Pergamon

0273-1223(95)00007-0

Wat. Sci. Tech. Vol. 30, No. 8, pp. 269–279, 1994.

0273–1223/94 $7·00 + 0·00

ECOCLIMATIC INFLUENCE ON WASTE STABILIZATION PONDS (WSP) EFFICIENCIES. CASE STUDY OF THE SESIMBRA SYSTEM

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ABSTRACT

Portugal has a great diversity of ecoclimatic areas and Sesimbra was chosen to carry out a study on WSP efficiencies over five years (1989 to 1993). According to Pina Manique & Albuquerque (1954), the climate is classified as Atlantic Mediterranean (AM). Some environmental and climatic parameters have been studied in order to define the area. The treatment system at Sesimbra has three ponds: anaerobic, facultative and maturation. The physical and chemical parameters studied in the WSP system were: Temperature, pH, Dissolved Oxygen, Conductivity, BOD_5, COD, nitrates, nitrites, ammonia and total nitrogen, total and volatile suspended solids, total phosphorus and orthophosphates. Algal populations and the following microbiological parameters were studied: total and fecal coliforms, fecal *Streptococci*, *Clostridium perfringens*, *Pseudomonas aeruginosa* and some Enterobacteriaceae. The K and K_{20} kinetic parameters were studied and derived for the three ponds utilizing the seasonal regional characteristics from the surrounding area. These values were then correlated with temperature and the subsequent removal efficiencies for each pond deduced. The data obtained indicate a necessity to determine the seasonal fluctuations of the K and K_{20} kinetic parameters for the WSP systems.

KEYWORDS

Ecoclimatic relationships; removal efficiency; pathogenic microorganisms; waste stabilization ponds.

INTRODUCTION

About 30 km to the south of Lisbon, near Sesimbra village and the estuary of the Sado river, a WSP system for urban wastewater treatment, has been working since 1989. The project population was 10,000 inhabitants. A seasonal, as well as an annual, variation in flow and organic load was observed during the previous years. In winter, the population is below that limit and in summer, owing to tourism, the volume treated is significantly increased. The treated effluent is influenced by the above factors.

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The Ministry of Environment and Natural Resources was responsible for the control of the system. In 1990, a protocol was signed between the Group of Disciplines on Aquatic Ecology/F.C.T (New University of Lisbon) and the General Directorate for Environmental Quality. This protocol includes the analytical control of the system and the use of this facility for student training and research studies. Experimental data, obtained since 1989, made possible the study of some relationships between climate, ecological characteristics and system performance, concerning chemical and biological removal efficiencies and dynamics.

AREA AND WSP SYSTEM CHARACTERISTICS

The WSP system is located within the area of Santana-Ferraria (Figure 1). The characteristics of the Sesimbra WSP are presented in Table 1. The area is characterized by a mild winter and a temperate summer, according to the main parameters presented in Table 2. The annual average rainfall is 712 mm and the annual average temperature is 16.5°C. According to Pina Manique & Albuquerque (1954), the region is classified as a basal Atlantic-Mediterranean on a phytoclimatic basis, and as Calco-Mediterranean on an edaphic climatic aspect. On an ecoclimatic basis, the area is defined by the following indices: (a) Pluviothermic coef. Enberger = 43.0; (b) Xerothermic expression = 7.1; (c) Coef. Dantin & Revenga = 2.2; (d) Summer coef. Giacobbe = 0.42; (e) Index of aridity from Eagleman = 43.5%; (f) Net primary productivity ($g.m^{-2}.year^{-1}$): Miami Model (temperature) = 1970, Miami Model (rain) = 1130, Montreal Model = 1043; (g) Photosynthetic efficiency = 2.32%; (h) Algae productivity (kg $D.M.ha^{-1}$ $year^{-1}$) = 143.1.

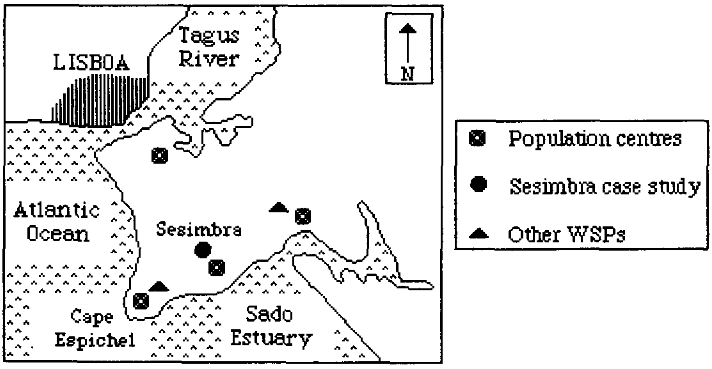

Fig. 1. Location of the Sesimbra WSP system.

TABLE 1. Sesimbra WSP Characteristics

Pond	Volume (m^3)	Area (m^2)	Slope	Flow ($m^3.d^{-1}$)	Detention time (days)
Anaerobic	6080	2604	1/2.5	1199.2	5.07
Facultative	17200	14106	1/2.5	1202.8	14.3
Maturation	6039	6506	1/2.5	1200.6	5.03

MATERIAL AND METHODS

The sampling of raw sewage, influent and effluent was performed between March/1989 and April/1993. Chemical, physical and microbiological analyses were performed according to Standard Methods (APHA, 1985). Microbiological samples were collected using sterile glass bottles and transported to the laboratory in cooled boxes. Fecal coliforms, fecal *Streptococci*, *Pseudomonas aeruginosa* and *Clostridium perfringens* were enumerated by Multiple Tube Technique (MPN/100ml). The bacteria, after growing in pre-enrichment media (GN Broth, Hajna-Difco), were subsequently cultivated and isolated with appropriate selective culture media (Bismuth Sulfite Agar, Cetrimide Agar Base, SS Agar and Nutrient, all from Difco) and identified using the API 20 E and API 20 NE system (BioMqérieux). Planktonic sampling was performed at a depth of 60 cm and transported to the laboratory in cooled boxes. Filtration and concentration followed the classical procedures. Microscopic examination, identification and enumeration followed the same procedures, utilizing the relative population criteria (present, not frequent, frequent and very frequent), as reported in Table 3.

TABLE 2. Climatic Average Characteristics Observed in Sesimbra

Characteristics	Average minimal temperature of coldest month	Number of days whose minimal temperature is < 0°C	Number of days whose maximal temperature is > 25°C
Mild Winter	> 6°C	< 2	_____
Temperate Summer	23°C - 29°C	_____	20 - 100

BIOLOGICAL POPULATIONS PRESENT WITHIN THE PONDS

The species that have been identified in the ponds of Ferraria-Santana are reported in Tables 3 and 4, showing the variability of influent (Mendes & Nascimento, 1990). The algae species of *Euglena* and *Chlorophyta* were the most dominant.

The variation in bacterial population was important throughout the year. The following genera and some specific strains were identified: *Pseudomonas, Serratia, Proteus, Aeromonas, Enterobacter, Klebsiella, Clostridium* and *Citrobacter* (Table 4). Between March and September, *Pseudomonas cepacia*, *Serratia* spp and *Proteus mirabilis* were predominant in the anaerobic and maturation ponds. Between November and February, *Proteus mirabilis*, *Aeromonas* spp, *Aeromonas hydrophila* and *Citrobacter freundii* were predominant in the anaerobic and maturation ponds. *Citrobacter freundii* appeared during Winter.

In the facultative pond, *Proteus mirabilis* was present throughout the year. *Citrobacter freundii* was present only during January and February. *Enterobacter sakazakii* was present in November, December and April. A higher diversity of the genera was observed in October.

PHYSICAL AND CHEMICAL PARAMETERS

The variability of the physical and chemical parameters is summarized in Table 5. The calculation of coefficient variability ((s/x)*100) showed the influence of seasonal variations on the number and diversity of the population. The quality of final effluent was acceptable and could be used for irrigational purposes.

BOD REMOVAL EFFICIENCY

The BOD removal may be described by the classical first-order kinetics model. K_t was calculated for the dissolved fraction of the effluent organic matter and K_{20} was also calculated using the Van't Hoff-Arrhenius expression (Θ=1.036).

TABLE 3. Frequency of Biological Populations

SPECIES	FACULTATIVE POND							MATURATION POND						
	III 89	V 89	X 89	XII 89	II 90	V 90	VI 90	III 89	V 89	X 89	XII 89	II 90	V 90	VI 90
BACTERIA														
Filamentous bacteria			4	1			3		1	1	2	1	3	3
Beggiatoa alba			1	3	1			1		1	3		1	1
Spirochaeta spp		1								1		1		1
PYRRHOPHITA														
Gimnodinium spp									2					1
CYANOPHITA														
Oscillatoria tenuis	1								1					1
Spirulina spp							3				1			2
EUGLENOPHYTA														
Euglena pisciformis	4	4	4	4	4			2	4	4	4	4	4	4
Euglena proxima			1							2				
Euglena rubra			3							2				
Euglena texta				1								1		
Euglena spp	1	1	3	1			1		1	4				
Heteronema acus			3	1										
Lepocinclis ovum	1			1			3			1				1
Lepocinclis texta			1							1	2			
Lepocinclis spp				1							1			
CRYSOPHYTA														
Anthophysa vegetans	1				1							1		
CHLOROPHITA														
Ankistrodesmus falcatus	1	1		1		1			1		3	1		
Ankistrodesmus falcatus acicularis var.			3	3			4	1		2			1	4
Chlorella botryoides								3	1					
Chlorogonium elongatum					3							3		1
Chlorogonium fusiforme			2											
Closterium acutum													1	
Coel. microporum			1				1						1	1
Coel. pseudomicroporum														1
Eudorina spp						4							3	
Korshikoviella mystacina	3	3		3				3	3	1	3			
Micractinium pusillum	3			1	1	1	3		1		1		3	3
Oocystis borgei			3			4							1	1
Oocystis lacustris	1													
Pandorina morum						3							1	
Scenedesmus acuminatus	3						1	1	1		1		1	1
FLAGELLATA														
Collodictyon triciliatum		3	1	2						1	3			1
CILIATA														
Aspidisca costata							3			1				
Coleps hirtus		1		3	2		1	3	2	1	3	2		3
Cyclidium glaucoma	2			1				3			1		1	
Enchelys spp	1							3						
Halteria grandinella	1			1							1			
Paramecium caudatum				1		2	2							
ROTATORIA														
Brachionus urceolaris	3													
Filinia longiseta		1		1		1			1		1			
Pompholyx sulcata							1							
other Rotifer species						4								

1 - present; 2 - not frequent; 3 - frequent; 4 - very frequent

TABLE 4. Dominant Bacteria Species

MONTHS	RAW SEWAGE	ANAEROBIC POND	FACULTATIVE POND	MATURATION POND
March	*Ps. cepacia* *Serratia* spp *Prot. mirabilis* *Esch. coli* *Kl. pneumoniae*	*Ps. cepacia* *Serratia* spp *Prot. mirabilis* *Esch. coli* *Kl. pneumoniae*	*Prot. mirabilis* *Prot. vulgaris* *Prot. penneri* *Esch. coli*	*Ps. cepacia* *Serratia* spp *Prot. mirabilis*
April	*Ps. cepacia* *Serratia* spp *Prot. mirabilis* *Aeromonas* spp *Ent. sakazakii* *Flavobacterium* spp	*Ps. cepacia* *Serratia* spp *Prot. mirabilis* *Aer. hidrophila* *Ent. sakazakii*	*Prot. mirabilis* *Prot. vulgaris* *Prot. penneri* *Ent. sakazakii*	*Prot. mirabilis* *Kl. oxytoca*
May	*Ps. cepacia* *Serratia* spp *Prot. mirabilis* *Aeromonas* spp *Kl. pneumoniae*	*Ps. cepacia* *Serratia* spp *Prot. mirabilis* *Kl. pneumoniae*	*Prot. mirabilis* *Prot. vulgaris* *Prot. penneri* *Esch. coli*	*Ps. cepacia* *Serratia* spp *Prot. mirabilis*
June	*Ps. cepacia* *Serratia* spp *Prot. mirabilis* *Aeromonas* spp *Kl. pneumoniae*	*Ps. cepacia* *Serratia* spp *Prot. mirabilis* *Kl. pneumoniae*	*Prot. mirabilis* *Prot. vulgaris* *Prot. penneri* *Esch. coli*	*Ps. cepacia* *Serratia* spp *Prot. mirabilis*
July	*Ps. cepacia* *Serratia* spp *Prot. mirabilis* *Aeromonas* spp *Kl. pneumoniae*	*Ps. cepacia* *Serratia* spp *Prot. mirabilis* *Kl. pneumoniae*	*Prot. mirabilis* *Prot. vulgaris* *Prot. penneri* *Esch. coli*	*Ps. cepacia* *Serratia* spp *Prot. mirabilis*
September	*Ser. odorifera* *Prot. mirabilis* *Kl. pneumoniae* *Achromobacter* spp	*Ser. odorifera* *Prot. mirabilis* *Kl. pneumoniae* *Achromobacter* spp	*Ps. aeruginosa* *Prot. mirabilis*	*Ps. aeruginosa* *Prot. mirabilis*
October	*Ps. aeruginosa* *Prot. mirabilis* *Aer. hidrophila* *Ent. agglomerans* *Flavobacterium* spp *Chromo. violaceum* *Vibrio* spp	*Ps. aeruginosa* *Prot. mirabilis* *Aer. hidrophila* *Flavobacterium* spp *Chromo. violaceum* *Vibrio* spp	*Ps. aeruginosa* *Prot. mirabilis* *Vibrio* spp	*Prot. mirabilis* *Flavobacterium* spp *Chromo. violaceum*
November	*Prot. mirabilis* *Aer. hidrophila* *Ent. aerogenes* *Kl.oxytoca* *C.freundii*	*Ps. aeruginosa* *Prot. mirabilis* *Ent. sakazakii* *Kl.oxytoca* *C.freundii*	*Prot. mirabilis* *Ent. sakazakii*	*Prot. mirabilis* *Aeromonas* spp *Aer. hidrophila* *C.freundii*
December	*Prot. mirabilis* *Aer. hidrophila* *Ent. aerogenes* *C.freundii*	*Prot. mirabilis* *Aer. hidrophila* *Ent. sakazakii* *Kl.oxytoca* *C.freundii*	*Prot. mirabilis* *Ent. sakazakii*	*Prot. mirabilis* *Aeromonas* spp *Aer. hidrophila* *C.freundii*
January	*Serratia* spp *Prot. mirabilis* *Aer. sobria* *Ent. sakazakii* *C.freundii*	*Ps. aeruginosa* *Prot. mirabilis* *Aeromonas* spp *Aer. hidrophila* *C.freundii*	*Ps. aeruginosa* *Prot. mirabilis* *C.freundii*	*Prot. mirabilis* *Serratia* spp *Aer. sobria* *Ent. sakazakii* *C.freundii*
February	*Serratia* spp *Prot. mirabilis* *Aer. sobria* *Ent. sakazakii* *C.freundii*	*Ps. aeruginosa* *Prot. mirabilis* *Aeromonas* spp *Aer. hidrophila* *C.freundii*	*Ps. aeruginosa* *Prot. mirabilis* *C.freundii*	*Prot. mirabilis* *Serratia* spp *Aer. sobria* *C.freundii*

TABLE 5. Physical, Chemical and Microbiological Parameters of the Sesimbra Waste Stabilization Ponds

PARAMETERS	Raw Influent			Anaerobic Pond			Facultative Pond			Maturation Pond		
	Mean	s	n	Mean	s	n	Mean	s	n	Mean	s	n
Sample Temp. (°C)	18.4	3.1	19	18.6	3.8	20	19.2	4.8	20	19.6	4.2	19
pH	7.5	0.6	19	7.2	0.5	20	8.3	0.6	20	8.6	0.8	19
Dissolved Oxyg. (ppm)	1.8	3.4	7	1.6	3.3	7	10.5	3.7	7	10.0	5.5	8
Conductivity ($\mu S.cm^{-1}$)	844	594	14	782	589	15	701	529	15	639	479	15
BOD_5 ($mg.L^{-1}$)	220.2	146.3	17	124.2	75.4	17	91.5	53.8	16	81.3	47.1	15
COD ($mg.L^{-1}$)	474.1	262.1	19	249.3	120.2	19	181.3	61.6	19	156.1	96.6	19
Ammonia (mg $N.L^{-1}$)	46.5	18.5	15	30.0	12.4	15	12.7	8.6	15	5.3	3.6	15
Nitrite (mg $N.L^{-1}$)	0.1	0.1	18	<0.1	<0.1	18	0.1	0.2	18	0.2	0.2	18
Nitrate (mg $N.L^{-1}$)	0.7	0.7	20	0.6	0.7	20	0.7	0.8	20	0.7	0.7	20
N-Kjeldahl (mg $N.L^{-1}$)	86.1	31.9	9	57.0	29.4	10	36.7	29.2	10	31.8	27.0	10
Total Solids ($mg.L^{-1}$)	951	175	6	803	107	6	778	137	6	645	278	6
Volatile Suspended Solids ($mg.L^{-1}$)	160	84	8	115	76	8	76	57	8	84	37	8
Orthophosphate (mg $P.L^{-1}$)	8.5	4.3	19	7.3	3.7	18	4.7	2.1	19	4.3	4.5	18
Total Phosphorus (mg $P.L^{-1}$)	15.9	11.5	19	15.6	9.1	19	9.1	5.9	19	5.3	4.1	19
Chlorophyll *a* ($\mu g.L^{-1}$)	-	-	-	-	-	-	1531	993	12	1717	889	12
Fecal Colif. (MPN/100 ml)	1.3e11	5.4e11	20	2.7e8	1.1e9	20	1.8e6	5.6e6	20	1.6e6	6.9e6	19
Fecal Strept. (MPN/100 ml)	3.3e9	8.4e9	8	1.4e9	3.9e9	8	1.4e7	3.9e7	8	1.4e6	3.9e6	8
Cl. perfringens (MPN/100 ml)	1.3e10	5.5e10	19	1.4e8	5.6e8	18	1.0e6	3.4e6	19	4.5e4	8.5e4	19
Ps. aeruginosa (MPN/100 ml)	4.1e10	9.7e10	6	1.9e10	4.5e10	6	2.1e7	4.4e7	6	1.9e7	4.5e7	6

s - standard deviation, n - number of samples, e= exponent.

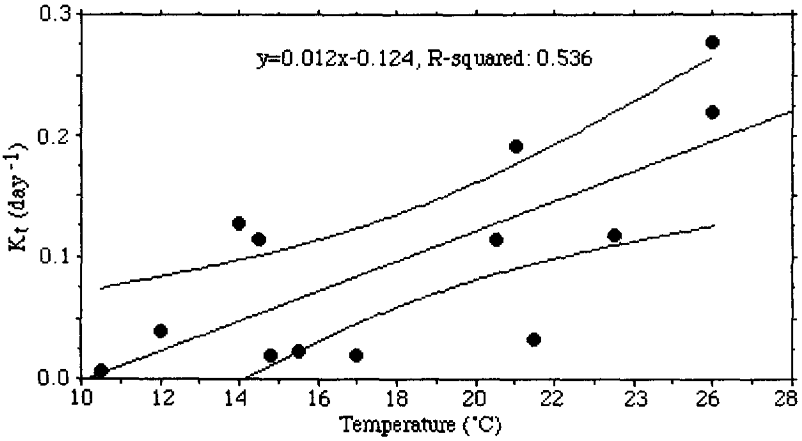

Fig. 2. Correlation between temperature and K_t on the facultative pond with 95% confidence interval to the true mean value of K_t.

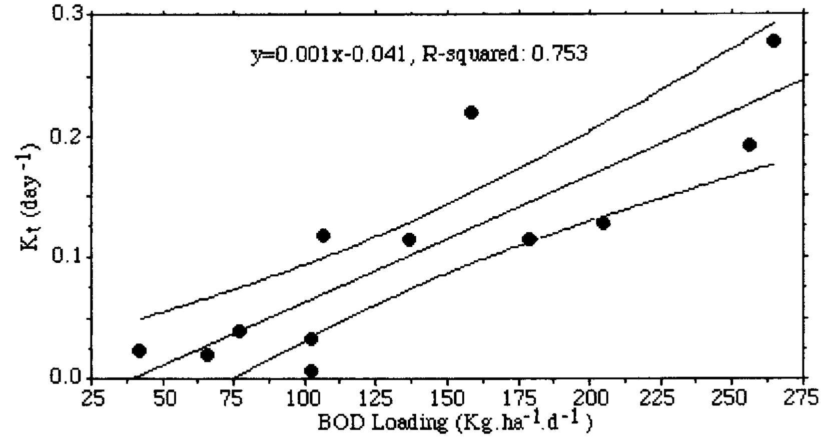

Fig. 3. Correlation between BOD loading and K_t on the facultative pond with 95% confidence interval to the true mean value of K_t.

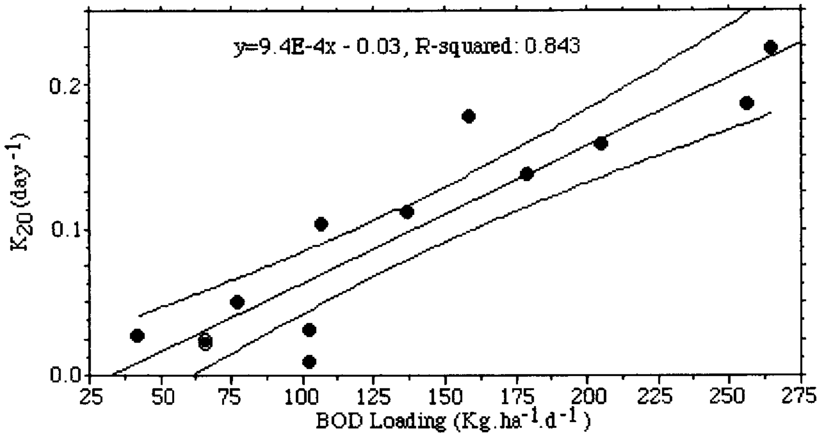

Fig. 4. Correlation between BOD loading and K_{20} on the facultative pond with 95% confidence interval to the true mean value of K_{20} (E= exponent).

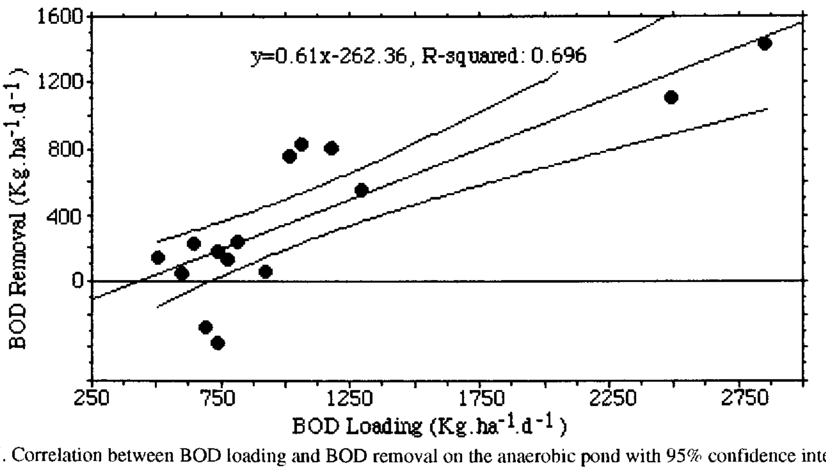

Fig. 5. Correlation between BOD loading and BOD removal on the anaerobic pond with 95% confidence interval to the true mean value of BOD removal.

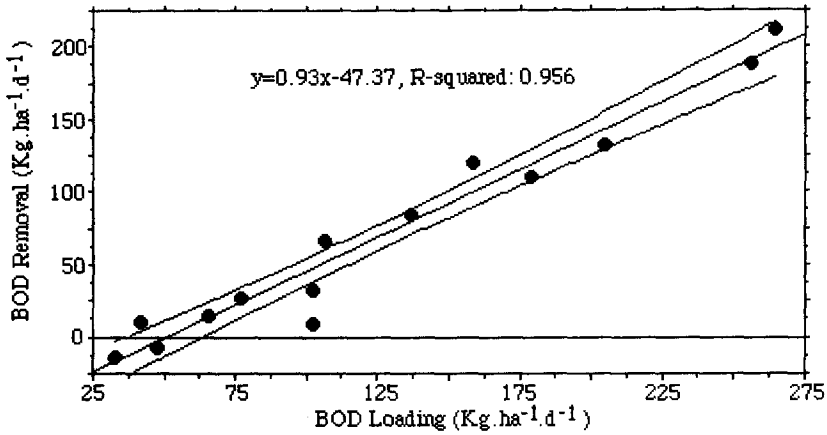

Fig. 6. Correlation between BOD loading and BOD removal on the facultative pond with 95% confidence interval to the true mean value of BOD removal.

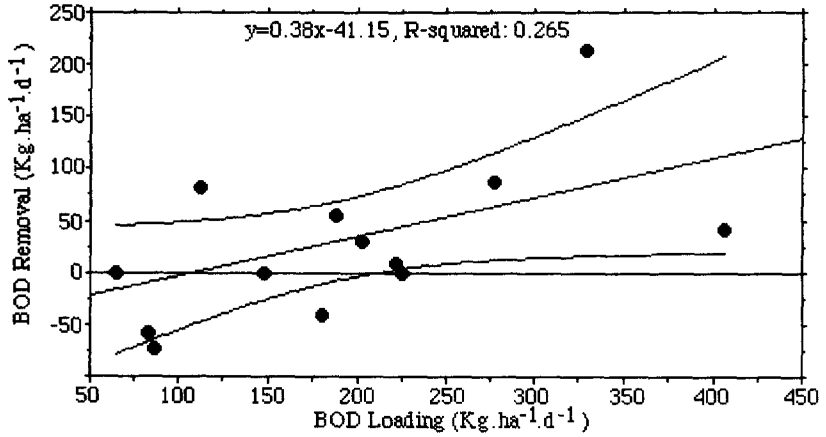

Fig. 7. Correlation between BOD loading and BOD removal on the maturation pond with 95% confidence interval to the true mean value of BOD removal.

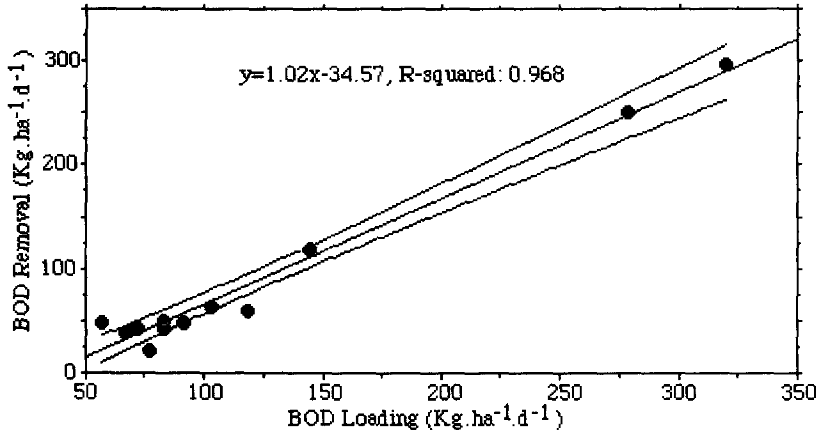

Fig. 8. Correlation between BOD loading and BOD removal on the WSP system with 95% confidence interval to the true mean value of BOD removal.

The following significant correlations were observed on the facultative pond: (i) between K_t and pond temperature (Figure 2); (ii) between K_t and total BOD loading (Figure 3); (iii) between K_{20} and the total BOD loading (Figure 4).

Another significant multiple correlation was observed between K_t values, pond temperature and total BOD loading. The relation between these variables can be expressed by the following equation:

$$Y = 7.27 \times 10^{-3} X_1 + 8.13 \times 10^{-4} X_2 - 0.142 \qquad (r^2=0.904) \qquad (1)$$

where $Y = K_t$ (d^{-1}); X_1 = Temperature (°C); X_2 = BOD loading ($kg.ha^{-1}.d^{-1}$).

Using the model of McGarry and Pescod (1970), the relationship between dissolved BOD removal and total BOD loading was highly significant on the anaerobic and facultative ponds (Figure 5 and 6), but not significant on the maturation pond (Figure 7). A subsequent significant correlation fit was then achieved for the whole system (Figure 8).

REMOVAL EFFICIENCIES OF PATHOGENS

The removal yield (η) of fecal indicators was calculated using the following expression: $\eta=(N_{inf}-N_{eff})/N_{inf}$, where N_{inf} is the Most Probable Number (MPN)/100 ml of microorganisms in the influent, and N_{eff} is the MPN/100 ml in the effluent. The results are shown in Tables 6, 7 and 8 for the anaerobic, facultative and maturation ponds, respectively.

TABLE 6. Removal Yields from the Anaerobic Pond

MONTH	η Fecal Coliforms	η Fecal *Streptococci*	η *Pseudomonas aeruginosa*	η *Clostridium perfringens*
MARCH	0.94	0.99	-2.00	-
APRIL	0.98	0.96	0.98	0.99
MAY	0.98	0.92	0.47	0.97
JUNE	0.79	0.94	0.33	0.99
JULY	0.99	0.99	0.88	-12.00e3
SEPTEMBER	0.90	0.86	0.79	0.87
OCTOBER	0.69	0.92	0.92	0.99
NOVEMBER	0.99	0.84	0.77	0.44
DECEMBER	-34.00	-6.00	-0.75	0.65
JANUARY	0.97	0.00	0.93	0.63
FEBRUARY	-28.41	0.99	0.99	0.98

TABLE 7. Removal Yields from the Facultative Pond

MONTH	η Fecal Coliforms	η Fecal *Streptococci*	η *Pseudomonas aeruginosa*	η *Clostridium perfringens*
MARCH	0.98	0.90	0.82	-
APRIL	0.99	0.99	0.99	0.80
MAY	0.99	0.99	0.99	0.99
JUNE	0.99	0.99	0.99	0.71
JULY	0.97	0.99	0.99	0.99
SEPTEMBER	0.47	0.99	0.99	0.95
OCTOBER	0.99	0.99	0.99	0.96
NOVEMBER	0.99	0.79	0.98	0.99
DECEMBER	0.99	0.89	0.98	0.94
JANUARY	0.99	0.99	0.99	0.99
FEBRUARY	0.99	0.99	0.96	0.99

TABLE 8. Removal Yields from the Maturation Pond

MONTH	η Fecal Coliforms	η Fecal *Streptococci*	η *Pseudomonas aeruginosa*	η *Clostridium perfringens*
MARCH	0.93	0.62	0.55	-
APRIL	0.43	0.00	0.50	-1.20
MAY	0.65	0.90	0.53	-4.65
JUNE	0.98	0.45	-37.57	0.99
JULY	-2.36	-4.00	-0.73	0.99
SEPTEMBER	0.99	0.71	0.52	0.93
OCTOBER	0.99	0.46	-0.60	-9.71
NOVEMBER	0.94	0.99	0.77	0.56
DECEMBER	0.47	0.99	0.78	0.35
JANUARY	0.97	0.99	0.97	-21.00
FEBRUARY	0.99	-2.14	-0.29	0.27

In the anaerobic pond, re-growths of microorganisms were observed in December and February for fecal coliforms, in January and December for Fecal *Streptococci*, in March and December for *Pseudomonas aeruginosa* and in July for *Clostridium perfringens* (Table 6).

In the facultative pond, the removal yields of all microorganisms were higher than those in the anaerobic pond, with a noticably decreased value (0.47) for the fecal coliforms in September (Table 7).

The removal yields of microorganisms in the maturation pond (Table 8) showed a different pattern: (1) during April and December a decrease (0.43 and 0.47) in the removal of fecal coliforms was observed, and in July a re-growth took place; (2) a fecal *Streptococci* re-growth was observed in July and February and there was no removal in April. The removal during the other months fluctuated; (3) the removal of *Pseudomonas aeruginosa* was variable. A re-growth was observed in February, June, July and October; (4) the removal of *Clostridium perfringens* was variable during the year, showing re-growths in April, May, October and January. The pattern of removal/re-growth of the various microorganisms, and a different dominance of some Enterobacteriaceae in the ponds (Table 4), showed that the integration of all the factors involved in the kinetics of the treatment process is a complex phenomena (Oliveira, 1993).

CONCLUSIONS

The dynamics of chemical and microbiological parameters in the Sesimbra WSP were influenced by the seasonal variability of influent temperature and surrounding temperature of the area. The data indicated that variation of ecoclimatic parameters, throughout the year, may play an important role in the resistances/sensitivities of microorganisms. Thus, the removal efficiencies and the quality of final effluent were also affected by these parameters (Mendes *et al.*, 1993 a, b), which are not considered in the models more commonly used for the design and dimensioning of WSP systems (McGarry & Pescod, 1970; Mara & Pearson, 1987).

The data showed the importance of the seasonal fluctuations of K and K_{20} kinetic parameters in the removal efficiencies of the ponds. The ecoclimatic situation must be considered in the design and dimensioning of WSP systems, in order to improve the quality of final effluent. Eventually, K and K_{20} regional/seasonal values could be determined and utilized for the establishment of design guidelines.

ACKNOWLEDGEMENT

Identification and enumeration of algae was carried out by Mrs. Isabel Andrade (MARN).

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