PILOT PLANT OPERATION OF THE AGF (ANOXIC GAS FLOTATION) STABILIZATION PROCESS AT POTATO PROCESSING FACILITIES

Dennis A. Burke

Cyclus Envirosystems, 6007 Hill Road NE, Olympia, WA 98516-9551

ABSTRACT

The AGF (Anoxic Gas Flotation) Stabilization process is a high rate anaerobic digestion process capable of treating waste containing substantial quantities of suspended solids and oil and grease. A clear efțuent is produced, allowing the recovery of soluble nutrients from the efțuent. The results of two pilot plants treating potato dehydration waste and french fry processing waste are presented. The pilot plants treating waste with high COD, suspended solids, and oil and grease concentrations. Total COD and particulate COD reductions greater than 95% were achieved with contact reactor volumetric loading rates of 15 Kg/m^3/day and process volumetric loading rates of 5 Kg/m^3/day. Doubling the volumetric loading decreases the COD reduction from 97% to 80%. Particulate COD was digested with the same efŢciency as soluble COD. Chemicals were not required to adjust ințuent pH. Struvite ($Mg\ NH_4\ PO_4.6\ H_2O$) can be economically recovered from the efțuent to achieve substantial reductions of phosphate. Addition of phosphate and magnesium can result in substantial nitrogen reductions.

KEYWORDS

Anaerobic digestion, contact process, stabilization process, gas țotation, potato waste, organic loading, volatile solids destruction, SRT/HRT ratio, particulate hydrolysis, biogas production, efțuent quality.

INTRODUCTION

Large volumes of high strength waste are produced by dehydration and french fry potato processing plants throughout the state of Idaho. A typical plant will produce 4,500 m^3 per day of warm waste (30°C to 40°C) having a COD concentrations exceeding 5,000 mg/L. The waste typically has a high particulate COD and oil and grease content. Concentrated waste from dehydration potato processing may have total COD concentrations as high as 15,000 mg/L.

A variety of processes are used to dispose of the waste. Most waste receives primary treatment wherein the suspended solids are removed by primary clarification. The settled solids are then concentrated by centrifuge, vacuum filter, or belt press for ultimate disposal as cattle feed or simply land applied. Dissolved air flotation is often used to remove oil and grease from the centrifuge centrate or the clarified effluent. If the solids can not be disposed through land application, or as cattle feed, they are dried for reuse at considerable cost. The clarifier underflow solids have little net economic value since they are commonly sold for less than $5 per dry ton. When converted to methane gas, the solids have a value of $35 per dry ton. However, removal of the suspended solids through primary clarification preconditions the waste for subsequent high rate anaerobic treatment (USAB, Contact, AFB). Traditional high rate anaerobic treatment is not effective for raw waste having the suspended solids and oil and grease content of potato waste.

Primary clarification is also advantageous since a portion of the nitrogen is removed with the underflow solids. Nitrogen removal is significant, because it is the rate limiting constituent when land application of the residual waste is practiced. On the other hand, primary clarification depresses the pH of the warm waste due to rapid acidification within the clarifiers. The clarifier effluent must be treated with magnesium hydroxide, magnesium oxide or other caustic chemical to raise the pH from values as low as 4.5 prior to subsequent treatment. The cost of such neutralization commonly exceeds $200,000 per year for a typical processing facility.

Treatment process selection is ultimately based on the most economical method of exporting the waste. If sufficient land is available, the waste can be applied to land and exported as a crop. The application rates will be controlled by nitrogen. However, significant quantities of land are required. If primary clarification is used, the suspended solids, PCOD, oil and grease, and organic nitrogen can be exported as animal feed. If an aerobic treatment process is used, the waste can be exported as aerobic biomass or waste activated sludge. Waste activated sludge has little value, and is difficult to dispose. However, aerobic processes can incorporate nitrification and denitrification unit processes which address the nitrogen limitations.

If anaerobic treatment is used, the waste can be exported as energy in the form of methane gas. However conventional, and traditional high rate anaerobic processes produce a poor quality effluent having high suspended solids concentrations. In addition, high rate anaerobic processes are not effective in treating waste with high suspended solids concentrations or oil and grease. Finally, anaerobic digestion does little to address the nitrogen limitations, since the nitrogen is simply converted to ammonia in the digestion process.

Economic analysis has established that the most beneficial option is to export the entire waste load as methane gas, produce an effluent free of suspended solids for subsequent nutrient recovery, and anaerobically digest the waste using long solids retention times, such that biomass yields and solid disposal costs are minimized.

AGF STABILIZATION PROCESS

The AGF (Anoxic Gas Flotation) process is simply a liquid solids separation procedure. Since oxygen is toxic to anaerobic bacteria, anoxic gas, or gas without oxygen, is used to float and concentrate bacteria from the digester (Burke, 1992). Flotation is less expensive when compared to other separation processes. It is not harmful to anaerobic bacteria, nor does it disrupt the bacterial community. Since flotation does not impair the bacterial community, loadings can greatly exceed the limits experienced with disruptive devices such as cross flow membranes (Brockmann and Seyfried, 1996) and centrifuges. Flotation is an inexpensive tranquil separation process. The AGF process is an effective separation technique since anaerobic bacteria naturally tend to float rather than settle. Methane gas, biogas from the digester, or any other anoxic gas can be used to accomplish the separation. The AGF process has been fully described in a number of publications (Burke, 1991, 1992,1996,1997(a), 1997(b), 1997(c)).

All separation and recycle processes are limited by the accumulation of inorganic silts and precipitates, as well as the accumulation of slowly degrading organic constituents within the digester. The accumulation of inorganic materials, and slowly degrading organic materials, will severely limit the performance of anaerobic retained biomass systems. Solids accumulation will limit digester mixing and the efficiency of any separation process. The economical separation of biomass requires relatively dilute solutions. To counteract the accumulation of solids, wasting is normally increased. Increased solids wasting lowers the solids retention time (SRT) and reduces the efficiency of the process.

The AGF Stabilization process minimizes the inherent limitations of retained biomass systems. Two smaller anaerobic reactors are used. The process incorporates a device that removes inorganic particulates ($> 50\ \mu$) while retaining the organic constituents. Dissolved constituents, such as ammonia and hydrogen sulfide, which may inhibit the process are elutriated from the system. One of the anaerobic reactors provides prolonged hydrolysis of slowly degrading materials in the presence of concentrated biomass. As a result, the solids retention time is substantially increased while carrying out the biomass separation under relatively dilute conditions. Dilute conditions significantly reduce the cost and energy required for separation. The process minimizes the total digester volume while maximizing the conversion of waste to gas and soluble products. A maximum SRT/HRT ratio is obtained. Figure 1, below presents the process.

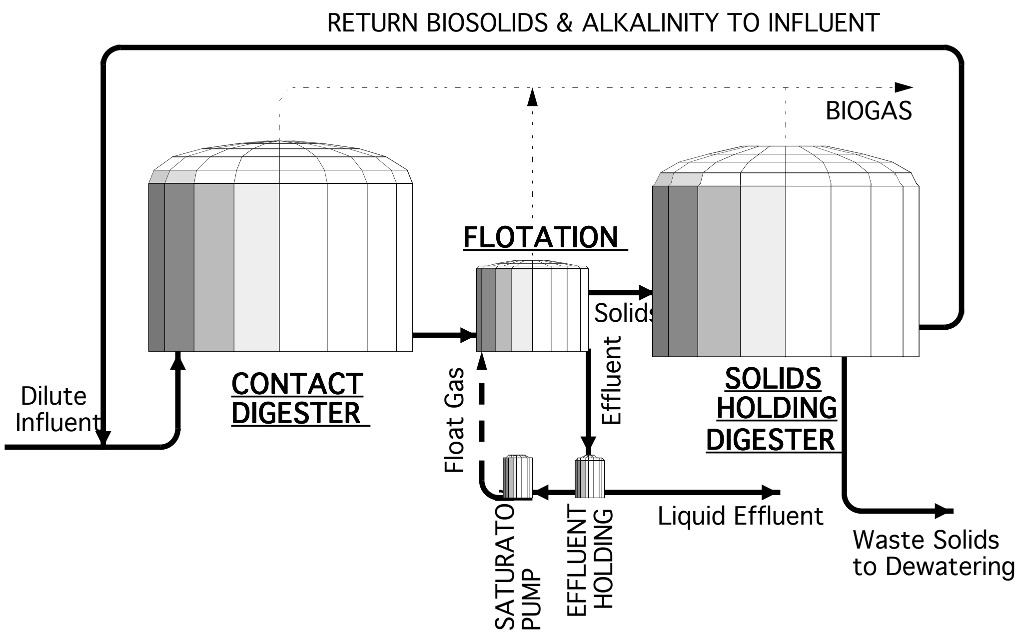

FIGURE 1. AGF STABILIZATION PROCESS

PILOT INVESTIGATIONS

The AGF Stabilization process offered the potential of treating raw potato waste, having high concentrations of suspended solids and oil and grease, without neutralization chemicals, while exporting the waste as methane gas. Since the process produced a clear effluent, the potential existed for nitrogen recovery as an inorganic fertilizer while producing a limited quantity of waste organic biosolids.

During 1996 and early 1997, the Idaho Association of Commerce and Industry, the U.S. Department of Energy, and a consortium of potato processing firms including; the J.R. Simplot Company, Ore Ida Foods, Idaho Supreme Potatoes, Nonpareil, and Pillsbury, funded two pilot plant investigations to document the performance of the AGF Stabilization Process. The first pilot plant treated french fry potato waste from the J.R. Simplot potato processing plant in Caldwell, Idaho from April 14 to September 11, 1996. Western Environmental Engineers operated the pilot plant while the J.R. Simplot Company performed the laboratory analysis of all process waste streams. The second pilot plant treated potato dehydration process waste from the Idaho Supreme Potato's processing plant in Firth, Idaho from November 14, 1996 to February 19, 1997. Idaho Supreme Potatoes and Cyclus EnviroSystems jointly operated the plant and performed the physical and chemical analysis.

A schematic of the pilot plant is shown in Figure 2 below. The pilot plant included a small nutrient removal device for recovering nitrogen from the effluent which is not shown in the schematic.

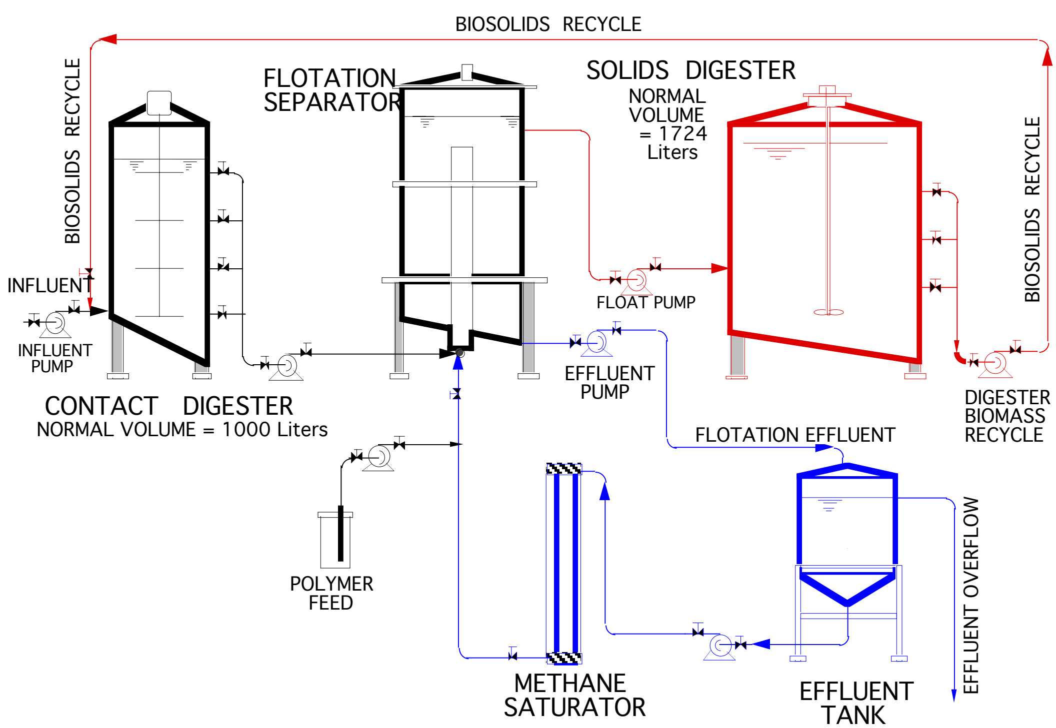

FIGURE 2. PILOT PLANT SCHEMATIC

The pilot plant consisted of a baffled plug flow contact reactor, a completely mixed solids holding digester and an AGF separator. The contact digester had a maximum working volume of 1.0 m^3 gallons. The influent waste was mixed with return flow from the solids holding digester. Anaerobic degradation of the soluble COD and the easily degradable particulate COD occurred within the contact digester. The quantity of biomass returned from the solids digester to the influent stream must be sufficient to accomplish the task of degrading the COD without depressing the pH of the contact reactor to values below 6.5. Sufficient alkalinity must be obtained to buffer the organic acids produced during degradation. A large methanogen population will assist in controlling the pH by rapidly removing the organic acids. The biomass which is recycled from the solids holding digester to the contact digester must be sufficient to provide the microorganism to food ratios required. Values between 4 and 6 g/g COD were used to treat the dehydration potato waste, while values as high as 10 g/g of total COD were used for the french fry waste.

After substantial digestion of the inţuent soluble waste within the contact reactor, the waste is transferred to the ţotation separator. The biomass and undigested solids are concentrated in the separator “ţoat”. The pilot plant ţotation separator had a volume of 1400 m^{3} and a surface area of 1.0 m^2. The ţotation unit was much larger than necessary when compared to the other processing units. Consequently, the ţotation unit performance was never taxed during the pilot operation.

The liquid efţuent from the separator was transferred to the efţuent holding tank. A portion of the efţuent was returned to the ţotation separator to provide the dissolved gas, and solids elutriation within the separator. The remaining efţuent was discharged to an inorganic nutrient removal process. The solids which were concentrated in the ţotation separator were pumped to the solids holding digester and subsequently returned to the contact reactor. The solids holding digester had a working volume of 1.985 m^3 while treating french fry waste, and an volume of 1.758 m^3 while treating potato dehydration waste.

WASTE CHARACTERISTICS

Physical chemical analysis of each process ţow stream was performed daily. The average characteristics for the french fry and potato dehydration waste are presented in the Table 1 below. The values presented in Table 1 were average throughout the operating periods.

TABLE 1. INFLUENT WASTE CHARACTERISTICS

PARAMETER	FRENCH-FRY POTATO WASTE	DEHYDRATION POTATO WASTE
Temperature (°C)	32.2	33.8
pH (units)	6.2	5.9
COD (mg/L)	4,375	12,121
SCOD (mg/L)	1,941	
PCOD (mg/L)	2,434	
Total Solids (mg/L)	3,852	11,420
Volatile Solids (mg/L)	2,738	8,382
Fixed Solids (mg/L)	1,114	3,038
Volatile Solids (%)	71	73.4
Total Suspended Solids (mg/L)	1,686	3,642
Total Dissolved Solids (mg/L)	2,166	
Total Nitrogen (mg/L)	103	787
Ammonia (mg/L)	28.3	83
Organic Nitrogen (mg/L)	74.7	704
Total Phosphorus (mg/L)	28.5	131
Ortho- Phosphorus (mg/L)	13.7	110
Part. Phosphorus (mg/L)	14.8	21

The raw french-fry waste was approximately 55% particulate COD. Oil and grease was observed in the waste, but was not analyzed. The volatile solids content of the waste averaged 72 percent of the total solids. The inorganic solids were primarily dissolved solids. At times, the COD of the dehydration waste exceeded

15,000 mg/L. The influent pH values were as low as 4.5. Influent temperatures varied from a low of 27°C to a high of 40°C.

PILOT PLANT OPERATION

During the treatment of french-fry waste there were three distinct operating periods. Eleven operating periods were used while treating the potato dehydration waste. The operating periods were characterized as times when the influent waste characteristics, or flow was distinctly different from other operating periods. Each operating period lasted one or more weeks. Table 2 below, presents the maximum, minimum, and average operating conditions for both pilot operations.

TABLE 2. RANGE OF OPERATING CONDITIONS

OPERATING PERIOD	HRT Contact Reactor (days)	HRT Solids Digester (days)	Eq. HRT[a] Contact Reactor (days)	Eq. HRT[b] Both Reactors (days)
French Fry Maximum	0.35	1.07	0.817	0.45
French Fry Minimum	0.107	0.34	0.23	1.43
French Fry Average	***0.27***	***0.76***	***0.70***	***1.89***
Dehydration Maximum	0.44	1.61	0.83	2.29
Dehydration Minimum	0.13	0.5	0.23	0.6
Dehydration Average	***0.26***	***0.90***	***0.53***	***1.46***

a. Equivalent HRT is based on influent flow alone and is not the actual detention time.

b. Equivalent HRT is based on influent flow alone and is not the actual detention time.

During both pilot investigations, solids wasting was minimized. The solids concentration of the solids holding digester increased from 3.7% to 4.9% during the french-fry pilot operation. During the last week, 57 liters of 4.8% solids were wasted from the solids holding digester. The SRT of the french fry pilot operation exceeded 300 days. During the dehydration pilot investigation an average of 80 Liters of solids were wasted from the solids holding digester each week. The average SRT was 150 days. During the dehydration pilot operation, the total solids in the solids holding digester increased from 3.80 to 3.88%.

OPERATING RESULTS

The following is a summary of the important operating results.

pH Values . During the french-fry pilot operation, a small amount of magnesium oxide was used to maintain the pH of the contact reactor at 7.0 or above. During the dehydration waste pilot operation, no buffering agent was required. The pH in the contact reactor was maintained at 6.7 by recirculating adequate biomass. The pH of the solids holding digester was maintained at 7.1. Adequate alkalinity was created, and recirculated to maintain the neutral pH values.

Solids . The fixed solids were discharged with the effluent. Less than 6% of the fixed solids were retained in the process during both pilot operations. On average, 96% of the dehydration waste volatile solids, and 82% of the french fry volatile solids were converted to gas and soluble products.

Nitrogen. Ninety three, and ninety five percent of the organic nitrogen was converted to ammonia nitrogen in each pilot operation. Twenty four percent of the TKN in the french-fry waste, and 30% of the TKN in the dehydration waste accumulated in the system, or was removed with the waste solids. Some loss as gas in the flotation unit occurred.

Phosphorus . Twenty one percent, and thirty percent of the influent total phosphorus accumulated, or was wasted with the solids in each pilot operation. Eighty five percent of the organic phosphorus was converted to soluble ortho-phosphate and discharged with the effluent.

Nutrient Removal . Seventy to eighty percent of the total influent nitrogen, and total phosphorus were discharged from the anaerobic system as soluble ammonia and ortho-phosphate. A nutrient removal device was installed on the effluent line to recover the nitrogen and phosphorus as struvive ($Mg\ NH_4\ PO_4.6\ H_2O$). The pH was increased from an average of 7.2 to 8.8. Seventy five percent of the total phosphorus was removed with the struvite during the pilot operation. Additional phosphate and nitrogen were removed during various trials, provided magnesium was added to the effluent.

Chemical Oxygen Demand. An average of 94% of the total COD and 98% of the particulate COD was reduced during the french-fry pilot investigations. The COD reductions achieved were directly related to the volumetric loading rate. Figure 3 below, presents the COD reductions as a function of the volumetric loading rate for the dehydration waste pilot operation. Two relationships are presented Figure 3. The first predicts the percent COD reduction based on the loading to the contact reactor. The second predicts the COD reduction based on the loading to the entire process.

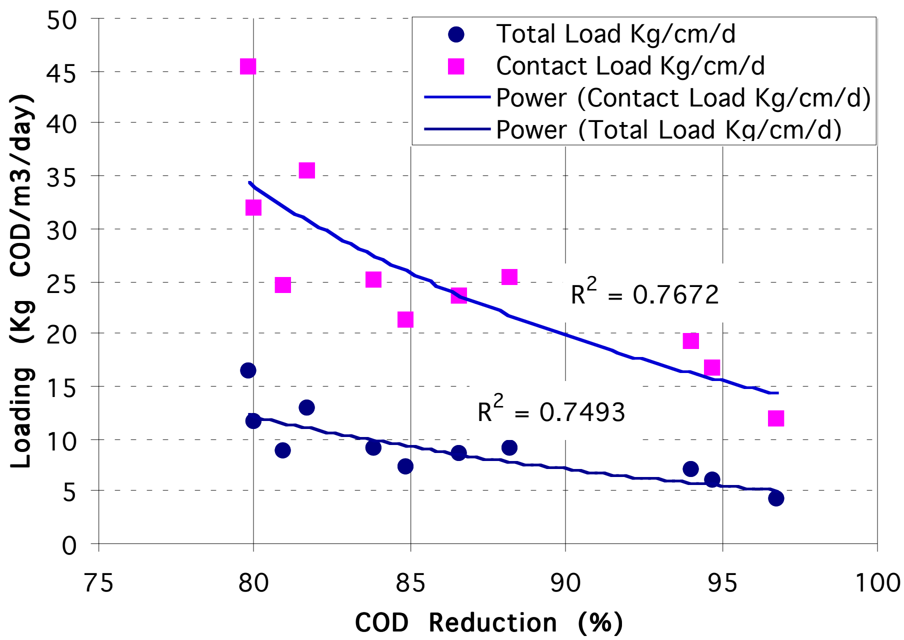

FIGURE 3. COD REDUCTIONS RELATED TO LOADING

It should be noted that the COD reduction is more sensitive to the contact reactor loading. Consequently, the contact reactor loading will be the controlling factor in the design. The hydraulic retention time of the digester must be doubled to increase the COD reduction from 80% to greater than 95%.

Gas Quality and Quantity . Biogas quality was documented during the dehydration waste pilot operation. The carbon dioxide concentration of the gas from the contact reactor averaged 43.25%, whereas the carbon dioxide concentration of the gas from the solids digester was 32.6%. The hydrogen sulfide concentration was much higher in the contact reactor. The hydrogen sulfide concentration in the contact reactor's gas averaged 2,560 mg/L as opposed to the solids holding digester's gas which had a lower concentration of 1,660 mg/L. Both values were very high when compared to other substrates of equal strength.

The gas production was monitored throughout each day. The specific methane production values were only 70% of the theoretical maximum. This was partially due to the fact that methane gas production was not measured in the flotation unit, dissolved methane gas was lost in the effluent, and a significant amount of the COD substrate was used to produce the large quantities of hydrogen sulfide.

The quantity of methane gas produced by the solids digester varied with the organic loading. At high loadings a larger percentage of methane gas was produced by the stabilization digester. During high loadings, organic material that was not degraded in the contact reactor, was removed by the separator and degraded in the solids holding digester. For dehydration waste, approximately 50% of the methane gas was produced in the solids holding digester at an organic loading of 30 Kg/m^3/day. At lower loadings, a larger percentage of the methane gas was produced in the contact reactor.

CONCLUSIONS

The pilot plants were operated successfully for 7 months. During that time, it was established that the volumetric loading was the primary determinant of the COD reductions and effluent quality achieved. To achieve COD reductions greater than 95%, the contact reactor volumetric loading must be less than 15 Kg/m^3/day. For COD reductions greater than 95%, the *total process* volumetric loading must be less than, or equal to 5 Kg/m^3/day. Doubling the loading decreases the COD reduction from 97% to 80%. Particulate COD was digested with the same efficiency as soluble COD.

Chemicals are not required to adjust influent pH. Since the process is controlled by *loading*, recycling a portion of the treated effluent, or contact digester effluent, to improve the influent pH can be used if necessary.

Struvite ($Mg\ NH_4\ PO_4.6\ H_2O$) can be economically recovered from the effluent to achieve substantial reductions of phosphate. Addition of phosphate and magnesium can result in substantial nitrogen reductions.

REFERENCES

Brockmann, M., Seyfried, C.F. (1996). Sludge Activity and Cross-Flow Microfiltration - A Non-Beneficial Relationship, Wat.Sci.Tech., 34(9). 205-213

Burke, D.A. (1991). U.S. Patent Number 5,015,384

Burke, D.A. (1992). Sewage Sludge Digestion Utilizing the AGF Process. Proceedings the WEF Specialty Conference Series: The Future Direction of Municipal Sludge (Biosolids) Management

Burke, D.A. (1996). Improved Biosolids Digestion Utilizing Anoxic Gas Flotation. Proceedings WEFTEC, 1996

Parkin, Gene F., Owen, William F (1986), Fundamentals of Anaerobic Digestion of Waste Sludges. Journal of Environmental Engineering, 112 (5). 867-920