Removal of microorganisms in different stages of wastewater treatment for Mexico City

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Abstract In this study the removal of a diversity of microorganisms during different stages of treatment was evaluated. The process scheme consisted of Advanced Primary Treatment (APT), sand filtration, and chlorine disinfection. During the first 2 stages, fecal coliforms were reduced from 1.24×10^9 to 1.2×10^8 MPN/100 mL and helminth ova were reduced to less than 1 ova/L. Nevertheless, to obtain an effluent water quality that meets the microbiological standards recommended by the World Health Organization (1989) and the Mexican norm for water destined for agricultural reuse it was necessary to disinfect the effluent with a chlorine dose of 12 mg/L for a 3 hour contact time. Under these conditions, fecal coliforms were reduced from 1.2×10^9 to 5.8×10^1 MPN/100 mL, *Salmonella* spp. from 5.0×10^8 MPN/100 mL to below the detection limit, *Pseudomonas aeruginosa* from 2.0×10^5 MPN/100 mL to below the detection limit, and protozoan cysts from 1052 to 31 cysts/L. Regrowth of bacteria was never observed during the 48 hours period following disinfection. The active chlorine was primarily in the form of chloramines thus reducing the formation of other potentially carcinogenic disinfection byproducts.

Keywords Agricultural reuse; chlorination; disinfection; fecal coliform and pathogens

Introduction

Wastewater treatment systems are, in essence, the most fundamental tool used to control the contamination of water in the environment. Through wastewater treatment the water quality is improved, both the ecology of receiving bodies and public health are protected, and potential reuse applications become more favorable.

The increase of gastrointestinal infections due to the use of untreated wastewater has lead to the development of strict water quality standards for effluents destined for reuse. To address site specific conditions within an environmental improvement program, the appropriate type of wastewater treatment will be unique to each country and even city. Within all types of treatment, disinfection plays a critical role because it guarantees the elimination of indicator organisms (i.e., fecal coliforms) and other types of microorganisms, especially pathogens, to safe levels.

One of the most common types of disinfection is chlorination, although the requirements vary considerably depending on the quantity and types of microorganisms present, as well as the presence and nature of organic compounds and potential interactions with industrial discharges, given that the concentration of organic matter affects the chlorine demand. For fecal coliform removal, typical doses range from 5 to 20 mg/L and contact times from 30 to 60 minutes. When treating lower quality waters such as effluents from primary treatment and rotating biological filters, the dose and contact times may be higher and should be determined experimentally for each specific case (Lazarova *et al*., 1999).

This study was comprised of an evaluation of the removal of various microorganisms commonly found in wastewater in developing countries [fecal coliforms, *Salmonella* spp., *P. aeruginosa*, and protozoan cysts (*Giardia* spp. and *Entamoeba histolytica*)]. The removal was evaluated at each stage of the treatment process, which was comprised of Advanced Primary Treatment (APT), high rate filtration, and chlorine disinfection. The regrowth of microorganisms for 48 hours following disinfection was also evaluated.

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Background

The wastewater produced in the Valley of Mexico is transported to the Mezquital Valley by three drainages: the Grand Drainage Canal, constructed at the beginning of this century, the Central Emisor, which is a tunnel constructed in the 1970s, and the Western Emisor, which was constructed in the 1960s. Currently, the 74.5 m^3/s of wastewater produced in the Valley of Mexico (70% domestic, industrial and commercial and 30% stormwater) is used to irrigate 90,000 hectares (ha) in the Mezquital Valley. The National Institute of Public Health has demonstrated that, because the wastewater does not receive any treatment before being used, the incidence of gastrointestinal illnesses is 13 times higher in this valley compared to zones where first-use or treated water is employed.

Based on research conducted at the Institute of Engineering at the National Autonomous University of Mexico (UNAM), the principal problem that restricts agricultural reuse is the concentration of microorganisms, given that the wastewater contains an average helminth ova concentration of 24.8 ova/L, with values ranging from 6 to 96 ova/L, and an average fecal coliform concentration of 6.5×10^8 MPN/100 mL, ranging from 4.1×10^7 to 5.5×10^9 MPN/100 mL (Jiménez *et al*., 1999). In addition, the wastewater contains a wide diversity of pathogens at high concentrations, as shown in Table 1. Therefore, the removal of pathogens is the major treatment objective such that a water quality can be obtained that meets the recommendations of the World Health Organization (1989), Shuval (1989), and Bartone (1991), and required by the Mexican norm (NOM 001 ECOL/96) for agricultural reuse. Thus the focus of this study was the elimination of organisms during each treatment step.

In Mexico, APT followed by filtration has been studied widely as a method for removing helminth ova to concentrations less than 1 ova/L while minimizing the removal of organic matter and nutrients (N and P) due to the soil and agronomic benefits they present (Jiménez and Chavez, 1997, and Jiménez *et al*., 1999). However, this system must be combined with disinfection to reduce fecal coliforms (and thus other microorganisms) to less than 1000 MPN/100 mL; this protects the health of agricultural workers and the general population and avoids the need to restrict the types of irrigated crops, thus benefiting the local economy. Thus it was considered of interest to study the performance of a system composed of APT, filtration, and chlorination with the objective of removing fecal coliforms and pathogenic organisms present in this type of wastewater. Given the microbiological variability, the effectiveness of fecal coliforms to serve as indicators of the pathogens present was also studied.

Experimental methods

This research was conducted on site, using wastewater directly from one of the Mexico City sewers with an average flow of 30 m^3/s (Central Emisor). A diagram of the treatment process is presented in Figure 1.

Table 1 Comparison of the microbiological content of wastewater in Mexico and as reported in the literature

Countries	Microorganism	Unit (MPN/100 mL)	Reference
Mexico	Fecal coliforms	10^7 to 10^9	Jiménez *et al.,* 1999
USA	Fecal coliforms	10^3 to 10^5	Stover *et al*., 1995
Israel	Salmonella	10^1 to 10^2	Armon *et al.,* 1994
USA	Salmonella	10^2 to 10^4	NRC, 1998
Mexico	Salmonella	6×10^5 to 3×10^9	Jiménez *et al.,* 1999
Mexico	Pseudomonas	10^4 to 10^7	Jiménez *et al.,* 1999

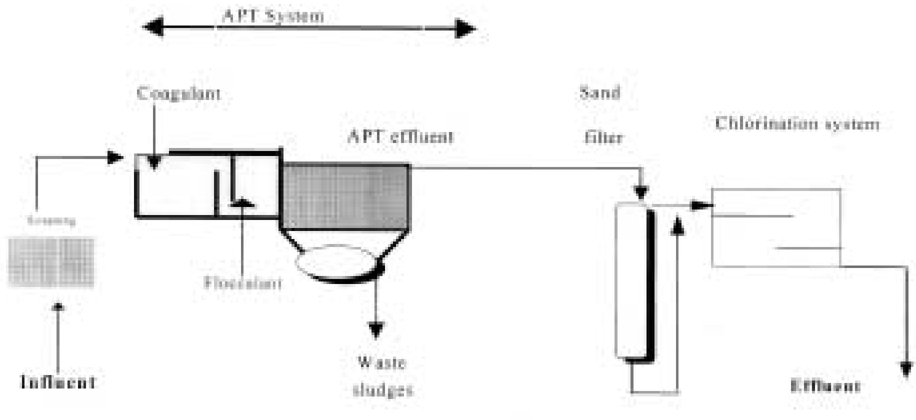

Figure1 Diagram of the treatment system

Advanced Primary Treatment (APT) and filtration

The wastewater was pumped from the sewer to a pilot plant with a capacity of 20 L/s. The system consisted of static bar screens to retain large solids, followed by a rapid mix coagulation tank in which 50 mg/L aluminium sulfate was added, and a slow mix flocculation tank in which 1.0 mg/L of a high molecular weight anionic polymer was added. The water then passed to a high rate sedimentation basin with a hydraulic residence time varying between 15 and 50 minutes depending on the sedimentation rate applied. The APT treatment was followed by an upflow filter using sand media ranging from 1 to 2 mm in diameter, and a filtration rate between 15 and 20 m/h.

Evaluation of continuous chlorination of the filtered APT effluent

After filtration, 15 L/min of the treated wastewater was diverted by a 2″ (5.1 cm) diameter pipe to the chlorination tank, the specifications of which are reported in Table 2. To evaluate the chlorination efficiency three doses were studied (8, 10, and 12 mg/L) with contact times of 0.5, 1.0, 2.0, and 3.0 hours. To determine the potential for regrowth after chlorination, 10 L of chlorinated water were stored at ambient temperature and exposed to light; aliquots were removed for analysis after 0.5, 1, 2, 3, 6, 8, 24, and 48 hours. A summary of the parameters analyzed is presented in Table 3. All analysis were conducted according to Standard Methods (1995).

Results and discussion

The concentrations of fecal coliforms present at the different stages of treatment and after chlorination with various doses and contact times are presented in Table 4. The fecal coliform concentration in the raw wastewater was between 7.8×10^8 and 1.2×10^9 MPN/100 mL, and less than one log removal was observed after APT and filtration. After the addition of 8 mg/L of chlorine and 3 hours of contact, fecal coliforms were reduced to 6.3×10^4 MPN/100 mL. With a dose of 10 mg/L fecal coliforms were reduced to 1.1×10^3 MPN/

Table 2 Design specifications of the chlorination tank

Parameter	Values	Parameter	Values	Parameter	Values
Total height, m	1	Length, m	2.25	HRT per module, h	1
Useful height, m	0.6	Total area, m^3	19.5	Total Volume, m^3	4.4
Width, m	1.95	Number of units	3	Useful volume, m^3	2.7

Table 3 Physico-chemical and microbiological parameters measured in the wastewater

Parameter	Influent and APT effluent	Filtration	Disinfection	Method	Frequency
		Microbiological			
Fecal coliform, MPN/100 mL	xx	xx	xx	Membrane Filter	Routine
Salmonellas spp., MPN/100 mL	xx	xx	xx	Membrane Filter*	Sporadic
P. aeruginosa, MPN/100 mL	xx	xx	xx	Membrane Filter*	Sporadic
Protozoan cysts, Cysts/L	xx	xx	xx	Membrane Filter	Sporadic
		Physico-chemical			
Turbidity, UTN		xx	xx	Nefelometric	Routine
TSS, mg/L	xx	xx	xx	Gravimetric	Sporadic
pH		xx	xx	Potentiometric	Sporadic
Organic N, mg/L	xx	xx	xx	Titration	Sporadic
Ammonia N, mg/L	xx		xx	Titration	Sporadic
Total COD, mg/L	xx	xx	xx	Photometric	Sporadic
Free chlorine, mg/L			xx	Titration (DPD)	Routine
Combined Chlorine, mg/L			xx	Titration (DPD)	Routine
TKN, mg/L	xx	xx	xx	Titration	Sporadic
Conductivity (mμhos/cm)	xx	xx	xx		
Sporadic TDS, mg/L	xx	xx	xx	Gravimetric	Sporadic

* verified with the API 20E technique

Table 4 Effect of dose and contact time on chlorine disinfection (MPN/100 mL)

Chlorine dose (mg/L)	Number of samples	Influent	Effluent	Filtration	0.5	1.0	Contact time (h) 2.0	3.0
			Fecal coliform (MPN/100 mL) (geometric mean)					
8	392	7.8×10^8	1.1×10^8	1.1×10^8		3.4×10^4	3.9×10^4	6.3×10^4
10	398	1.1×10^9	1.8×10^8	7.5×10^7	1.6×10^4	4.5×10^3	1.7×10^3	1.1×10^3
12	258	1.2×10^9	3.5×10^8	1.2×10^8	1.6×10^4	3.7×10^3	1.8×10^3	5.8×10^1

100 mL, but to comply with the norm of 1000 MPN/100 mL a dose of 12 mg/L was required and a 3 hour contact time.

The microbiological quality of the effluent in terms of fecal coliform concentration for 48 hours after chlorination is illustrated in Figure 2. Regrowth was not observed under any of the conditions studied. With the 10 mg/L dose, the concentration remained constant (between 3.5 and 4.5×10^4 MPN/100 mL) from 0.5 hours up to 5 hours after chlorination. With the 12 mg/L dose, the fecal coliform concentration continued to decline for 4 hours after the chlorine was added; after this the concentration remained constant at less than 1000 MPN/100 mL for 48 hours. Thus with a dose of 12 mg/L it can be assured the effluent is free of microorganisms and post-chlorination would not be necessary in the irrigation canals. In the Irrigation District where the wastewater is currently used (DR 03), only 62% of the 575 km of canals in the distribution network are lined. The travel time for the wastewater to reach the most distant point in the network is 24 hours, and so it is important to know the potential for regrowth during this interval.

The raw wastewater contained a high concentration of other microorganisms that should be considered important because of their potential impact on public health. *Salmonella* spp. was found in concentrations around 10^8 MPN/100 mL, *P. aeruginosa* in concentrations from 10^4 up to 10^6 MPN/100 mL and protozoan cysts from 1.2×10^3 up to 1.8×10^3 cysts/L (*Giardia* from 10^2 to 10^3 and *Entamoeba histolytica* of 10^2 cysts/L). The APT system and filtration were capable of reducing the concentrations by 1 to 2 orders of magnitude. The

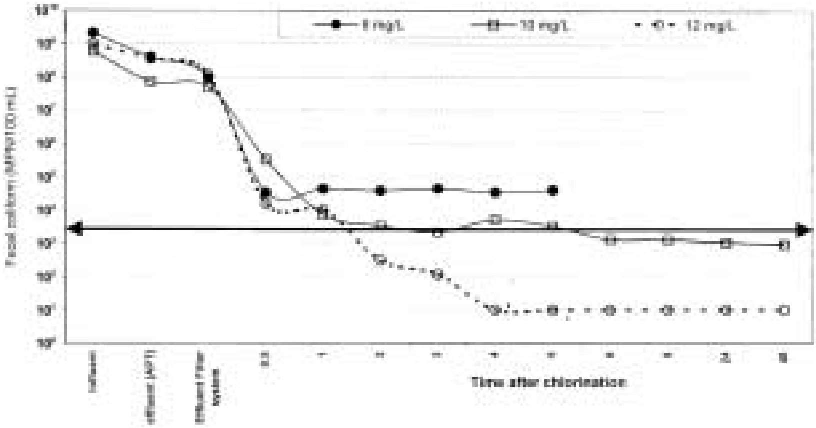

Figure 2 Fecal coliform concentrations at the different stages of treatment and up to 48 hours after chlorination

reduction of these organisms after each stage of treatment and after exposure to various chlorine doses with contact times up to 48 hours is shown in Table 5. Despite the high concentrations of pathogens in the filter effluent, chlorine doses above 10 mg/L and contact times greater than 0.5 hours were sufficient to efficiently remove the organisms, and no regrowth was observed even after prolonged contact times. In the case of protozoan cysts, increasing chlorine doses were not capable of achieving complete cyst removal; however, the viability of the residual cysts was not determined and thus it is not known they would present a risk if this water was reused.

As seen in Figure 3, fecal coliforms were a good indicator of the concentration and inactivation of the pathogens measured in the water. A dose of 12 mg/L assured that the effluent produced and destined for agricultural reuse complied with the required standards; fecal coliforms, *Salmonella* spp. and *P. aeruginosa*, and protozoan cysts were efficiently removed by chlorination.

One of the principal objectives of wastewater treatment destined for agricultural reuse in Mexico is to minimize the removal of organic matter. However, the presence of organic matter during chlorination can favor the formation of precursors to chlorinated organics,

Table 5 Removal of pathogenic microorganisms during chlorination

	***Salmonella* sp (NMP/100 ml)**				***P. Aeruginosa* (NMP/100 ml)**				**Protozoan cysts (cysts/L)***			
	Chlorine dose (mg/L)											
	10	**11**	**12**	**14**	**10**	**11**	**12**	**14**	**10**	**11**	**12**	**14**
Influent	7.5×10^8	5.4×10^8	5.0×10^8	1.1×10^8	1.4×10^6	4.0×10^4	2.0×10^5	7.5×10^5	1222	1397	1052	1814
Effl. (APT)	7.5×10^7	5.6×10^7	6.0×10^7	3.1×10^6	5.2×10^4	3.0×10^3	2.3×10^4	2.2×10^4	435	301	313	524
Effl. Filtration	2.8×10^7	5.8×10^6	1.5×10^7	4.8×10^7	2.3×10^4	1.5×10^3	3.2×10^4	7.0×10^3	211	79	201	235
0.5 h	28				455	0	160	0	NA	NA	NA	NA
1 h	9	ND	2930	ND	2511	49	0	0	NA	NA	0 1	30
2 h	ND	ND	ND	ND	895	0	0	0	77	34	50	63
3 h	ND	ND	ND	ND	38	0	0	0	53	25	31	39
4 h	ND	ND	ND	ND	130	0	0	0	37	12	26	NA
5 h	ND	ND	ND	ND	0	0	0	0	NA	NA	NA	NA
6 h	ND	ND	ND	ND	0	0	0	0	NA	NA	NA	NA
24 h	16750	ND	ND	0	464	0	0	0	NA	NA	29	NA
48 h	34520	ND	ND	0	1680	0	0	0	12	NA	19	21

* *Giardia spp, and Entamoeba histolytica*
ND = Not detected NA = Not analyzed

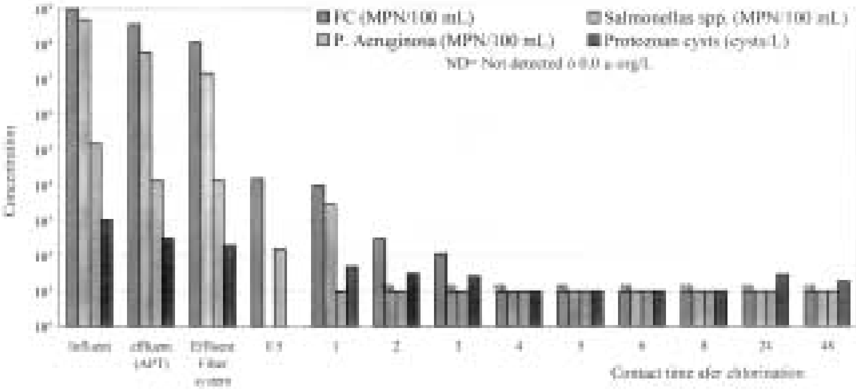

Figure 3 Removal of microorganisms using 12 mg/L chlorine

many of which present high health risks. The concentration of N-NH_4 (15.1 mg/L) and the diverse forms of combined organic matter present in the wastewater in this research led to the formation of chloramines, which are also effective disinfectants; although the reaction rate of chloramines is slower, they remain in the water longer (Metcalf & Eddy, 1991). The dominant form of chloramine compounds depends on the temperature and pH, with monochloramine being favored at the pH (6.7) encountered in this water (Blatchley *et al.*, 1991).

A summary of the main constituents of importance in the wastewater after each stage of treatment is presented in Table 6 for a chlorine dose of 12 mg/L and 3 hour contact time. The residual free chlorine concentration in the effluent (0.93 mg Cl_2/L) and the combined chlorine concentration (7.86 mgCl_2/L) were sufficient to prevent regrowth even prolonged periods (refer to Figures 2 and 3). An increase in the chlorine dose would imply a higher concentration of free and combined chlorine, with the latter dominating.

The chlorine doses recommended for different uses by several different references are listed in Table 7. The doses found to be effective in this research are basically in agreement with those listed in the Table 7, although the recommended contact times are typically shorter, between 15 and 60 minutes (Narkis *et al.*, 1995). No references were found in the literature addressing the specific case of chlorination of water containing high organic matter and nutrient concentrations, but it is assumed that because of these conditions longer contact times were required in our research. It should be mentioned that an increase in the contact time in the Mexico City case would not require a greater capital investment; chlorine could be injected directly into the distribution pipes in which the minimum contact time of 3 hours would be achieved, thus saving the cost of the contact tank.

Conclusions

The raw wastewater, which is currently used untreated for irrigation, contained high concentrations of a variety of microorganisms. The concentration of fecal coliforms varied between 7.8×10^8 and 1.2×10^9 MPN/100 mL, *Salmonella* spp. between 1.1×10^8 and 7.5×10^8 MPN/100 mL, *P. aeruginosa* between 3.9×10^4 and 1.6×10^6 MPN/100 mL, and protozoan cysts (only to *Entamoeba histolytica* and *Giardia*) between 1.0×10^3 and 1.8×10^3 cysts/L. These levels must be reduced by a wastewater treatment system before reuse due to the health risks they present.

Under the conditions of this research, the APT system combined with filtration was capable of reducing the microorganism concentrations by 1 to 2 orders of magnitude. The addition of a disinfection step was thus necessary to further reduce the concentrations.

Table 6 Water quality parameter after each stage of treatment and different chlorine contact times

Contact time	Cl_2 dose (mg/L)	Fecal coliforms (MPN/100 mL)	Cl_2 free mg Cl_2/L	Cl_2 combined mg Cl_2/L	CODt mg/L	N-NH_4 mg/L	pH
Influent	–	1.2E+09	–	–	382		6.7
Effluent (APT)	–	3.2E+08	–	–	197	15.7	6.4
Effluent Filtration	–	1.2E+08	–	–	191	12.3	6.43
0.5 h	12	1.6E+04	1.5	6.6	170	15.1	6.5
1 h	12	3.7E+03	1.3	7.0	164	14.6	6.6
2 h	12	1.8E+02	1.1	7.5	156	14.8	6.6
3 h	12	5.8E+01	0.9	7.8	147	15.7	6.7

Contact time	Cl_2 dose (mg/L)	Conductivity µmhos/cm	Turbidity UTN	N-total mg/L	N-Org. mg/L	P-Total mg/L	TSS mg/L
Influent	12	1300	32	15.7	0.8	1.8	261
Effluent (APT)	12	1315	32	13.2	1.7	1.4	37
Effluent Filtration	12	1261	25	17.4			38
0.5 h	12	1286	28	15.8	1.0	1.2	27
1 h	12	1272	27	15.8	1.0	2.4	25
2 h	12	1289	25	15.8	1.1	1.9	24
3 h	12	1278	22	16.0	1.1		21

Table 7 Typical chlorine doses (Adapted: Environment Federation and American Society of Civil Engineers, 1992)

Type of wastewater	Wastewater Engineering	Handbook of chlorination mg/L	Ten State Standards (USA)
Pre-chlorination of wastewater	6 – 25	15 – 40	20
Primary effluents	5 – 20[a]	18 – 24[b]	–
Activated sludge effluents	2 – 8[a]	6 – 9[b]	8[a]
Filtered effluents	1 – 5[a]	4 – 6[b]	6[a]

a) For specified coliform values
b) For 100–200 MPN/100 mL fecal coliform
* Original reference

Using a chlorine dose of 12 mg/L and a contact time of 3 hours, the concentrations were reduced to satisfactory levels; fecal coliforms were reduced to 5.8×10^1 MPN/100 mL, *Salmonella* spp. and *P. aeruginosa* were reduced to below the detection limit, and protozoan cysts were reduced to 21 cysts/L.

The concentration of residual free chlorine (0.93 mgCl_2/L) assured that no bacterial regrowth occurred for prolonged periods after disinfection (up to 48 hours). The concentration of combined chlorine (7.86 mgCl_2/L) would also have a residual effect and serve as disinfectant although at a slower rate. The pH of the effluent (6.7) and the presence of ammonia nitrogen (15.1 mg/L) favored the formation of combined chlorine products principally in the form of monochloramine.

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