tower where they are reacted with sulfuric acid to produce solid ammonium sulfate, removing up to 80% of ammonia. Aeration also increases pH of effluent, causing phosphate to become charged. An organic polymer is added to flocculate (bind to) the phosphorous increasing its effective molecular weight and causing it to settle. Solids are allowed to settle and the separated. According to DVO, this will allow removal of 75 – 90% of phosphorous. Finally, hydrosulfuric acid stripped out of the biogas is added back to liquid effluent to lower its pH for field application.

Quasar installs complete mix AD systems similar to the college’s system. Their Phosphorous Recovery System (PRS) can be used for raw or digested manure. A centrifuge removes solids (25% TS) with 90 – 95% of the phosphorous. The liquid produced (supernate) is mixed with liquid hydrated lime (Ca(OH)2) to increase the pH to 10.5 facilitating coagulation and precipitation of the solids not captured by the centrifuge. These coagulated and precipitated solids settle in a tank, and clarified liquid is removed and filtered. The filtrate has a phosphorous content of < 1 mg/L but is rich in nitrogen and potassium and can be used as low-phosphorous fertilizer. Quasar’s mobile PRS unit costs $600,000.

Machia & Son’s Dairy in Sheldon, VT removes about 40% of phosphorous from manure using a screw press auger followed by a centrifuge. The diary does not have an anaerobic digester, but installed a screw-press separator to produce bedding from raw manure. Increased levels of mastitis led them to install a drum composter than heats raw manure to 140-160°F and tumbles it for 24 hours to compost and kill pathogens. Bacterial counts drop from 27 E6 to 2 E5. Recently they installed a 3600 rpm centrifuge that spins the liquid effluent to remove fines and the phosphorous that they hold. Incoming manure has a total solids content of 9-11%. Effluent leaving the screw-press separator has 4-6% TS and after centrifugation, TS is decreased to 2-3%. The solids produced have are 36% total solids and phosphorous is reduced by 40% by the entire solids separation process. Their cows love the bedding. The farm is selling bedding to other farmers and separated phosphorous to a nearby composter. They do anticipate high maintenance costs for the centrifuge and running the separation system costs thousands of dollars a month for electric power.