Application of the AGF (Anoxic Gas Flotation) Process

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Abstract: The AGF (Anoxic Gas Flotation) process is an improved anaerobic digestion process that uses anoxic gas (without oxygen) to float, concentrate, and return bacteria, organic acids, protein, enzymes, and undigested substrate to the anaerobic digester for the rapid and complete conversion of waste slurries to gas and soluble constituents. The process has been used to treat sewage sludge (3 to 6% solids), dairy manure (7% solids), and potato waste from french-fry and potato flake production (0.4 to 1.2% solids). Flotation gases used include methane, CO_2 and biogas with various concentrations of CO_2 and methane. The process has been found to substantially improve anaerobic digester loading and solids conversion to gas. The process also provides other benefits such as the removal of CO_2 and H_2S from biogas, foam prevention, inhibition of scale formation, and improved down stream processing and dewatering of residual waste solids. The process has been used in the contact, stabilization, and residual pasteurization modes or operation.

Keywords: flotation, anaerobic digestion, gas, methane, CO_2, food waste, sludge, manure, solids destruction, gas cleaning, scale control, carbonates, anaerobic activated sludge, Struvite, MAP, pasteurization,

Introduction

The AGF process is an innovative anaerobic digestion process that improves the conversion of solids to gas by recycling bacteria and undigested solids to the anaerobic digester (Burke 1991). Bacterial solids are separated from the digester effluent, concentrated, and returned to the digester. Since oxygen is toxic to anaerobic bacteria, anoxic gas, or gas without oxygen, is used to float and concentrate bacteria from the digester. Although a variety of liquid / solids separation devices have been used to improve the solids retention time (SRT) of anaerobic digesters, gas flotation offers many advantages over conventional techniques. Gas flotation is less disruptive to the bacterial consortia when compared to centrifuges or cross flow membranes (Pfeffer 1968). Gas flotation uses less polymer and is thus less expensive to operate than centrifuges or gravity belts (Poling 1985). Gas flotation concentrates the solids (5% to 6%) more effectively than gravity thickeners or plate separators (Tropey and Melbinger 1967). It is not harmful to anaerobic bacteria, nor does it disrupt the bacterial community (Burke 1997). Gas flotation is an effective separation technique since anaerobic bacteria naturally tend to float rather than settle. In addition, flotation concentrates soluble organic acids and proteins, including enzymes, through hydrophobic attachment at the gas / liquid interface. Gas flotation also offers the opportunity to effectively elutriate inhibitory end products of digestion such as ammonia and sulfide. Flotation with carbon dioxide also forms carbonates that inhibit MAP (Struvite) scale formation in the digester and effluent piping. Biogas flotation produces an effluent gas containing a significantly higher percentage of methane and lower concentration of hydrogen sulfide (Burke 1997). Finally, a clear effluent is produced from which MAP (magnesium, ammonium phosphate) can be recovered.

Methane gas, biogas from the digester, or any other anoxic gas can be used to accomplish the flotation separation.

AGF Process Description

Figure 1 below presents an illustration of the process.

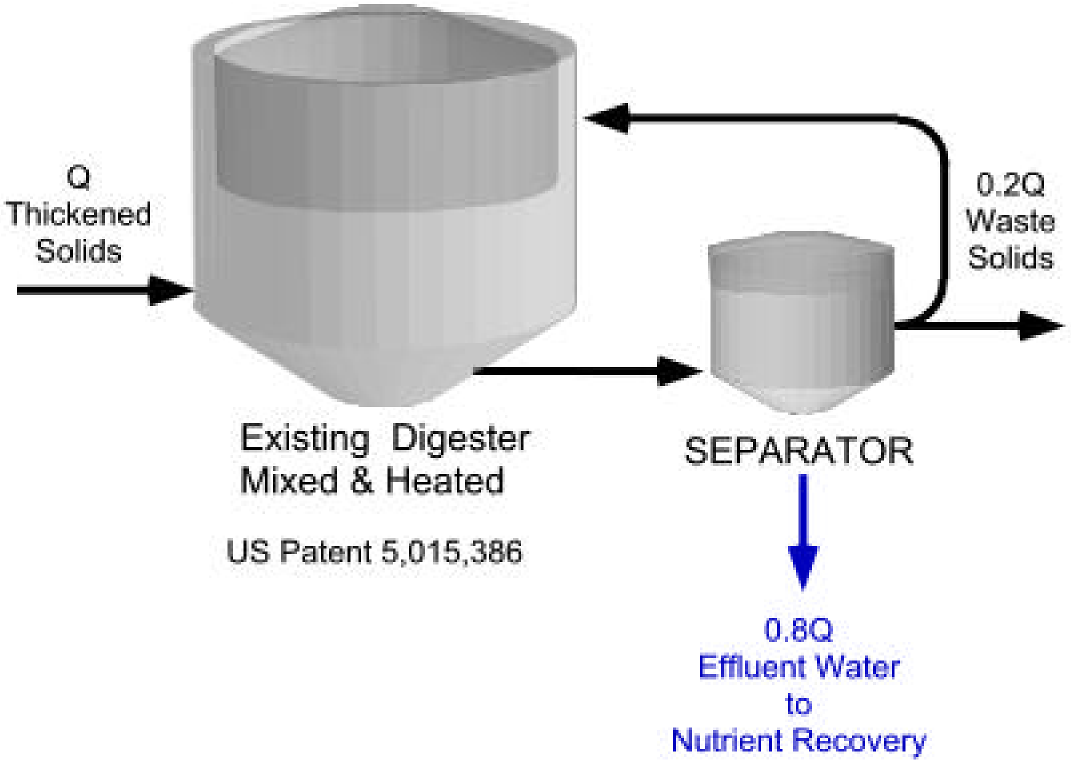

Figure 1 AGF Process Schematic

As shown in the schematic above, thickened solids are delivered to the anaerobic digester for conversion to gas and soluble constituents. The influent solids from the primary and secondary sewage treatment processes can be either dilute or pre-thickened. Since the AGF process is load sensitive (kg/m^3/d), rather than flow sensitive, intense pre-thickening is neither required nor desired. Pre-thickening increases the concentration of inhibitory end products that must be removed for optimum performance. Solids are retained in the AGF digester for sufficient time to convert the waste to gas and dissolved constituents. The gases (methane and carbon dioxide) exit the process as biogas, while the dissolved solids exit the digester with the digested solids. The dissolved solids and biosolids are separated in the AGF separator. The biosolids are returned to digester to enhance the degradation of the influent slurry. The dissolved solids leave the AGF separator and are returned to the secondary treatment plant.

Excess anaerobic bacteria and solids that are not converted to gas are disposed. As shown in Figure 1, biosolids are wasted from the return solids stream since the return solids are more concentrated than the digester solids (6% vs. 4%). The return solids are also charge neutralized because of polymer added to the flotation unit. Wasting return solids substantially reduces (50% to 75%) the quantity of polymer used in the subsequent solids dewatering process. Flotation is accomplished by dissolving biogas in the liquid effluent with either a saturator or saturator pump. The dissolved gas is then released upon contact with the digested solids. The gas bubbles attach to the solids and are floated to the top of the flotation separator where thickening occurs.

The objective of the AGF process is to convert a maximum percentage of influent solids to inorganic constituents and gaseous products, and to discharge those constituents in the gas and liquid effluent streams. Wasting solids is only necessary to maintain fluid mixing conditions and unhindered solids separation. To minimize organic solids wasting, separate removal of inorganic solids, sands, silts, and grit is beneficial and recommended.

The AGF process shown in Figure 1 is utilized to treat concentrated organic waste having relatively uniform consistency. The treatment of dilute waste composed of constituents with different rates of degradation can be rapidly and effectively accomplished with the ClearCycle™ modification of the AGF process. Dilute wastes include sewage, food-processing waste, or dilute primary and waste activated sludge. The ClearCycle™ process minimizes the digester volume by holding the slowly degradable solids in a stabilization reactor for a prolonged period of time.

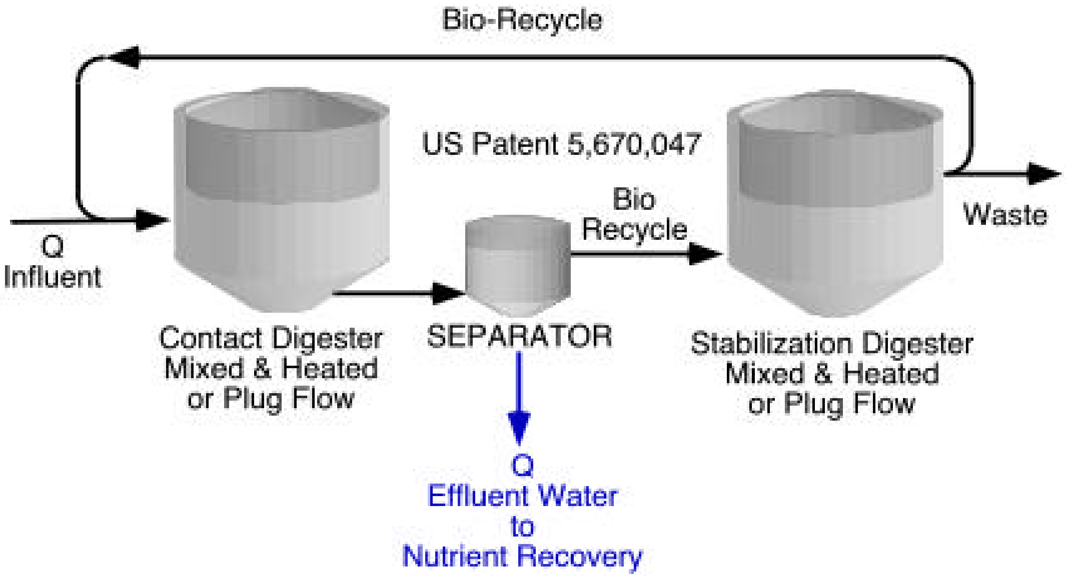

Figure 2 AGF Stabilization Process (ClearCycle™ process)

The ClearCycle™ process shown in Figure 2 is composed of three tanks, a small anaerobic digester, a solids-holding digester, and an AGF unit. Concentrated biomass is retained in the stabilization reactor for a prolonged period while slowly degrading particulate solids are hydrolyzed. The highly concentrated bacteria in the solids-holding reactor are subsequently used to promote rapid degradation of the waste entering the contact digester. Within the contact digester, the soluble and easily degraded particulate waste is converted to gas in a short period of time. The dilute slurry composed of anaerobic biomass and slowly degrading particulate matter is concentrated in the AGF unit and subsequently transferred to the solids holding reactor.

The removal of soluble constituents in the contact digester, and colloidal or particulate substrate and bacteria in the AGF flotation unit, produces a high quality liquid effluent containing primarily dissolved inorganic constituents. The technology offers other process advantages including control of digester alkalinity through recycle and the elutriation of digester contents to remove hydrogen sulfide, ammonia, and other inhibitory constituents.

The third process configuration, the AGF pasteurization process takes advantage of the enhanced digestion capabilities of the AGF process. Typically the AGF process increases the capacity of a single digester by three to four times its conventional capacity. Additional digesters are then available to re-digest pasteurized solids. An AGF separator will occupy less that 1/4 the space of a single digester, uses less energy than that required to mix a single digester, and will cost less than 1/3rd the cost of a single digester. Therefore, it is more advantageous to install an AGF unit rather than another digester. The pasteurization process is shown in Figure 3.

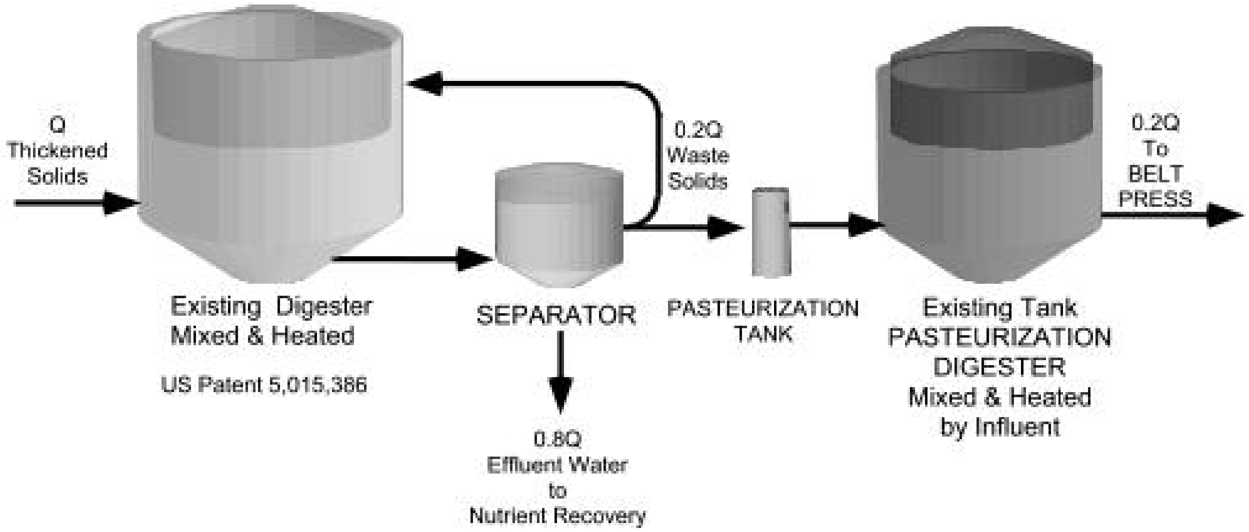

Figure 3 AGF Pasteurization Process

The low volume of waste solids from the AGF process can be economically pasteurized in small pasteurization tanks with detention times of 0.5 to 1.0 hours. Small quantities of thickened waste solids are withdrawn from the float, or thickened return flow at one-hour (±) intervals throughout the day. The float solids are generally 5.5% to 6% total solids. The thickened solids are diluted to a digester concentration of 2.75% to 3.5% with steam to reach the 70°C pasteurization temperature. The pasteurized solids are then re-digested in a second digester. Re-digestion of the pasteurized solids increases the total volatile solids reduction by an additional 5% to 10%. An overall process volatile solids reduction of 70% to 85% is achieved.

The secondary digester obtains sufficient heat from the pasteurized influent. No additional digester heating is required. The AGF pasteurization process is more economical than other thermophilic or pasteurization processes since only a small fraction of the total flow is heated to higher temperatures. Both of the AGF digesters are operated at mesophilic temperatures, minimizing heat requirements and losses. The AGF pasteurization process does not require any more additional heat than that required by two conventionally insulated mesophilic digesters.

Operating Results

The AGF process has been used at pilot and full scale to treat sewage sludge and dairy cow manure. The ClearCycle™ process has been use to treat a variety of potato wastes while the AGF pasteurization process has been used to treat sewage sludge. The results to date are summarized below.

Sewage sludge treatment at King County, WA, USA

From 1995 through 1996 a pilot plant was operated at King County's Renton, Washington wastewater treatment plant. The pilot plant treating concentrated primary and waste activated sludge was operated in parallel with a conventional digester. Methane gas was used for flotation. A cationic polymer was used as a flotation aid. Elutriation, through the addition of various quantities of water to the saturator, was practiced.

The AGF pilot plant was operated for one year at Hydraulic Retention Times (HRT) of 6, 9, and 17 days with associated solids retention times (SRT) of 19, 29, and 58 days. An SRT/HRT ratio of 3.4 was obtained. A parallel pilot-scale conventional digester was operated at a 19-day HRT and SRT. Both digesters were operated at 35° C. The AGF digester achieved a 64% volatile solids reduction at a 6-day HRT, a 67% volatile solids reduction at a 9-day HRT and a 72% reduction at a 19-day HRT. The conventional process achieved a 59% volatile solids reduction. The concentration of ammonia and sulfides were significantly lower in the AGF digester. The ability of the AGF process to increase volatile solids reduction at significantly shorter HRT's can result in much smaller digesters, greater gas production, and less biosolids mass to haul and dispose.

AGF flotation thickening concentrates particulate materials, including anaerobic biomass, while allowing dissolved and soluble end products to be flushed from the system. The extent of thickening is controlled by the flotation design, while the quantity of dissolved constituents flushed, or elutriated from the system is controlled by the quantity of material processed through the flotation unit and the quantity of dilution water added to the gas flotation liquid. The average increase in concentration (thickening) or decrease in concentration (elutriation) across the flotation thickener for the entire pilot plant period is shown in Figure 4.

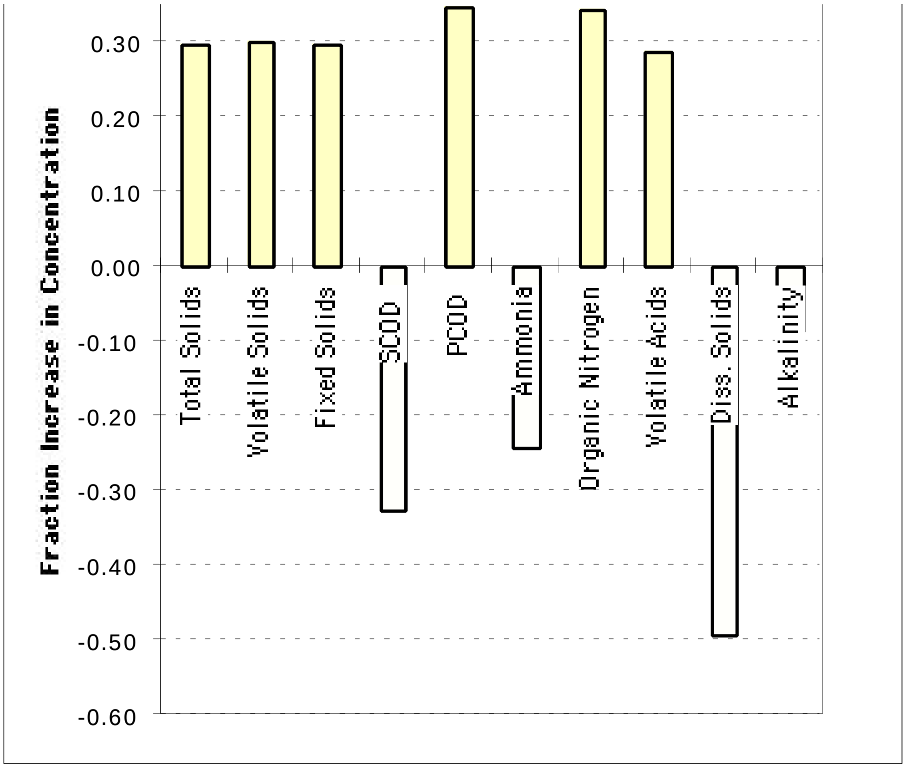

Figure 4 Increase in float concentration across flotation thickener

As shown, the particulate and surface active constituents such as the solids, particulate COD, and volatile acids are concentrated, while the dissolved and soluble constituents such as ammonia, dissolved solids, and to a lesser extent alkalinity are elutriated.

Municipal sewage sludge treatment at SWSSD, WA, USA

In 1998 a full-scale AGF plant was installed at the SWSSD treatment plant in Burien, WA, USA. The pasteurization process was installed shortly thereafter. The AGF facility uses biogas for flotation and a cationic polymer as a flotation aid. The AGF facility achieves a 72% volatile solids conversion to gas at a loading of 3.15 $Kg/m^3/d$. The AGF process increased the biogas methane concentration from 64% at the digester to 80% as a final product and reduced the H_2S concentration from 300 ppm to less than 30 ppm. The process reduced the time required to dewater the solids from 32 hours per week to 8 hours per week. The process also reduced the quantity of solids requiring disposal by 34%. Polymer used for dewatering was reduced by 50% while cake solids concentrations were increased by 20%. Overall plant polymer use has increased slightly.

The pasteurization process has increased volatile solids destruction by an additional 7% resulting in a 79% overall VS conversion to gas.

Potato waste treatment

The AGF ClearCycle stabilization process was operated for a year at two potato processing facilities in Idaho, USA. Both plants used methane gas and a cationic polymer for flotation separation. A clear effluent having only a slight odor was produced.

The first plant treated french-fry waste having a COD concentration of 5,000 mg/L with high suspended solids and oil and grease concentrations. No primary sedimentation occurred prior to treatment. Approximately 50% of the COD was particulate COD.

The overall HRT was varied between 0.5 and 1.4 days. The contact reactor had an HRT as low as 2.5 hours. However, the SRT exceeded 300 days. Total COD and particulate COD reductions greater than 95% were achieved at a contact reactor volumetric loading rate of 15 Kg/m3/day and overall process volumetric loading rate of 5 Kg/m3/day. Doubling the volumetric loading decreased the COD reduction from 97% to 80%. Particulate COD was digested with the same efficiency as soluble COD. Chemicals were not required to adjust influent pH. The process substantially reduced the time required for digestion while eliminating the need to dispose of primary solids, or to add alkalinity to, or adjust the pH of the influent.

The second plant treated potato flake, or dehydration waste. The dehydration waste had a total solids concentration of 11,400 mg/L with an average COD of 12,100 mg/L. Influent pH values were as low as 4.5.

The operating HRT of the dehydration waste facility varied between 0.6 and 2.2 days. The average SRT was 151 days. Treatment efficiencies varied from 96% COD reduction at a loading of 0.1 Kg COD Influent / Kg COD under digestion to 80% COD reduction at a loading of 0.45 Kg COD Influent / Kg COD under digestion.

Biogas composition varied between the contact and stabilization digesters. The contact reactor had a 56% methane content whereas the stabilization reactor had a 68% methane content.

Substantially all of the suspended solids were removed from the effluent of both plants. The clear effluent allowed economical recovery of residual nutrients such as magnesium ammonium phosphate MAP (Struvite). Struvite (Mg NH4 PO4.6 H2O) was economically recovered from the effluent. Eighty five percent reductions of total P were achieved. Most was converted to MAP.

Manure treatment

A pilot plant was operated treating dairy manure for 9 months during 1998. The plant treated raw dairy manure with sawdust bedding having a COD concentration of 85 g/L, a nitrogen concentration of 3.6 g/L, and a phosphorus concentration 0.81 g/L. Biogas with a cationic polymer was used in the flotation separator. Use of biogas caused a 0.25 point reduction in pH.

A 78% COD reduction was achieved at ambient temperature with a 24 day HRT. The solids retention time was controlled by the requirement to remove refractory wood chip bedding material. Sixty seven percent of the nitrogen was concentrated in the separator allowing only ammonia to exit the process in the effluent. Eighty-five percent of the total P was concentrated in the separator allowing 93% of the ortho-P to exit. Only a small portion of the N&P were converted to MAP. It is believed that the excess carbon dioxide driven into solution by the saturator formed magnesium carbonate and thus inhibited MAP formation. Although MAP was not formed N&P were substantially retained in the float, thus enriching the nutrient value of the waste solids.

Summary

Over the past six years the AGF process has been demonstrated at pilot and full scale treating a variety of wastes. The process has been proven to economically recover energy and nutrients from waste slurries. Other process benefits are as follows:

- Smaller anaerobic digesters can be used (1/2 to 1/4 of conventional).
- Higher organic loading can be achieved.
- Greater solids conversion to gas can be realized.
- Greater methane gas production by virtue of greater solids destruction.
- Less energy for mixing and heating is required.
- Increased operational flexibility, especially dewatering requierments.
- Reduced volume of waste solids requiring less time and energy to dewater.
- Reduced Struvite (MAP) scaling potential.
- Reduced pre-thickening requirement.
- Clean and concentrated effluent for MAP recovery.
- Improved biogas quality by virtue of gas scrubbing
- Very high solids retention times are achieved resulting in lower biomass yields and smaller quantities of waste residual solids to be disposed.
- Reduced chemical utilization for maintaining alkalinity.
- Reduced volume of solids for pasteurization and re-digestion.

References

Burke, D. A. (1991). Anoxic Gas Flotation. USA.
Burke, D. A. (1997). Anaerobic Digestion of Sewage Sludge Using Anoxic Gas Flotation. 8th International Conference on Anaerobic Digestion, Sendai Japan.
Burke, D. A. (1997). Anaerobic Treatment Process for the Rapid Hydrolysis and Conversion of Organic Materials to Soluble and Gaseous Components. USA.
Pfeffer, J. T. (1968). “Increased Loadings on Digesters with Recycle of Digested Solids.” Journal Water Pollution Control Federation **40**(11): 1920-1933.
Poling, M. (1985). Thickening of Digested Sludge for Improved Plant Performance. Seattle, Municipality of Metropolitan Seattle.
Tropey, W. N. and N. R. Melbinger (1967). “Reduction of Digested Sludge Volume by Controlled Recirculation.” Journal Water Pollution Control Federation **39**(9): 1464-1474.