Vol.45, n. 3 : pp. 385-392, September 2002
ISSN 1516-8913 Printed in Brazil

BRAZILIAN ARCHIVES OF BIOLOGY AND TECHNOLOGY

A N I N T E R N A T I O N A L J O U R N A L

Modelling and Optimisation of Stabilisation Ponds System for the Treatment of Swine Wastes: Organic Matter Evaluation

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ABSTRACT

The fast increase of the swine production, specially in the west region of Santa Catarina, Brazil, did not have a parallel program for the valorisation of its dejection, not even processes for the treatment of the organic residues. Most of the producers keep their animals confined in small areas, having as a consequence the production of a large volume of wastes in the same place. This waste is diluted in water used to clean the bays, resulting in contamination of the watercourse. Thus, it is necessary to develop treatment processes to minimise the environmental problems caused by the swine breeding activities. The stabilisation ponds have been used due to its excellent efficiency in the removal of the organic matters, solids, nutrients and faecal coliforms; besides the low implantation and maintenance costs. This work was assisted in a series of four stabilisation ponds, real scale, treating swine wastes in Concórdia/SC at CNPSA. The ponds system was evaluated during a period of 20 months, objecting to get its principal work parameters, as well as information about the capital and operational costs, in order to adjust the equations to model and optimise the systems about the removal of the organic matters.

Key words: Stabilisation ponds, swine wastes, costs, models, optimisation

INTRODUCTION

The swine wastes treatment systems have a great sanitary importance, because due to fast increased, in the swine breeding activity particularly in small areas production of manure has increase, which is highly pollutant and causes environmental degradations. The volume of waste produced in the farms, which is rich in nutrients such as nitrogen and phosphorus, most of times is not used to fertilise the land, because breeders do not have enough area to absorb all the wastes produced.

Santa Catarina, which has the estimated number of 3.8 of swine (Suinocultura Industrial, 1997), presents a critical situation, specially in the west region, where the swine production corresponds to 17.7% of the national herd. Thus, through the modernisation of the swine confinement systems, there was an increase in the use of water to clean the bays. The purpose of using water is to dilute the faeces and urine concentrations and treat them as liquid residues, making them easy to manipulate. Andreadakis (1992) reported that it was probable that the dilution was not always available because it increased the volume of

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residue and could represent difficulties in the treatment.

The swine wastes treatment processes are more diverse. Nevertheless, among the technologies used in the region, stabilisation ponds have been utilised with more frequency by medium and great producers for being a simple procedure with low operational cost and good efficiency, specially where the climate conditions are propitious and the ground area is available.

This work presents results obtained from series of stabilisation ponds, during a period of 20 months, looking for the adjust of the cap ital and operational equations for the optimisation of system in economic conception, in order to remove the organic matter and utilise it in agriculture.

MATERIALS AND METHODS

The experimental pond system for the swine waste treatment was installed in *Centro Nacional de Pesquisas de Suínos e Aves – CNPSA, at Empresa Nacional de Pesquisa Agropecuária – EMBRAPA, Concórdia/SC, Brazil.* The system consisted of an tank followed by a slat decanter, two anaerobic ponds (AP1) and (AP2), a facultative pond (FP) and a water hyacinth pond (WHP), in real scale and continuous flux, disposed in series. Figure 1 presents schematically this system.

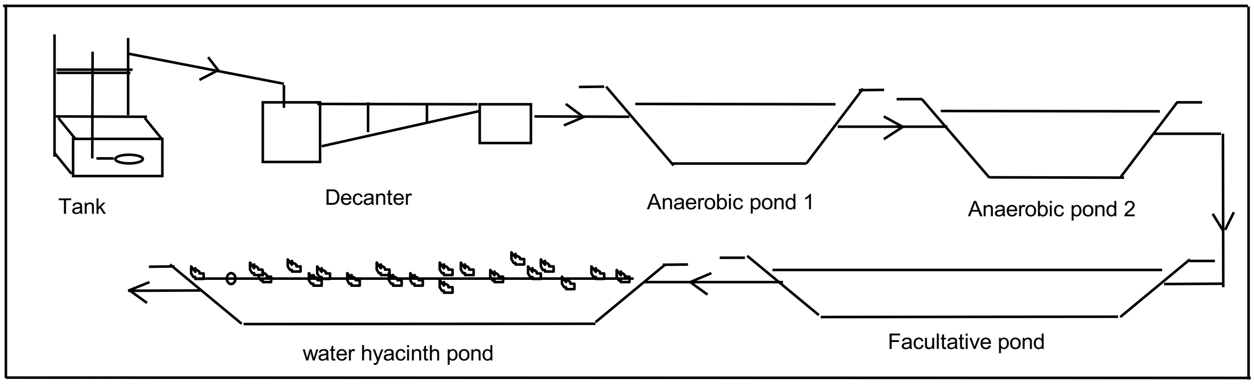

Figure 1 - Experimental system for the treatment of swine wastes

Physical and operational characteristics o f the ponds are presented in Table 1.

Table1 - Physical and operational characteristics of the ponds

Parameters		*AP1*	*AP2*	*FP*	*WHP*
Top surface	(m^2)	83.62	83.62	105.60	100.00
Bottom surface	(m^2)	44.50	44.50	67.60	46.00
Depth	(m)	1.70	2.20	0.85	0.80
Volume	(m^3)	106.40	137.70	73.00	58.00
Discharge	(m^3/d)	3.00	3.00	3.00	3.00
Retention time	(d)	35.00	46.00	24.00	19.30

Feeding System

The system was filled daily. Dejections of the bays of swine were transported to the tank at experimental unit. In the tank, the dejections were homogenised by a submerged bomb and driven to decanter with a rate of constant flow of approximately 20 litters/min, completing $3m^3$. These residues were sent by gravity to the anaerobic pond AP1.

Monitoring and Physico-Chemical Analysis

The experiment was carried out over the periods of January/96 to August/97 in pond AP1, and February, March and October of 1996 to August of 1997 in ponds AP2, FP and WHP respectively, after a initial phase stationary. The samples were collected weekly in the influents and effluents of each pond and samples for COD were collected twice a week and following parameters were determinate in each sample: pH, Total Solids (TS), Fixed Solids (FS), Volatile Solids (VS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Nitrogen (Nt), Total Phosphorus (Pt), Faecal Coliforms (FC) and Temperature according to "Standard Metho ds" (1992).

RESULTS AND DISCUSSION

The average, minimum and maximum values obtained from the treatment system at the "Experimental Unit of Treatment of Swine Wastes" of the CNPSA, are presented in Table 2.

It Can be seen that the carbonaceous pollution (BOD and COD) was removed about 78% in the primary anaerobic pond AP1, with 35 days. The secondary anaerobic pond AP2, which received effluents from AP1, had larger retention time, but the efficiency in the removal of the carbonaceous pollution decreased.

Table 2 - Results from the influents and effluents of each pond (total detention time = 125 days)

Average, Minimum and Maximum of		*influents and effluents of each pond*							
		AP1		*AP2*		*FP*		*WHP*	
		inf	*ef*	*inf*	*ef*	*inf*	*ef*	*inf*	*ef*
pH	Av.	7.0	7.4	7.4	7.7	7.7	7.8	7.8	7.7
	Min	6.2	6.8	6.7	6.7	6.7	6.8	6.8	6.8
	Max	7.9	8.1	7.9	8.3	8.3	8.4	8.4	8.9
BOD_5	Av.	8,304	1,833	2,137	778	831	435	454	213
(mg/l)	Min	3,000	758	1,100	347	350	100	140	70
	Max	13,500	3,067	3,067	1,450	1,450	700	650	750
COD	Av.	15,153	3,308	3,281	1,439	1,498	807	844	355
(mg/l)	Min	4,570	1,100	1,435	507	507	290	290	160
	Max	47,200	7,095	7,095	3,296	3,296	1,730	1,730	830
TS	Av.	9,950	4,773	4,660	3,266	3,391	2,254	2,512	1,320
(mg/l)	Min	3,788	3,193	3,170	940	940	1,247	1,400	229
	Max	26,660	10,254	10,254	5,284	5,284	3,224	3,224	2,400
FS	Av.	4,056	2,543	2,503	1,962	2,013	1,360	1,498	779
(mg/l)	Min	577	1,357	1,357	377	377	632	632	41
	Max	14,839	5,100	5,100	2,654	2,654	2,265	2,265	1,672
VS	Av.	5,894	2,230	2,156	1,305	1,378	894	1,014	541
(mg/l)	Min	1,670	897	897	563	563	448	568	188
	Max	21,127	5,154	5,154	3,879	3,879	2,006	2,006	1,144
Nt	Av.	1,825	1,409	1,424	970	1,005	413	420	173
(mg/l)	Min	850	888	888	563	597	150	150	57
	Max	3,931	3,790	3,790	1,324	1,324	702	667	328
Pt	Av.	391	140	141	67	69	48	56	26
(mg/l)	Min	70	27	27	21	30	20	24	9
	Max	896	780	780	121	121	97	97	53
FC	Av.	2.1E10	4.9E7	4.7E7	4.5E5	4.7E5	1.5E4	1.5E4	3.7E3
(MPN/100 ml)	Min	1.0E7	6.0E5	6.6E5	1.0E3	1.0E3	1.1E2	3.6E2	2.2E2
	Max	2.3E11	2.3E8	2.3E8	4.9E6	4.9E6	7.1E4	6.4E4	1.3E4

It could be explained by the fact that the remained pollution was more resistant to biodegradation.

Nitrogen was better removed in the facultative pond (FP), and the rem oval corresponded to 59% of the average values (varying between 45 and 75% for the minimum and maximum values). The pond with water hyacinth also contributed in a important way, removing about 58% from the average concentrations (varying between 50 and 58% for the minimum and maximum values).

About 64% of the phosphorus was removed in the first anaerobic pond AP1 from the initial average concentrations, while the entire anaerobic process (AP1 and AP2) removed 82% and the aerobic processes (FP and WHP) removed 62% of the remained Phosphorus from the anaerobic treatment.

In all, the treatment system removed 90% of the total nitrogen and 93% of the total phosphorus, what represented a very good index of removal for this type of wastes.

SYSTEM OPTIMISATION

In stabilisation ponds system, the optimisation consists in minimising the total cost, characterised by the sum of the capital and operational costs, which are inherent to the distribution of the organic charge of each pond (Meisheng et al., 1992; Kezhao, 1994) and obtain an adequate final effluent in terms of organic matter. According to Yang and Chen (1994), the costs involved are capital, and can be divided in land, construction, operational and maintenance costs. Thus it is necessary to obtain the model costs of earth, construction and pond maintenance. Besides these, this work presents the model cost of pond revetment and the efficiency models of organic matter.

Pond Efficiency

The average results obtained along the flow of each pond, at the "Experimental Unit of Treatment of Swine Wastes" of CNPSA seemed to be almost identical. So the degradation coefficient (k_i) of BOD for the ponds AP1, AP2, FP and WHP was determined, admitting the degradation rate through the first order kinetic and using the complete mixture model (Medri, 1997), although the geometric relation length/width that exists between them.

Considering the average concentration values of influents and effluents in terms of BOD of each pond, the mathematical models of efficiency for the ponds can be presented by the following equation:

$$E_i = \frac{k_i \, t_i}{1 + k_i \, t_i} \qquad (1)$$

where:

E_i is the removal efficiency of pond i;

t_i is the detention time , in day.

It was observed during the experiment that the organic matter (BOD and COD) was better removed in the anaerobic pond AP1 (about 78%). The removal of the ponds AP2 was 64%, FP was 48% and WHP was 53%, what added up 97% for the pond series.

Although the kinetic removal of BOD were the same for the anaerobic ponds AP1 and AP2 (first order kinetic), the higher was the concentration of BOD of the medium, the higher was the removal rate of BOD. The adjusted efficiency curves of the anaerobic ponds AP1 and AP2 are presented in Figures 2 and 3, and of the facultative ponds (FP) and with water hyacinth (WHP) are in Figures 4 and 5.

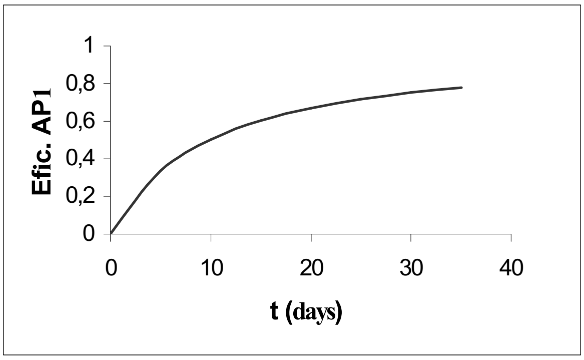

Figure 2 - Relation between the BOD efficiency and detention time in the pond AP1

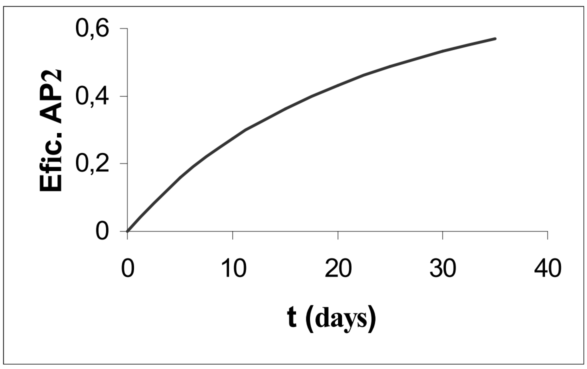

Figure 3 - Relation between the BOD efficiency and detention time in the pond AP2

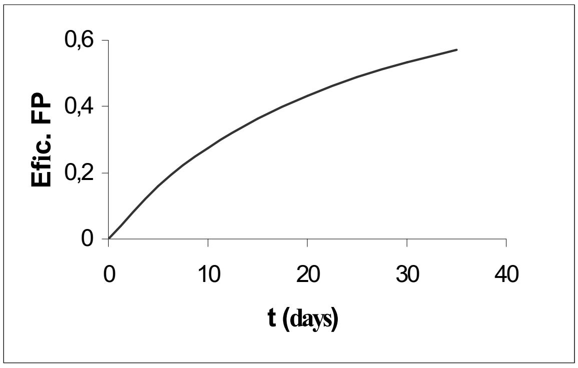

Figure 4 - Relation between the BOD efficiency and detention time in the pond FP

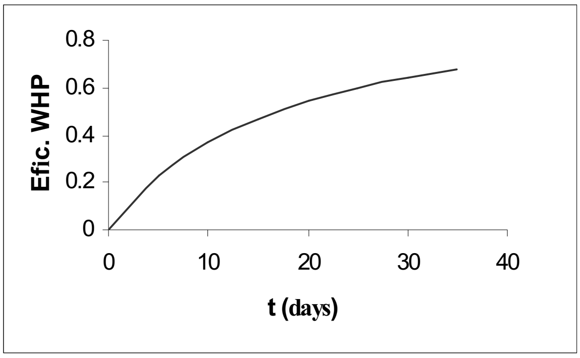

Figure 5 - Relation between the BOD efficiency and detention time in the pond WHP

Retention Time

The retention time of each stabilisation pond is expressed by:

$$t_i = \frac{V_i}{Q} \quad (2)$$

where:
V_i is the volume of pond i, in m^3;
Q is the system capacity, in m^3/day.

Land Cost

The land cost consists of the pond area plus 100% of the adjacent areas for people and vehicles circulation. As the decision variables are the ponds efficiency, which are the volume function, the mathematical model that better characterise the land cost is given by the equation:

$$C_{ei} = 2\,\gamma_i P_e V_i \quad (3)$$

where:
C_{ei} is the cost of the land used with pond i, and adjacent areas, in US $;
γ_i is the relation between the surface and the volume of pond i, in m^2/m^3;
P_e is the land price, in US $/$m^2$.

Construction Cost

The construction cost is a non linear equation, in which includes the cleaning of the area, mechanical excavation and transport of the land surplus. The mathematical model, adjusted after the constants that better express the pond construction costs were calculated, is represented by the expression:

$$C_{ci} = 5.514\, V_i^{0.678} \quad (4)$$

where: C_{ci} is the construction cost of pond i, in US $.

Ponds Revetment Cost

The ponds were coated with flexible PVC, obtaining a non linear equation. So, after having determined the constants, the model that better express the ponds revetment cost is represented by the equation:

$$C_{rei} = 18.592 V_i^{0.732} \quad (5)$$

where: C_{rei} is the revetment cost of pond i, in US $.

Maintenance Cost

The maintenance of the ponds system is estimated based on the minimum number of people necessary to clean the adjacent areas. Admitting that the maintenance area is alike the ponds areas, the system maintenance is characterised by the sum of the ponds areas by the equation:

$$A_t = A_1 + A_2 + ... + A_n = \sum_{i=1}^{n} A_i \quad (6)$$

in which $A_i = \gamma_i V_i$ (7)

It is important to emphasise that the swine producers will have month expenses, throughout the planing horizon. Area researchers as Yang et al. (1997), studying ponds system for the treatment of swine manure, suggest a period of ten years. Then, after the obtainment of the constants, the months cost will be accounted in the date of the investment through the followi ng expression:

$$Ct_{ma} = \Phi\ 0.164\left(\sum_{i=1}^{n}\gamma_i.V_i\right)^{0.830} \qquad (8)$$

where $$\Phi = \frac{(1 + r)^n - 1}{r\,(1 + r)^n} \qquad (9)$$

Ct_{ma} is the total cost of the pond system maintenance, in US $;
ϕ is the factor of the present value;
r is the interest annual rate;
n is the life time of the ponds, in years.

From equations (3) to (8), it is possible to calculate the ponds cost.

$$C_i = 2\,\gamma_i P_e V_i + 5.514V_i^{0.678} + 18.592V_i^{0.732} + C_{mai} \qquad (10)$$

From equations (1) to (2), it is possible to have the ponds volume:

$$V_i = Q\,E_i\,[k_i\,(1 - E_i)]^{-1} \qquad (11)$$

Substituting equation (11) in equation (10), it gives the ponds cost:

$$C_i = 2\,\gamma_i\,P_e\,Q\,E_i\,[k_i\,(1 - E_i)]^{-1} + 5.514\{Q\,E_i\,[k_i.(1 - E_i)]^{-1}\}^{0.678} + 18.592\{Q\,E_i\,[k_i\,(1 - E_i)]^{-1}\}^{0.732} + C_{mai} \qquad (12)$$

where: C_i is the cost of pond i, in US $.

Objective Function

The objective function in the optimisation of the stabilisation ponds system is given by the equation:

$$Min\ C_T = \sum_{i=1}^{n} C_i + C_{ev}$$

$$s.to.: \quad E_O \geq E_d \qquad (13)$$

$$0 \leq E_i \leq 1$$

where:
C_T is the total cost of the system, in US $;
C_{ev} is the eventual cost, in US $;
E_o is the efficiency obtained in the system;
E_d is the efficiency willed in the system.

So, the problem can be formulated as it is below:

$$Min\ C_T = \sum_{i=1}^{n}\{2\gamma_i P_e Q E_i [K_i(1-E_i)]^{-1} + 55.514[Q\,E_i(k_i\ (1-E_i))^{-1}]^{0.678} + 18.592[QE_i(k_i(1-E_i))^{-1}]^{0.732} + \Phi\ 0.164[Q(\gamma_i E_i(k_i(1-E_i))^{-1})]^{0.830}\} + C_{ev}$$

$$s.to.: \quad 1 - (1-E_i) \geq E_d \qquad (14)$$

$$0 \leq E_i \leq 1$$

Practice Application

Researches developed by Kawai and Grieco (1983) in pond water hyacinth showed that these plants needed free space to grow (about 7 0%), other wise their productivity decreased and so was the efficiency in the manure treatment. According to the authors, the growth rate was in order of 5% a day, so in 15 days, 50% of the plants must be removed from the pond.
Results of present made in the water hyacinth pond with a superficial area of $100m^2$, showed that it is necessary 2 hours to remove $50m^2$ of these plants. To remove two times in a month, four hours were necessary. In a simple comparison, the model cost of pond maintenance (eq. 8) with servitor hour cost for the producer (Medri et al., 1996), it was possible to observe that the maintenance cost of the pond with water hyacinth was approximately the double of other pond with the same area. Thus, it would be necessary to make a study with more details about the cost the removal of the water hyacinth.
Making a study for ten years and admitting a annual interest rate of 15%, the factor of the present value ϕ given by equation (9) would be alike 64.3. The information about the influent and

effluent evaluated of the ponds, in terms of degradation constants k (BOD) were: 0.101 d^{-1} for AP1 with 35 days of retention; 0.038 d^{-1} for AP2 with 46 days of retention; 0.038 d^{-1} for FP with 24 days of retention and 0.059 d^{-1} for WHP with 20 days of retention. The values for k were determined with average temperature of 21.6 $^{\circ}$C for pond AP1; 20.6°C for pond AP2; 19.8°C for pond FP and 22.1°C for pond WHP. The relation surface/volume of each pond in this research is so that: $\gamma_1 = 0.8$; $\gamma_2 = 0.65$; $\gamma_3 = 1.1$ e $\gamma_4 = 1.1$ (m^2/m^3). Considering the four ponds AP1, AP2, FP and WHP form CNPSA, the equation (14) could be described as:

$$
\begin{aligned}
\text{Min } C_e = {} & 2 \times 0.80\, P_e\, Q\, X_1\, [0.101\,(1 - X_1)]^{-1} + 5.514\{Q\, X_1\, [0.101(1 - X_1)]^{-1}\}^{0.678} + \\
& 18.592\{Q\, X_1\, [0.101\,(1 - X_1)]^{-1}\}^{0.732} + \\
& 2 \times 0.65\, P_e\, Q\, X_2\, [0.038\,(1 - X_2)]^{-1} + 5.514\{Q\, X_2\, [0.038\,(1 - X_2)]^{-1}\}^{0.678} + \\
& 18.592\{Q\, X_2\, [0.038\,(1 - X_2)]^{-1}\}^{0.732} + \\
& 2 \times 1.10\, P_e\, Q\, X_3\, [0.038\,(1 - X_3)]^{-1} + 5.514\{Q\, X_3\, [0.038(1 - X_3)]^{-1}\}^{0.678} + \\
& 18.592\{Q\, X_3\, [0.038\,(1 - X_3)]^{-1}\}^{0.732} + \\
& 2 \times 1.10\, P_e\, Q\, X_4\, [0.059\,(1 - X_4)]^{-1} + 5.514\{Q\, X_4\, [0.059(1 - X_4)]^{-1}\}^{0.678} + \\
& 18.592\{Q\, X_4\, [0.059\,(1 - X_4)]^{-1}\}^{0.732} + \\
& 64.3 \times 0{,}164\{Q[0.80\, X_1\, (0.101(1 - X_1))^{-1} + 0.65\, X_2\, (0.038\,(1 - X_2))^{-1} + \\
& 1.10\, X_3\, (0.038\,(1 - X_3))^{-1} + 2^{(1/0.830)}\, 1.10\, X_4\, (0.059\,(1 - X_4))^{-1}]\}^{0.830}
\end{aligned}
$$

$$\text{s. to.:} \quad 1 - (1 - X_1)(1 - X_2)(1 - X_3)(1 - X_4) \geq X_d$$

$$0 \leq X_1 \leq 1;\ 0 \leq X_2 \leq 1;\ 0 \leq X_3 \leq 1;\ 0 \leq X_4 \leq 1$$

Table 3 - presents the physical characteristics of the ponds and the costs of land, mechanical excavation, pond revetment and system maintenance, supposing discharge of 30 m^3/d, land cost US \$ 3000.00/ha and system efficiency of 98%.

Pond efficiency	*Retention time (days)*	*Pond volume (m^3)*	*Pond area (m^2)*
E_1 = 0.843	t_1 = 53	V_1 = 1,590	A_1 = 1,272
E_2 = 0.603	t_2 = 40	V_2 = 1,201	A_2 = 781
E_3 = 0.440	t_3 = 21	V_3 = 621	A_3 = 684
E_4 = 0.427	t_4 = 13	V_4 = 380	A_4 = 418
Land cost (US $)	***Construction cost (US $)***	***Revetment cost (US $)***	***Maintenance cost (US $)***
C_{e1} = 763.14	C_{c1} = 816.56	C_{re1} = 4,099.42	C_{ma1} = 3,436.82
C_{e2} = 468.50	C_{c2} = 675.25	C_{re2} = 3,339.05	C_{ma2} = 2,109.89
C_{e3} = 410.10	C_{c3} = 431.87	C_{re3} = 2,060.91	C_{ma3} = 1,846.92
C_{e4} = 250.57	C_{c4} = 309.24	C_{re4} = 1,436.93	C_{ma4} = 2,256.91
Total 1,892.31	2,232.92	10,936.31	9,650.55

Total cost of the system: US $ 24,712.08

It could be seen from Table 3 that the anaerobic ponds must be constructed in larger volume than the other ponds (FP and WHP), as the objective of this work was to optimise the system considering only the organic matter (BOD), which was better removed in these ponds, specially in AP1, in about 78%.

CONCLUSION

The results obtained from the experimental system for treatment of swine wastes, constituted by a decanter, two anaerobic ponds, a facultative pond and a water hyacinth pond in series of continuous flux, conclude that:

- the treatment of wastes with high concentration of organic matter (BOD_5 ~ 8,000 mg/L, COD 15,000 mg/L) and solids (10,000 mg/L) could be made through stabilisation ponds;
- the combined removal efficiency of the pond system (AP1, AP2, FP and WHP) was approximately 97% of BOD_5, COD; 87% of TS; 91% of VS; 90% of Nt; 93% of Pt and 7 units log of FC, when total detention time was 125 days.

The removal of the organic matter (BOD_5 and COD) occur specially in the first anaerobic pond LA1, in about 78% of each parameter in 35 days. The total cost (costs: of land, construction, revetment and maintenance) of the ponds system: two anaerobic (AP1 and AP2), a facultative (FP) and one of water hyacinth (WHP) was of U$ 24,712.08 with 98% of efficiency of BOD_5 and discharge of $30m^3/d$, admitting 15% of annual interest during ten years.

RESUMO

O modelo de produção adotado na suinocultura brasileira, principalmente na Região Oeste de Santa Catarina, é feita com os animais confinados em pequenas áreas, trazendo como conseqüência grande produção de dejetos. Este é diluído, através do uso de água para a limpeza das baias, aumentando seu volume. Seu lançamento nos cursos d'água da região está comprometendo a qualidade dos mananciais devido a contaminação bacteriológica e poluição por compostos químicos. Dessa forma, há necessidade de processos de tratamento para minimizar os problemas ambientais gerados por essa atividade. As lagoas de estabilização têm sido utilizadas, por apresentar um excelente desempenho quanto à eficiência de remoção da matéria orgânica, dos nutrientes e de coliformes fecais; além dos baixos custos de implantação e de manutenção. Este trabalho apresenta o monitoramento numa série de quatro lagoas de estabilização, em escala real, tratando dejetos suínos em Concórdia/SC, Brasil. O sistema de lagoas foi avaliado durante 20 meses, tendo o objetivo de buscar os parâmetros principais de funcionamento das mesmas, bem como a obtenção dos dados de custos de capital e operacional, para ajustamento de equações para a modelagem e otimização de sistemas quanto à remoção da matéria orgânica. O modelo desenvolvido é flexível, sua aplicação é válida para utilização como adubo dos despejos tratados em plantações de milho e outros cereais.

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Received: September 30, 1999;
Revised: February 20, 2001;
Accepted: June 21, 2001.