An ASAE/CSAE Meeting Presentation

Paper Number: 044058

Utilization of Brick Plant Air Scrubber By-product to Enhance Settling and pH Adjustment of Anaerobic Dairy Lagoon Sludge

Carla N. Thomas, Graduate Student, Institute of Environmental Toxicology, Clemson University, Clemson, SC. ncarla@clemson.edu
J. P. Chastain, Ph.D., Associate Professor, Department of Agricultural and Biological Engineering, Clemson University, jchstn@clemson.edu
T. O. Owino, Ph.D., Assistant Professor, Clemson University, Department of Agricultural and Biological Engineering, towino@clemson.edu
W. L. Bauerle, Ph.D., Assistant Professor, Clemson University, Department of Horticulture, bauerle@clemson.edu
K. P. Moore, Ph.D., Director, Clemson University, Agricultural Service Laboratory, kmr@clemson.edu

Written for presentation at the
2004 ASAE/CSAE Annual International Meeting
Sponsored by ASAE/CSAE
Fairmont Chateau Laurier, The Westin, Government Centre
Ottawa, Ontario, Canada
1 - 4 August 2004

Abstract. *There is increasing interest in the development of alternative methods of handling municipal and agricultural wastes. The chemical characteristics of the by-product generated by scrubbing stacks of brick plants (scrubber by-product) suggests that this material would be an effective chemical agent to enhance pathogen control and partitioning of solids and nutrients. Studies were conducted to evaluate the effectiveness of using brick scrubber by-product as a chemical agent for enhancing settling, nutrient removal, and pH adjustment of sludge. Sludge samples used in this study were obtained from the Clemson University Dairy Farm lagoon. Various amounts of scrubber by-product were added to approximately 1 L aliquots (influent samples) to produce treatments with scrubber by-product concentrations between 20 and 172 g/L. Electrical conductivity and pH determinations were made for each treatment. The effect of scrubber by-product on settling time and sludge thickening was investigated for each treatment by recording the volume of sludge settling over time in graduated cylinders. Supernatant from each treatment (effluent sample) was analyzed for solids and nutrients, and removal efficiencies were computed from a comparison of the constituents in the influent and effluent samples. An equilibrium pH of 11.4 was achieved at a scrubber by-product concentration of 85 g/L, providing 95% of the required pH adjustment for pathogen control. The volume of settled solids did not differ among treatments between 0 and 85 g/L scrubber by-product. Scrubber by-product enhanced removal of Organic-Nitrogen, Total Ammoniacal-Nitrogen, Total P, Fe, Cu, Zn, and Mn from dairy lagoon sludge.*

Keywords. Sludge treatment, Air scrubber by-product, pathogen treatment, pH adjustment

INTRODUCTION

In compliance with the 1990 Clean Air Act mandates, brick manufacturing facilities are equipped with scrubber systems to mitigate the emission of acid gases from their exhausts. One type of scrubber widely employed by brick plants is the dry scrubber system. This system utilizes limestone or hydrated lime as a neutralizing reagent for acid gases. The reaction product is collected in a baghouse. This by-product of the scrubbing process must be disposed of or utilized appropriately. Disposal in landfills is currently the principal method of getting rid of this solid waste; however the chemical characteristics of this material suggest that environmentally and economically plausible alternate utilization strategies are possible.

Precipitation, flocculation, settling, and pathogen control are important processes in the treatment of sludge from municipal, food processing, and agricultural waste. Sludge dewatering processes, such as gravity thickening or drying beds, are conventionally used to reduce transportation cost of the material and to concentrate valuable plant nutrients. In many cases, sludge treatment, handling, and transport are the most expensive aspects of waste treatment (GeneSyst, International Inc., 2001). Therefore, a lower cost dewatering system would be useful in any type of waste treatment system. The chemical characteristics of scrubber by-product suggest that it has the potential to be utilized as a precipitant or flocculant as well as a chemical agent in the control of pathogens in wastewater treatment processes. The present study was conducted to evaluate the potential of using scrubber by-product in the treatment of anaerobic lagoon sludge.

BACKGROUND

Anaerobic treatment, using a lagoon, is a common practice on modern dairy and swine farms in the Southeastern U.S. Most of the anaerobic sludge generated from these systems is applied to cropland. A cost-effective method to dewater anaerobic sludge produced on animal farms would greatly reduce the cost of sludge management.

Physical treatment methods have long been used in livestock waste management. Settling under gravity is a primary physical process that is used to treat animal waste. Although this method facilitates solids-liquids separation, only low amounts of some nutrients are removed by this process. One approach to treating wastewater involves the use of precipitants and flocculants such as salts of aluminum, iron, and calcium. Studies have shown that chemical treatment using precipitants and flocculants are more effective in enhancing nutrient and solids removal (Duan and Gregory, 2002; Chastain *et al.*, 2001; Omoike and Vanloon, 1999). These methods, however, can be expensive. It is hypothesized that some of the elements in scrubber by-product will enhance the gravity settling process in the same way as the more expensive chemicals.

The precipitation of most metals from animal waste requires an elevated pH (Morel and Hering, 1993; Stumm and Morgan, 1996; Szpak *et al*., 1996). This elevated pH can be attained with the use of scrubber by-product due to its alkaline nature. The calcium, aluminum, and iron content of the scrubber by-product would also facilitate coagulation of colloids and dissolved organic substances.

Several methods have been developed to kill or inactivate pathogens in sludge. One method utilizes the elevation of sludge pH to 12 over stipulated time periods (European Communities, 2001). It is postulated that the elevated pH conferred to sludge by the scrubber by-product will be useful in pathogen control.

MATERIALS AND METHODS

Sludge Collection

The sludge used in this study was collected from a lagoon at the Clemson University Dairy Farm. The farm facilities provided housing for 140 cows and include narrow open-sided freestall barns with separate feeding in an outside concrete lot. The stalls were bedded with modest amounts of organic bedding. Stalls and feed area alleys were flushed 1 to 2 times per day and the floors and holding parlors were cleaned by flushing 2 to 3 times per day. Rainwater from roofs and alleys as well as flushed manure from the stalls and milking center were conveyed to a treatment lagoon by gravity using concrete channels and a large pipe (46–61 cm).

Samples were collected from the lagoon using metal buckets with steel weights attached to one side to facilitate submergence of the bucket. Each bucket had a rope attached to the handle. Sludge samples were collected by throwing the bucket out into the lagoon and slowly pulling it to the bank after it had sunk to the bottom. Several samples were collected in this manner and pooled in plastic buckets. Lagoon supernatant samples were also collected to dilute the sludge samples. All samples were transported to Clemson University and refrigerated at 4 ºC until required for use.

Sludge and Scrubber By-product Characterization

The sludge samples collected from the lagoon were thoroughly homogenized using a heavy-duty drill and a large mixing paddle. Representative aliquots were removed using a 1 L long handled sampling cup. Care was taken to remove the aliquots while the sludge was being well mixed to prevent settling of the solids. Samples were analyzed to determine the concentration of the following constituents: Total Solids (TS), Volatile Solids (VS), Total Kjeldhal Nitrogen (TKN), Total Ammoniacal Nitrogen (TAN), Nitrate Nitrogen (NO_3-N) Total Phosphorus (P_2O_5), Total Potassium (K_2O), Ca, Mg, S, Zn, Cu, Mn, Na, Cl, Fe, Al, and B. Chemical analyses were done by the Agricultural Service Laboratory at Clemson University. The concentrations of the principal constituents in replicate samples of the dairy sludge are presented in Table 1.

Total solids and volatile solids of the sludge samples were determined in the Research Laboratory of the Department of Agricultural and Biological Engineering at Clemson University using standard techniques (APHA, 1995). Total solids concentration was determined by mixing samples of sludge in a beaker using a magnetic stirrer. Sub-samples (25 – 35 mL) were quickly decanted while mixing into pre-weighed porcelain crucibles. The crucibles were placed in a drying oven set at 105 ºC for 18 to 24 h. The samples were then allowed to cool in a desiccator after which the mass of the containers were determined and TS values were computed. The dry solids were incinerated in a furnace held at 550 to 600 ºC for 1 hr after which they were cooled and held in a desiccator until they were weighed. The container was again weighed and the mass of VS was determined as the difference between total and fixed solids. Determinations of TS and VS were done in duplicates. Following TS and VS measurements, the sludge samples were diluted appropriately with lagoon supernatant to attain a TS of approximately 30 g/L.

Air scrubber by-product was obtained as a powder from a brick manufacturing plant. Samples of the powder were analyzed by the Agricultural Service Laboratory and Soil Chemistry Laboratory at Clemson University for the following constituents: NO_3–N, TKN, P, S, Mg, Cu, Zn, Mn, Ca, Se, Al, Fe, Ni, Pb, Cr, B, Be, Co, As, Cd, Na, and Cl. Concentrations of the defined constituents of the scrubber by-product are presented in Table 2.

Table 1. **Concentrations of constituents (mg/L) in dairy lagoon sludge**.

Constituent	Rep 1	Rep 2	Rep 3
TS	31500	54450	28230
VS	21640	38491	1994
TKN	1220	2020	1170
TAN	250	240	260
Org-N	970	1780	910
NO_3-N	0	2	0.55
P_2O_5	884	1658	795
Sol-P	3	14	5
K_2O	402	489	360
Ca	972	1887	858
Mg	216	375	178
Cu	7.7	11.93	6.64
Mn	15.73	30	13.87
Na	89.75	105.92	78.1
Fe	278.11	523.06	246.03
B	1.19	3.19	0.62
Cl	2100	0	69000
Al	400.41	517	380.7
S	351	642	308
Zn	16.56	31.42	15.89

pH Adjustment of sludge Using Scrubber By-product

Various amounts of scrubber by-product were added to aliquots of diluted sludge samples to produce four treatments with scrubber by-product concentrations raging between 20 and 172 g/L. The mixture was thoroughly homogenized and measurements of pH along with electrical conductivities were taken for each treatment. A control without scrubber by-product was also included. The experiment was performed in triplicate to provide 3 replications for each treatment. Different scrubber by-product concentrations were obtained for each replicate treatment due to variations in influent sludge volumes. The treatments for each replicate however ranged between 20 and 172 g of scrubber by-product/L of dairy sludge.

Gravity Settling

Diluted lagoon sludge samples were thoroughly mixed in 5 gallon plastic buckets using a heavy-duty drill and mixing paddle. Sub-samples (approximately 500 mL) were removed for solids and nutrients analysis while the sludge was being homogenized to prevent settling of the solids. About 1 L of well mixed sludge (influent samples) was removed and quickly decanted into a 2 L plastic beaker. Pre-weighed quantities of the scrubber by-product were added to each ≈1 L aliquot to produce four treatments ranging between 20 and 172 g scrubber by-product/L sludge. The scrubber by-product was completely mixed into the sludge and each treatment was immediately decanted into 1 L graduated cylinders (Fig.1). A control treatment without scrubber by-product was also included. It was not possible to use exactly 1 L for each replication of each treatment since addition of small amounts of the influent sludge would induce a bias due to settling of solids. Therefore, the volume used was measured and the scrubber by-product application rate (g/L) was adjusted accordingly.

Table 2. Concentrations of plant nutrients and metals in brick air scrubber by-product.

Constituent	Mean mg/kg	*std mg/kg	**mg/kg Dry Matter	lb/ton
NO_3-N	563	125	568	1.127
TKN	1100	100	1110	2.200
P	57	48	57.5	0.113
K	900	100	908	1.800
S	135783	7458	137030	271.6
Mg	7483	1769	7552	14.97
Cu	6.2	6	6.3	0.012
Zn	18.3	10	18.5	0.037
Mn	25.1	5	25.3	0.050
Ca	321000	64131	323948	642.0
Se	62.3	4	62.9	0.125
Al	3535	1606	3568	7.070
Fe	1848	244	1865	3.696
Ni	8.43	7	8.51	0.017
Pb	5.4	2	5.45	0.011
Cr	6.64	3	6.70	0.013
B	38.6	15	39.0	0.077
Be	0.25	0.02	0.252	0.000
Co	9.5	0.2	9.6	0.019
As	34.2	13	34.5	0.068
Cd	0.32	0.03	0.323	0.001
Na	451	63	455	0.901
Cl	19367	2519	19545	38.73

*Standard deviation

* *moisture content = 0.91%

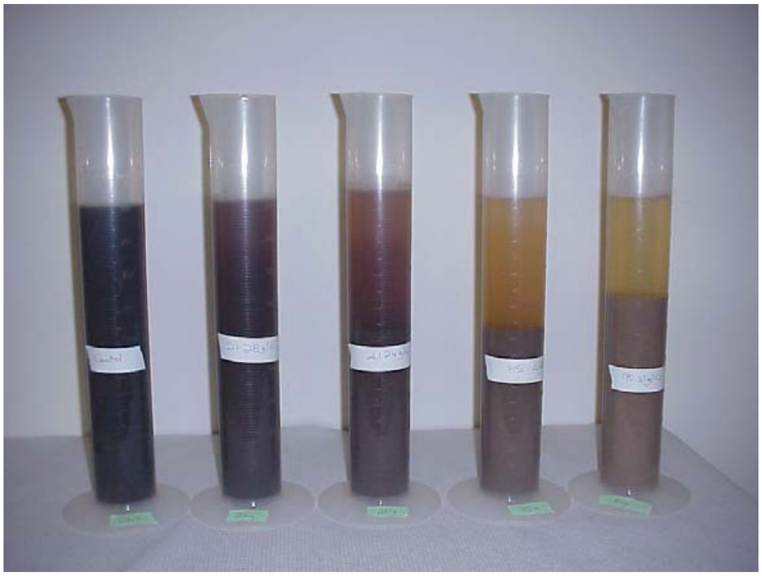

Fig.1. Gravity settling of dairy lagoon sludge

The initial time and actual volume of the sludge/scrubber by-product mixture in each cylinder was recorded. The volume of material settled over time was recorded until no further change in volume was apparent. The procedure was replicated three times. The volume of solids settling over time was normalized with respect to the initial volume and expressed as:

$$NSV = V_s/V_i. \quad (1)$$

Where,

NSV = normalized settled volume,

V_s = Settled Volume, and

V_i = Initial Volume.

This ratio was plotted as a function of time elapsed.

Solids and Nutrients Removal Efficiencies

Following gravity settling, the supernatant (effluent) from each treatment cylinder was decanted and analyzed for solids and principal constituents using procedures as for influent samples. The removal efficiencies for each constituent was determined using the following relationship:

$$RE_J = 100\ ([\ j\ ]_{IN} – [\ j\ ]_{OUT} / [\ j\ ]_{IN}).$$

(2)

Where,

RE_J = Removal Efficiency of j^{th} constituent

$[\ j\ ]_{IN}$ = Influent Concentration of j^{th} constituent, and

$[\ j\ ]_{OUT}$ = Effluent concentration of j^{th} constituent.

RESULTS AND DISCUSSION

pH Adjustment of Sludge using Scrubber By-product

The influence of scrubber by-product application on pH of dairy lagoon sludge is depicted in Fig. 2. The pH of the mixture gradually increased with successive additions of scrubber by-product. A pH of 11.4 was achieved at a scrubber by-product concentration of 85 g/L. Further increase in the amount of by-product to 172 g/L elevated the pH by only 1.8% (pH = 11.6). Therefore, addition of 85 g of scrubber by-product per L of anaerobic sludge will provide 95% of the required pH adjustment for pathogen treatment (pH 12). This suggests that scrubber by-product may reduce the cost of lime for pathogen treatment since addition of only a small amount of lime would be needed to achieve the required pH of 12.

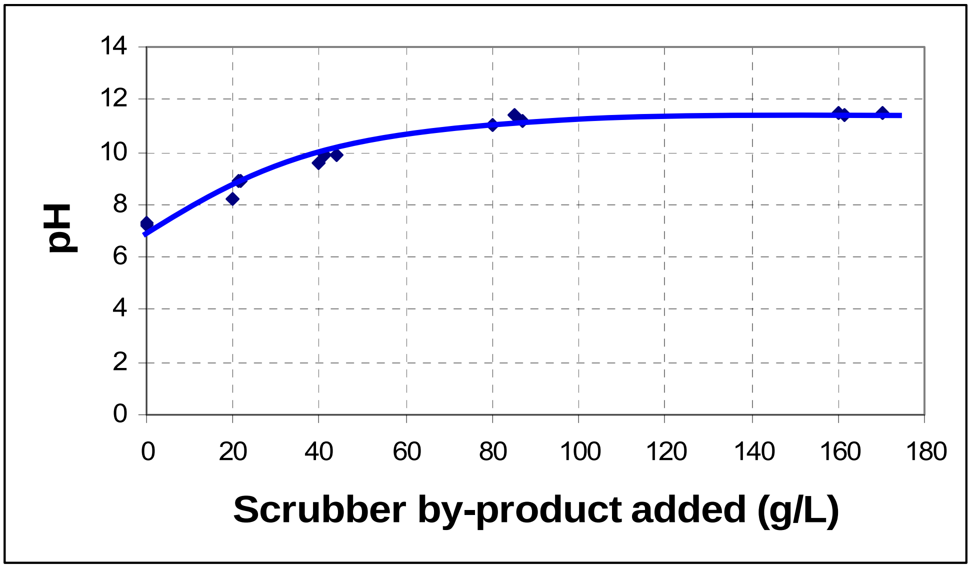

Fig. 2. ***Effect of scrubber by-product on pH of anaerobic dairy lagoon sludge*.**

Gravity Settling

The influence of adding 0 to 165.9 g of scrubber by-product per L on the normalized settled volume with respect to time is given in Table 3. The data given in the table indicate that there were no differences in the volumes of material settled over time for treatment levels between 0 and 86 g/L of scrubber by-product. However, at the highest treatment level (165.9 g/L) the settled solids occupied a significantly greater volume.

Table 3. **Effect of scrubber by-product on gravity thickening of anaerobic dairy lagoon sludge.**

Amount of Scrubber By-product Added (g/L)	Thickening Time				
	1 hr	5 hr	10 hr	20 hr	25 hr
	Normalized Settled Volume - V_S/V_i				
0	0.70	0.57	0.55	0.54	0.54
21.5	0.78	0.70	0.62	0.60	0.60
42.6	0.69	0.69	0.57	0.55	0.55
86.0	0.72	0.70	0.62	0.60	0.60
165.9	0.92	0.83	0.79	0.75	0.75

Solids and Nutrients Removal

Table 4 presents removal efficiencies for the major constituents of dairy lagoon sludge. These values were computed based on the difference between influent and supernatant concentrations for the analyzed constituents (equation 2). The results indicate that the removal efficiencies of organic nitrogen (Org-N), Cu, Mn, Zn, total P (expressed as P_2O_5), Fe, Al, and total ammoniacal nitrogen (TAN) were enhanced by adding scrubber by-product to anaerobic dairy lagoon sludge. Lower removal efficiencies were obtained for TS, K, B, S, and Ca for treated sludge compared with untreated sludge. This decrease in removal efficiencies is indicative of the introduction of these constituents to the sludge solution by the scrubber by-product (Table 2). These results indicate that the addition of scrubber by-product can significantly enhance the removal of major and minor plant nutrients by gravity settling.

Table 4. **Removal efficiencies (%) for dairy lagoon sludge treated with scrubber by-product (g/L).**

	Concentration of Scrubber By-Product (g/L)						
Constituent	**0**	**20**	**40**	**80**	**100**	**120**	**160**
TS	83.8	78.3	72.8	61.7	56.2	50.7	39.7
TAN	12.5	14.5	16.5	20.5	22.5	24.5	28.5
Org-N	85.1	97.6	97.6	97.6	97.6	97.6	97.6
$P_{□}O_5$	77.2	95.6	95.6	95.6	95.6	95.6	95.6
K_2O	10.2	6.5	2.7	-4.7	-8.5	-12.2	-19.7
B	0.5	48.0	68.7	29.4	-30.6	-117.5	-372.0
Ca	80.5	-60.2	-105.7	-196.7	-242.2	-287.6	-378.6
Mg	74.5	87.7	87.7	87.7	87.7	87.7	87.7
Mn	87.6	96.8	96.8	96.8	96.8	96.8	96.8
Fe	92.6	98.8	98.8	98.8	98.8	98.8	98.8
Al	91.6	99.3	99.3	99.3	99.3	99.3	99.3
Zn	86.7	99.0	99.0	99.0	99.0	99.0	99.0
Cu	-	97.7	98.6	99.1	99.2	99.3	99.4
S	100	92.2	88.2	82.3	79.8	77.5	73.3

CONCLUSION

- The present study demonstrates that scrubber by-product is capable of increasing the pH of sludge from an animal waste lagoon considerably and may be an effective agent in pathogen control.
- The addition of scrubber by-product at an optimal rate of 85 g/L did not adversely affect the settling and thickening of sludge.
- Scrubber by-product enhanced the removal of (Org-N), Cu, Mn, Zn, total P (P_2O_5), Fe, Al, and total ammoniacal nitrogen (TAN) from dairy lagoon sludge.

ACKNOWLEDGEMENT

The authors would like to thank the personnel at Lamaster's Dairy Farm of Clemson University. Funding for this work was provided by the National Brick Research Center.

REFERENCES

APHA. 19TH Ed. 1995. *Standard Methods for the Examination of Water and Wastewater*, eds. A.D. Eaton, L.S. Clesceri, and A. E. Greenberg, Washington, D.C.: American Public Health Association.

Chastain, J.P., M.B. Vanotti, and M.M. Wingfield. 2001. Effectiveness of liquid-solid separation for treatment of flushed dairy manure: A case study. *Applied Eng. in Agric*. 17(3): 343-354.

Duan, J. and J. Gregory. 2003. Coagulation by hydrolyzing metal salts. *Adv.Colloid Interface Sci*. 100(102): 475-502.

Europian Community 2001. Evaluation of sludge treatments for pathogen reduction – final report. Study Contract No B4-3040/2001/322179/MAR/A2 for the European Commission Directorate-General Environment. Available at http://europa.eu.int. Accessed 26 April 2004.

GeneSyst, International Inc. 2001. A Market Analysis: Costs analysis for sludge disposal alternatives and components. Available at http://www.genesyst.com. Accessed 26 April 2004.

Morel, F.M.M. and J.G. Hering. 1993. Principles and Applications of Aquatic Chemistry. Wiley-Interscience.

Omoike, A. I. and G.W. Vanloon. 1999. Removal of phosphorus and organic matter removal by alum during wastewater treatment. *Wat. Res.*. 33(17): 3617-3627.

Stumm. W. and J.J. Morgan. 1996. Aquatic Chemistry. 3rd ed. John Wiley and Sons.