

EFFICIENCY OF A WASTE STABILIZATION POND SYSTEM IN A SUBTROPICAL AREA OF MEXICO

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ABSTRACT

The efficiency of a modified sewage stabilization pond system in Ixtapan de la Sal, Mexico, was evaluated. The system was formed by an anaerobic pond with an high-rate clarifier, and a facultative and a maturation pond. Physical (temperature and conductivity), chemical (pH, DO, BOD₅, COD and solids) and biological variables (total and fecal coliform and fecal *Streptococcus*) were measured every two weeks through a six month period. A fissure in the clarifier wall caused the system to break down, letting raw organic matter of the clarifier go into the anaerobic pond and to the rest of the system. Two performance periods were established according to the observed changes in the ponds (color, odor, presence of flocs). Removal efficiencies during the first period (BOD₅ = 84%, COD = 70%, total coliform = 99%, fecal coliform = 97%) were higher than those of the second period (BOD₅ = 82%, COD = 18%, total coliform = 80%, fecal coliform = 85%). The BOD₅ removal in both periods were similar and adequate. Removal of the remaining variables were significantly lower. Nevertheless, the system fulfilled in both periods most of the standards imposed by the Mexican Legislation. When working properly, the modified system reached removal efficiencies similar to those obtained in the original system that used another facultative pond. The modified system implied reduced construction area as well as reduced function and maintenance costs.

RESUMEN

Se evaluó la eficiencia del sistema de estanques de estabilización de las aguas residuales de Ixtapan de la Sal. El sistema consiste en un estanque anaerobio con un sedimentador de alta tasa, un estanque facultativo y uno de maduración. Se midieron variables físicas (temperatura y conductividad), químicas (pH, OD, DBO₅, DQO y sólidos) y microbiológicas (coliformes totales, fecales y estreptococos fecales). Una fisura en el muro del sedimentador permitió que materia orgánica cruda pasara al estanque anaerobio y al resto del sistema, lo que causó el colapso de éste. Con base en los cambios observados en los estanques (color, olor y presencia de flóculos), así como en un análisis de cúmulos de las variables medidas, se establecieron dos periodos de eficiencia del sistema. La eficiencia de remoción en el primer periodo (DBO₅ = 84%, DQO = 70%, coliformes totales = 99%, coliformes fecales = 97%) fue mayor que en el segundo (DBO₅ = 82%, DQO = 18%, coliformes totales = 80%, coliformes fecales = 85%). Aunque la eficiencia de remoción de la DBO₅ fue similar en ambos periodos, para el resto de las variables fue significativamente menor en el segundo. A pesar de ello, el efluente del sistema cumplió con la mayoría de los estándares establecidos por la Legislación Mexicana salvo pH en el primer periodo, sólidos suspendidos en ambos y materia flotante y sólidos disueltos en el segundo. Trabajando en forma adecuada, la eficiencia de remoción es similar a la obtenida en el sistema no modificado que utilizaba un estanque facultativo adicional. Lo anterior permite reducir costos de construcción, funcionamiento y mantenimiento.

INTRODUCTION

The purposive discharge of organic wastes for disposal has been practiced since early times; such is the case of the European castle moats in the Middle Ages (Hawkes 1983), or the lake surrounding Tenochtitlan constructed by the Aztecs in 1245 (Alcocer and Escobar 1990). Although ponds, as an organic waste receptacle, have been well known in Asia and Europe for centuries (Rohlich 1976), their scientific study blossomed in the 1940s (Branco 1984), and nowadays they can be found everywhere from the poles to the equator and are one of the most important treatment systems for domestic wastewater (Gloyne 1973, Clark *et al.* 1977).

A waste stabilization pond is a natural or artificial large lentic body of water, enclosed by earthen embankments, in which organic wastewater (sewage or industrial effluents) is treated by natural—biological, biochemical and physical—processes involving both algae and bacteria (Mara 1976, Clark *et al.* 1977, Sundstrom and Klei 1979). Properly designed and operated ponds can be well balanced systems approaching natural treatment processes (self-purification) (Rohlich 1976), capable of producing high removal of organic materials, solids, and bacteria (WPCF and ASCE 1977).

As quoted by Espino and Aguirre (1976), Ramalho (1977) and Rohlich (1976) among many other authors, advantages of the stabilization ponds as a wastewater treatment system are various: they are inexpensive representing low operational and maintenance costs (small work force requirements), simplicity of construction and operation, resistance to hydraulic and organic shock loads, and high treatment efficiencies (specially fecal bacteria). These characteristics make the stabilization ponds appropriate for hot climates (Mara 1976) where large areas are available, odors problems are not a nuisance, temperature is most favorable and money is scarce.

The use of stabilization ponds as secondary treatment systems in México is recent and are used mainly in the states of North and South Baja California, Durango, Coahuila, Nuevo León, Puebla, Sonora, Tamaulipas and México. Before 1971 the Mexican ponds were limited to domestic sewage treatment because Mexican industries were not required to install water pollution control devices. Since then, wastewater discharges have been regulated and several industries constructed waste stabiliza-

tion ponds as low-cost waste treatment systems (Espino and Aguirre 1976).

Study Area and Wastewater Treatment System in Ixtapan de la Sal

Ixtapan de la Sal village in the southwest of the State of Mexico (18°50'13" N and 90°40'28" W) is situated 2020 m above sea level. Climate is warm and wet with a summer rain season; the mean annual precipitation is 1238 mm and the mean annual temperature, 15.4°C. According to the XI Censo General de Población y Vivienda of 1990, the population of the village was 24 297 inhabitants. Although located in a "hot climate area", the characteristics of the Mexican ponds differ in climate, operational conditions, and organic matter loadings from those encountered in the southwestern United States and South Africa (Espino and Aguirre 1976).

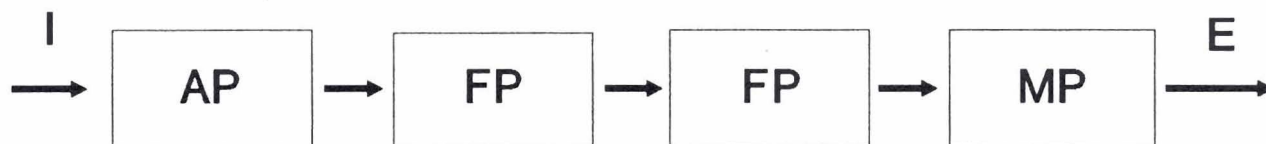
The stabilization pond system of Ixtapan de la Sal village, designed by Carlos Solís (Engineering Faculty, Autonomous University of the State of Mexico), started to operate in 1977. Four series of three ponds (two facultative and one of maturation) formed the original system. After 1982 one of the series was modified by adding an anaerobic pond (pretreatment) (Fig. 1a).

In 1988 a new modification was made consisting in the elimination of one facultative pond and the addition of a high-rate clarifier with a parallel plate series (Fig. 1b). The plates increase coarse solids settling in the first treatment stage. Sludge could be eliminated by purging making extraction easier by avoiding its accumulation in the clarifier bottom and thus increasing its useful life. Purged sludge are further dried and used as soil fertilizer. The purpose of this modification was to obtain higher or at least the same removal efficiencies in a smaller construction area.

Estimated retention times of the Ixtapan de la Sal pond system were as follow: 11 hours (high-rate clarifier), 3.38 days (anaerobic pond), 5.34 days (facultative pond), and 4.45 days (maturation pond); the surface organic loadings were 980 kg BOD₅/Ha/day (anaerobic pond), 161.2 kg BOD₅/Ha/day (facultative pond), and 101.1 kg BOD₅/Ha/day (maturation pond); the hydraulic surface loading of the high-rate clarifier was 5.75 m³/m²/day; and the raw water supply was maintained constant at 2 l/s (Solís and Solís 1992).

IXTAPAN DE LA SAL TREATMENT SYSTEM

(A)



(B)

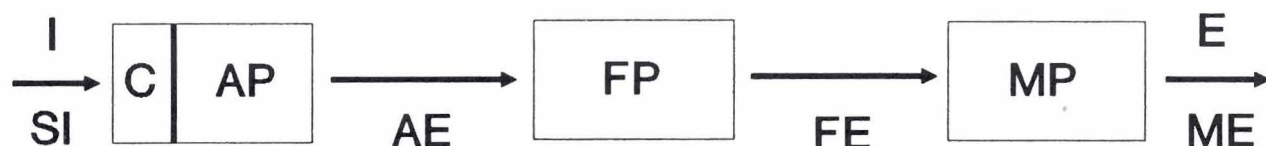


Fig. 1. Ixtapan de la Sal wastewater treatment system. Original (a) and modified (b) system. I = System Influent, E = System Effluent, C = Clarifier, AP = Anaerobic Pond, FP = Facultative Pond, MP = Maturation Pond. Sampling stations: SI = System Influent, AE = Anaerobic Pond Effluent, FE = Facultative Pond Effluent, ME = Maturation Pond Effluent

MATERIALS AND METHODS

In order to test the efficiency of the 1988 modified system (Fig. 1b), a sampling program was carried out every two weeks during a six months period. Samples were taken at the surface in each of the four sampling sites: system influent, and the effluents of the anaerobic, facultative, and maturation ponds.

According to the APHA *et al.* (1985) methodology, the variables measured were: temperature, pH, dissolved oxygen, biochemical oxygen demand (BOD₅), chemical oxygen demand (COD), total solids (TOT.SOL.), settling solids (SET.SOL.), suspended solids (SUS.SOL.), and dissolved solids (DIS.SOL.), total coliforms (TOT.COL.), fecal coliforms (FEC.COL.) and fecal *Streptococcus* (FEC.STR.) bacteria.

Data were standardized by logarithmic transformation for cluster analysis (distance unit: 1-Pearson r, linkage rule: central weighted pair-group, CSS Statistical package) to recognize spatial and temporal variation of the variables within the system.

RESULTS AND DISCUSSION

During the sampling program, the functioning of the system changed. The water color turned from bright green —characteristic color of the stabilization ponds effluents (Branco 1984)— to dark green and finally to purple red; floating material appeared at the surface and a rotten egg odor identified H₂S production. These changes in color were a useful guide to notice the alteration in the condition and the activity of the pond system (Hawkes 1983). Biological succession from green algae to sulphur bacteria suggested anaerobic conditions caused by overloading, and operational problems. Two months after the sampling program finished, the water acquired a dark gray or black color ratifying the breakdown of the system.

This fact led us to divide the sampling cycle in two periods, the first period, from July through October, when the system worked adequately, and the second from November to January characterized by the overloading and the breakdown of the system. A fissure in the clarifier wall had let raw organic mat-

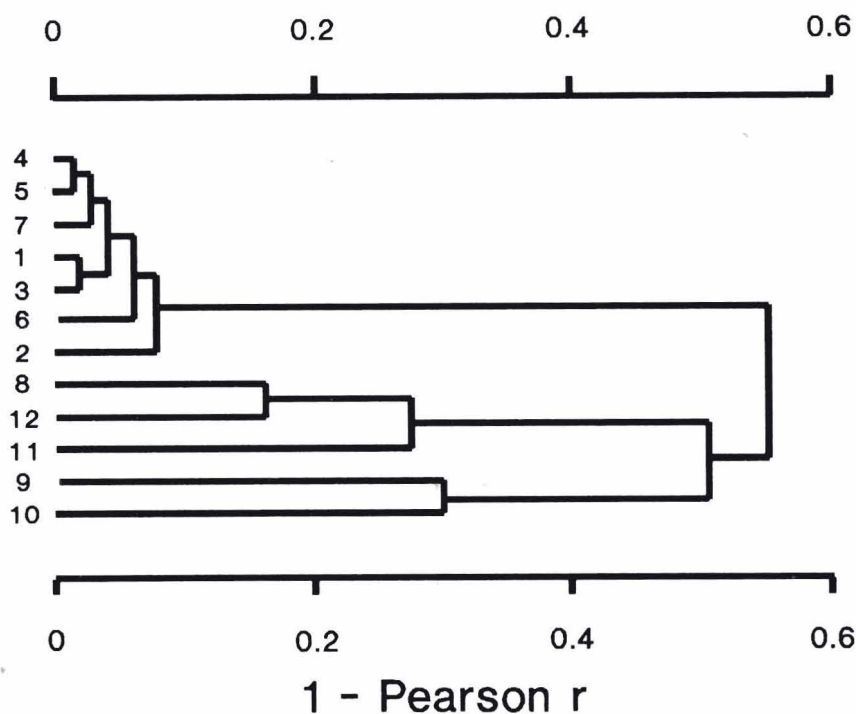


Fig. 2. Dissimilarity dendrogram (1-Pearson r , central weighted pair-group) showing the sampling program dates grouped in two clusters corresponding to the first and the second performance periods. First period: 1 (July 1988), 2 and 3 (August), 4 and 5 (September), and 6 and 7 (October), Second period: 8 and 9 (November), 10 and 11 (December), and 12 (January 1989)

ter (settled sludge) of the clarifier pass into the rest of the system since the beginning of its operation. The system tolerated the overloading during an eight month period before its collapse. A cluster analysis justified the partitioning of the sampling period in two different phases (Fig. 2). The first cluster grouped samplings one through seven, and the second, eight through twelve. Both phases agreed with those established *a priori* (July-October and November-January).

First Period

Table I shows the system variables obtained in the first period as well as in the second. Mean BOD_5 removal efficiency values—related to the general influent—for the clarifier and the anaerobic pond were between 50 and 80%, a value considered by Mara (1976) and Ramalho (1977) to be effective for conventional clarifiers. The facultative pond added an extra 8% purification. Finally, in the maturation pond the removal efficiency reached up to 84%, a standard value for similar systems (Ramalho 1977). According to WPCF and ASCE (1977) higher loa-

dings may be accepted in warmer areas than in temperate areas, because temperature has a predominant influence increasing the efficiency of organic removal.

72% of the non-biodegradable organic matter settled in the first treatment stage (high-rate clarifier-anaerobic pond). Nevertheless, purification efficiency decreased to 69-70% in the rest of the system due to the accumulation of non-degraded matter. Most of the COD material was settled as sludge in the bottom.

According to Ramalho (1977) solids removal efficiencies were high, reaching up to 97% for settleable and 87% for suspended solids in the anaerobic pond. Removal of dissolved and total solids was smaller. The clarifier function principle explains the difference. Organic matter and nutrients favored algae and protozoa growth increasing the amount of suspended solids in the last stages of the treatment. Solids are responsible of the greater part of the effluent BOD_5 , due to their long residence time (Sundstrom and Klei 1979, Hawkes 1983).

The removal of microorganisms increased along the system reaching values near 100% for total and fecal coliforms, and a total elimination for fecal *Streptococcus*. Facultative and maturation ponds showed the highest efficiencies in eliminating this indicator bacteria due to their long detention time (Mara 1976, Hawkes 1983).

Second Period

In spite of the accumulation of organic matter mainly in the high-rate clarifier-anaerobic pond but also in the rest of the system, BOD₅ was removed with an efficiency similar to the first period as can be observed in Table I. Nevertheless, the influent organic load in the second period was lower than during the first. In both cases, the high-rate clarifier and the anaerobic pond eliminated most of the biodegradable organic matter (up to 49%).

Opposite to the first period, COD removal efficiency was zero. As the fissure in the clarifier wall allowed raw organic matter to reach the rest of the system, the facultative pond worked as an extension of the clarifier and the anaerobic pond reaching a high COD removal efficiency (65%). However, the non-biodegradable matter at the final effluent of the system was high.

Total and dissolved solids were not removed from the system in the second period. On the contrary, settling solids showed an increased removal up to 74% in the final system effluent. The fissure did not diminish dramatically the removal efficiency of the settling solids. Furthermore, suspended solids were eliminated by 62% in the anaerobic pond, and reached a global removal efficiency of 63%. Under normal conditions sludge mats can float at high temperatures. Nevertheless, overloading and anaerobic

TABLE I. PHYSICAL, CHEMICAL AND BACTERIOLOGICAL CHARACTERISTICS OF THE SYSTEM DURING THE FIRST (UPPER ROW) AND SECOND (LOWER ROW) FUNCTIONING PERIODS

Parameter (units)	System influent	EFFLUENTS					
		Anaerobic Pond		Facultative Pond		Maturation Pond	
		Mean	Efficiency	Mean	Efficiency	Mean	Efficiency
BOD ₅	389 ± 103	140 ± 39	64%	110 ± 89	72%	63 ± 38	84%
(mg/L)	227 ± 30	116 ± 7	49%	81 ± 25	64%	42 ± 11	82%
COD	839 ± 497	232 ± 66	72%	261 ± 92	69%	249 ± 134	70%
(mg/L)	906 ± 542	1 642 ± 903	0%	315 ± 235	65%	746 ± 816	18%
TOT.SOL.	880 ± 204	581 ± 330	34%	534 ± 113	39%	484 ± 19	45%
(mg/L)	331 ± 117	1 452 ± 129	0%	633 ± 284	0%	707 ± 316	0%
SET.SOL.	8.13 ± 3.09	0.28 ± 0.42	97%	0.15 ± 0.21	98%	0.10 ± 0.12	99%
(mL/L)	5.50 ± 2.95	3.12 ± 3.91	43%	1.68 ± 2.28	70%	1.42 ± 1.95	74%
SUS.SOL.	152 ± 76	20 ± 16	87%	57 ± 16	63%	68 ± 18	55%
(mg/L)	176 ± 93	67 ± 14	62%	101 ± 24	43%	66 ± 10	63%
DIS.SOL.	728 ± 209	560 ± 316	23%	402 ± 84	45%	416 ± 25	43%
(mg/L)	157 ± 139	1 385 ± 124	0%	532 ± 295	0%	645 ± 324	0%
TOT.COL.	1 138 ± 1 099	543 ± 777	52%	544 ± 810	52%	9 ± 9	99%
(MPN/100mL)	2 104 ± 592	1 830 ± 802	13%	1 306 ± 588	38%	418 ± 413	80%
FEC.COL.	138 ± 152	427 ± 826	0%	39 ± 36	72%	4 ± 2	97%
(MPN/100mL)	1 441 ± 1 174	860 ± 678	40%	355 ± 623	75%	224 ± 354	85%
FEC.STR.	1 082 ± 1 147	908 ± 986	16%	15 ± 17	99%	2 ± 1	100%
(MPN/100mL)	2 400 ± 0	1 830 ± 802	24%	823 ± 845	66%	567 ± 610	76%

BOD₅ = biochemical oxygen demand, COD = chemical oxygen demand, TOT.SOL. = total solids, SET.SOL. = settling solids, SUS.SOL. = suspended solids, DIS.SOL. = dissolved solids, TOT.COL. = total coliforms, FEC.COL. = fecal coliforms, FEC.STR. = fecal *Streptococcus*

TABLE II. COMPARISON BETWEEN IXTAPAN DE LA SAL SYSTEM EFFLUENT VALUES AND THE MEXICAN LEGISLATION STANDARDS

PARAMETER (units)	LEGISLATED		MEASURED	
	*Crop irrigation	**Ixtapan de la Sal Plant	First period	Second period
pH (pH Units)	6.0-9.0	NS	9.4	8.3
Temperature (°C)	3.5 above NC	35.0	24.9	20.8
Conductivity (μ mhos/cm)	NS	2000	476	561
BOD ₅ (mg/L)	NS	70	63	42
Floating Matter	Absent	NS	Present	Present
SUS.SOL. (mg/L)	50	70	68	66
DIS.SOL. (mg/L)	2000	NS	416	645
TOT.COL. (MPN/100 mL)	1000	NS	9	418
FEC.COL. (MPN/100 mL)	NS	2000	4	224

* SEDUE (1986a)

** SEDUE (1986b)

NC = Natural Conditions

NS = Not Specified

degradation of the organic matter in the ponds formed floating flocs in the second period. This was not observed in the first stage. A color change associated to rising sludge may indicate a change in the character of the waste (Hawkes 1983).

During the second period, indicator bacteria removal efficiencies were lower than in the first period. Although a growing bacteria elimination was observed, maximum values reached only 80-85%. Septic conditions of the system favored bacteria thus increased their time of survival. Exposure to light (UV irradiation) is the main mechanism of bacterial die-off. In this way, shading by phytoplankton growth reduces the bacterial removal efficiencies. Nevertheless, high pH values produced during photosynthesis is also an important parameter for bacterial death (Hawkes 1983).

Sulphur bacteria were present during this period. These do not contribute to the breakdown of organic matter nor the production of oxygen, thus increasing the hydrogen sulphide concentrations (Hawkes 1983).

Global Removal Efficiencies

Global removal efficiencies at the maturation pond effluent are shown for both periods in Table I. The first period efficiencies were higher than those of the second period except the BOD₅. The fissure on the wall of the high-rate clarifier was the explanation in this difference efficiencies between periods.

The similar BOD₅ removal percentages in both periods proved the system capacity to tolerate an or-

ganic matter overload in its secondary section. COD, total and dissolved solids showed the highest removal difference.

By comparing removal efficiencies between the 1982 (Fig. 1a) (Solís 1982) and the 1988 systems (Fig. 1b) (e.g. in both periods), it can be concluded that the 1988 system did not improve the efficiency of the 1982 system (83%), but reached the same percentage. Although the 1988 system has one facultative pond less than the 1982 system, the efficiencies were similar. This fact represents a substantial reduction in the operational area, thus reducing construction, functioning and maintenance costs.

Water Quality

The Mexican Legislation establishes that wastewater treatment systems must fulfill a series of quality characteristics according to the treated water use (Diario Oficial de la Federación 1989). Moreover, the specific characteristics established that each Mexican wastewater treatment plant effluent must be accomplished (SEDUE 1986). The treated water from the Ixtapan de la Sal plant is mainly used for crop irrigation.

Table II compares the values obtained in this study for both periods with the standards of the Mexican Legislation. Although the average pH value was slightly higher during the first period with respect to the norm, it could be associated to a high primary production.

Floating material, algal mats and organic flocs, are not allowed. Since organic matter is transformed into inorganic through decomposition, water enriched itself with nitrogen and phosphorous inorganic compounds. This nutrient-rich water favors algae growth. Organic matter build up floating flocs when gas bubbles (H_2S and CH_4) rise them to the surface (Hawkes 1983). This phenomenon intensifies at temperatures higher than $22^\circ C$ (Mara 1976). Suspended solids as floating material were high as a result of primary production and floating organic matter. Nevertheless, suspended solids were slightly below the standards established for the Ixtapan de la Sal system (SEDUE 1986).

Although the Ixtapan de la Sal treatment system broke down in the second period, it fulfilled most of the standards imposed by the Mexican Legislation

and the specific characteristics established for the unmodified system. The system showed enough capacity to undertake higher organic matter loading than those specified by design, at the same organic matter removal efficiencies.

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REFERENCES

- Alcocer J. and Escobar E. (1990). The drying up of the Mexican Plateau axalapzcos. *Salinet* 4, 34-36.
- APHA, AWWA and WPCF (1985). *Standard methods for the examination of water and wastewater*. American Public Health Association, Baltimore, 1268 p.
- Branco S.M. (1984). *Limnología sanitaria. Estudio de la contaminación de aguas continentales*. Secretaría General de la Organización de los Estados Americanos, Washington DC, 120 p.
- Clark S.W., Viessman W.Jr. and Hammer M.J. (1977). *Water supply and pollution control*. 3th. Ed., Thomas Y. Crowell, New York, 661 p.
- Diario Oficial de la Federación (1989). Criterios ecológicos de calidad de agua. 13 de Diciembre de 1989.
- Espino E. and Aguirre J. (1976). Evaluation of waste stabilization pond performance. In: *Ponds as a wastewater treatment alternative* (E.F. Gloyna, J.F. Malina, Jr. and E.M. Davis, Eds.). University of Texas, Austin, pp. 275-283.
- Gloyne E.F. (1973). *Estanques de estabilización de aguas residuales*. World Health Organization, Ginebra, 191 p.
- Hawkes H.A. (1983). Stabilization Ponds. In: *Ecological aspects of used water treatment* (C.R. Curds and H.A. Hawkes, Eds.). Academic Press, London, Vol. 2, pp. 166-207.
- Mara D.D. (1976). *Sewage treatment in hot climates*. Wiley, Brisbane, 168 p.
- Ramalho R.S. (1977). *Introduction to wastewater treatment processes*. Academic Press, New York, 580 p.
- Rohlich G.A. (1976). Ponds as viable treatment alternatives. In: *Ponds as a wastewater treatment alternative* (E.F.

- Gloyna, J.F. Malina, Jr. and E.M. Davis, Eds.). University of Texas, Austin, pp. xi-xii.
- Secretaría de Desarrollo Urbano y Ecología (1986). Condiciones particulares de descarga para las lagunas de oxidación de Ixtapan de la Sal, México.
- Solís C. (1982). Experiencias acerca del comportamiento de lagunas de estabilización facultativas en serie en clima subtropical. Memorias del III Congreso Nacional de Ingeniería Sanitaria y Ambiental. México.
- Solís C. and Solís F. (1992). Coeficientes de velocidad de reacción de un sistema lagunar modificado modelo UAEM. Memorias del VII Congreso Nacional de Ingeniería Sanitaria y Ambiental. Cocoyoc, Morelos.
- Sundstrom D.W. and Klei H.E. (1979). *Wastewater treatment*. Prentice Hall, New Jersey, 444 p.
- WPCF and ASCE (1977). *Wastewater treatment plant design*. Lancaster Press, Lancaster, 560 p.