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ALTERNATIVE TREATMENT FOR WASTEWATER DESTINED FOR AGRICULTURAL USE

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ABSTRACT

An Advanced Primary Treatment (APT) system commercially known as ACTIFLO®, coupled with a system of filtration and chlorination are described. The system used microsand grains in the coagulation phase. This allowed an almost immediate start-up as well as an increase in loading in the sedimentation tank to rates far higher than those previously described (up to 180 m/h). The process was shown capable of treating wastewater from a combined drainage system, which typically varies in water quality and quantity. The ACTIFLO® process reduced TSS from 354 to 27 mg/L, helminth eggs from 24.8 to 1.2 HE/L, COD from 460 to 198 mg/L, TKN from 21.7 to 18.3 mg/L, and TP-P from 8.7 to 3.2 mg/L. To comply with WHO, 1989 recommendations regarding HE quality in water destined for irrigation of crops eaten raw it is necessary to add to the APT a system of filtration. In the paper two types of filter media are compared. In both cases the HE were reduced to <1.0 HE/L for filtration rates of up to 40 m/h. In the disinfection phase 10 mg Cl_2/L were used to reduce the number of fecal coliforms from 6.5 x 10^8 to 340 MPN/100 mL. © 1999 IAWQ Published by Elsevier Ltd. All rights reserved

KEYWORDS

Advanced primary treatment; ballasted sedimentation; helminth eggs; high rate sedimentation; reuse.

INTRODUCTION

In Mexico, the use of wastewater for agricultural irrigation is common practice. The wastewater from Mexico City has been so used since 1890, when three drainage canals were built to take wastewater out of the basin know as the Valley of Mexico. The wastewater is used to irrigate an important agricultural area north of the city, 90,000 ha, resulting in significant increases in crop yields. However it has been noted (Cifuentes, 1992), that the rate of parasitic illness found here is greater than in areas where first use water is employed for irrigation. Recommendations from WHO 1989, are that for crops eaten raw, the wastewater used for irrigation should contain less than 1 helminth egg (HE/L) and 1000 fecal coliforms (FC) (MPN/100 mL). The Mexican Standards (NOM-001-ECOL/96) are of < 1 HE/L and 1000 MPN/100 mL for all crop types and < 5 HE/L and 1000 NMP/100 mL for crops which are not eaten raw. On the other hand, the benefits in terms of crop yields where wastewater is used require that any treatment employed reduces only partially the nitrogen, phosphorus and organic matter present in the wastewater. Various processes exist which meet these two requirements. In this article the feasibility of an Advanced Primary Treatment (APT) which uses microsand grains in the coagulation-flocculation process is analyzed.

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BACKGROUND

According to the EPA report 1992a, there are some ten processes which will reduce bacteria, viruses, cysts and helminth eggs. TPA is one of these. As regards helminth eggs, the report states that these are reduced by an interval of between 0 to 3 logarithmic units (depending on which process is used). It also emphasizes the need for more research to confirm these values.

Advanced Primary Treatment (APT) is a physico-chemical process in which coagulant (aluminum sulfate or ferric chloride) along with flocculants, usually anionic compounds of high molecular weight, are added in smaller doses than those required by traditional physico-chemical processes (Harleman, 1992 and Shao et al., 1995). APT reduces the amount of material suspended in the water. Since HE are 20 to 80 μm and of 1.03 to 1.3 in density, they make up part of this suspended material and are therefore likely to be removed by processes such as APT. Various patented technologies using the APT principle are on the market. Each has its own advantages and disadvantages and one such is ACTIFLO®. This uses sand grains as ballast which greatly increases the speed of TSS sedimentation and deals efficiently with variations in the quantity and quality of the influent. The sedimentation speeds recommended for processes during coagulation-flocculation vary from 24 to 98 $m^3/m^2.d$ according to ASCE and AWWA, 1990; Metcalf and Eddy, 1991 and WEF, 1992. The ACTIFLO® (developed, patented and marketable by OTV) has been tested at speeds of up to 3120 $m^3/m^2.d$ (Guibelin et al., 1994). The objective of this study was to verify the efficiency of the system in removing HE and test these higher rates of sedimentation in conditions of continuous operation with wastewater.

METHODOLOGY

The treatment system is made up of an APT unit, filtration and chlorine disinfection, as seen in Figure 1. The APT, commercially known as ACTIFLO®, is composed of a coagulation-flocculation unit, in which aluminum sulfate (from 40 to 60 mg/L) and microsand of size 0.1 to 1.0 mm are used to separate the solids. Earlier jar tests demonstrated an optimum dose of 0.8 to 1.0 mg/L anionic polymer of high molecular weight. Next the wastewater and flocs are passed through a lamellar settling tank. The sludge produced is sent to a hydrocycloning unit where it is separated from the sand, which is then returned to the coagulation tank. Part of the treated water is then passed through sand filters, which function in parallel with two different filter types (Table 1). The filtered effluent goes through a contact tank where chlorine disinfection takes place.

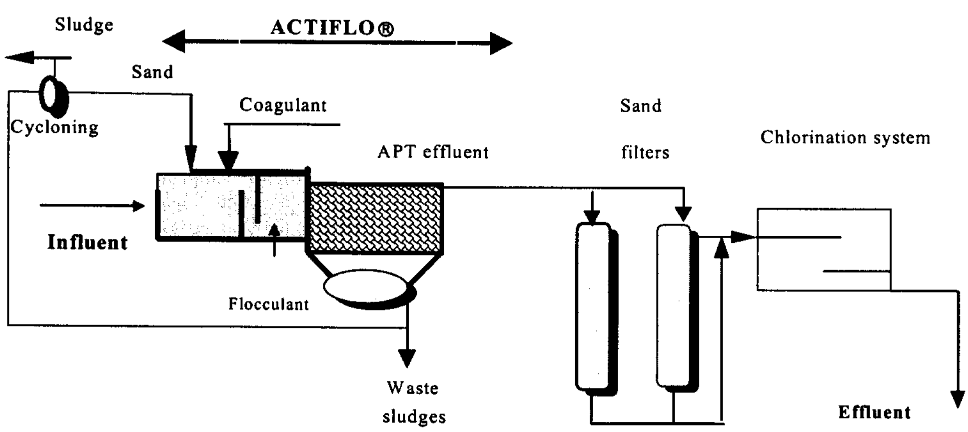

Figure 1. Flowchart of the treatment used.

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Table 1. Main characteristics of the filters

Parameters	Filter 1	Filter 2
Bed thickness (m)	1	1.5
Internal diameter (m)	0.30	0.30
Filtration speed (m/h)	10 to 40	30 to 40
Granular-Medium Filtration	Single-medium	Multi-medium

Throughout the process analysis of the parameters shown in Table 2 was carried out routinely. For 4 months samples were taken 3 times a day on 3 days of the week. For 2 months samples were taken 6 times a day, every day. The methods employed were based the Standard Methods, 1995 except in the case of HE detection, where the method was that of EPA, 1992b. In the start-up study the TSS and turbidity were measured every 5 minutes from the beginning of the operation for 50 minutes.

Table 2. Parameters analyzed at the pilot plant

Operating condition	Flow, hydraulic retention time, coagulant and flocculant doses and hydraulic load in sedimentation tank	
Influent, Effluent and Sludge	Physical	TTS, TTV, TSS, VSS, turbidity, color, temperature, redox potential, and particle size distribution
	Chemical	Nitrogen (Kjedahl, organic and inorganic), total phosphorus, orthophospates, total and soluble COD, sulphate, sulphur, cyanide, F, B, Al, Cd, Ca, Cu, Cr, Fe, Mg, Mn, Ni, Pb, Se, Na and As.
	Microbiological	Helminth eggs, Salmonella sp, Pseudomonas and fecal coliforms
Effluent	Chlorine demand	

RESULTS AND DISCUSSION

Performance in the treatment system

The average effluent quality (March-October, 1997) after each phase of the treatment system is shown in Table 3. By the end of the entire process the TSS were reduced from 354 to 10 mg/L (97.2%) and the helminth eggs from 24.8 to 0.28 HE/L (98.9%). With 10 mg/L of chlorine and a contact time of 3 hours, fecal coliforms were reduced from 6.5 x 10^8 to 340 MPN/100 mL. The values of TKN and TP-P in the effluent are 11.0 and 2.1 mg/L (47.0 and 75.8% reduction) respectively, values which offer quantities of 169 kg N/ha per year and 32.3 kg PT/ha per year, sufficient to guarantee the nutrient necessities of maize, alfalfa, barley and oats in the irrigation area. In addition, there are reductions of over 87% in the turbidity and color.

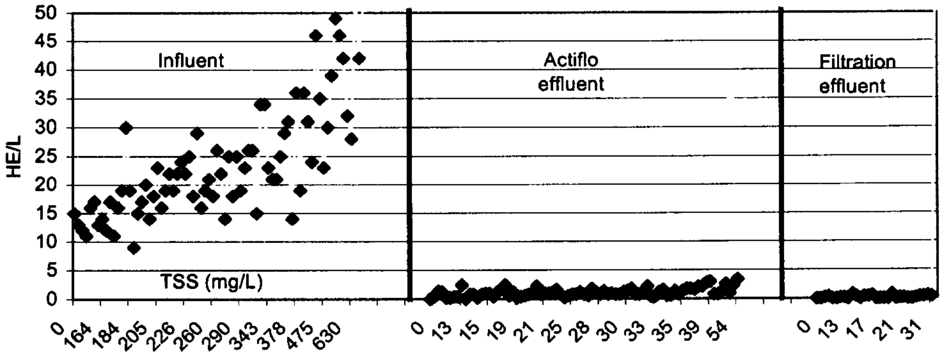

Figure 2. Relationship between helminth eggs and TSS in untreated wastewater, the APT effluent and the filtered effluent.

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The relation between HE and TSS in untreated wastewater is shown in Figure 2. The APT effluent average values were 1.2 ± 0.7 HE/L (3.4 maximum) which correspond to TSS of 27 ± 10.5 mg/L (55 mg/L maximum). Lower TSS values do not necessarily represent a reduction of HE in the effluent. In the filtered effluent the HE/L found varied between 0 to 0.8 HE/L, with an average of 0.28 HE/L.

Table 3. Effluent quality after each phase of the treatment system

Parameters, Units	Influent	Actiflo effluent	Filtration effluent	Chlorinated Effluent	Removal %
TSS, mg/L	354	27	15.6	10	97.2
VSS, mg/L	183	18	10.4		94.2
TS, mg/L	1380	821	948	710	48.5
HE, HE/L	24.8	1.2	0.28		98.9
FC, MPN/100 mL	6.5×10^8	2.2×10^7	3.2×10^7	$3.4E \times 10^2$	>99.9
TKN, mgN/L	21.7	18.3	12.0	11.5	47.0
NH_4-N, mg N/L	19.5	16.7	11.3	11.0	43.6
TP-P, mgP/L	8.7	3.3	2.3	2.1	75.8
Total COD, mgO_2/L	460	198	144	104	77.4
Soluble COD, mgO_2/L	217	157			
Turbidity, NTU	265	21	15.3	12.0	95.5
Color, Pt-Co	1060	109	131		87.6
pH	7.16	7.0	7.0	6.81	
Temperature, °C	21	20.5	21.3		
Redox potential, mV	-11.72	-5.5	1.40	3.4	
Conductivity, mS/cm	1186	1209	1251		
UV transmittance, %	14.3	31.3	28.4		
Total BOD, mgO_2/L /L	491	61	61		87.6
Soluble BOD, mgO_2/L	303	63	58		80.8
Sulphate, $mgSO_4/L$	174	145	126		27.6
Sulphur, mgS^{2-}/L	6.2	1.2	0.59		90.5

Performance of ACTIFLO®, (APT)

Start-up

One of the advantages offered by the use of sand in an APT process is the rapid start-up of the system. Figure 3 shows the behavior of the TSS for a hydraulic load of 120 m/h (2880 m^3/m^2.d) in the sedimentation tank, using 60 mg/L of aluminum sulfate. As can be seen, in the first 5 minutes TSS were reduced from 270 to 37 mg/L in the effluent reaching the lowest value of 29 mg/L after 10 minutes of operation (89% reduction). Therefore following any operational fault, only 10 minutes are needed before the system can again be producing effluent of a constant quality.

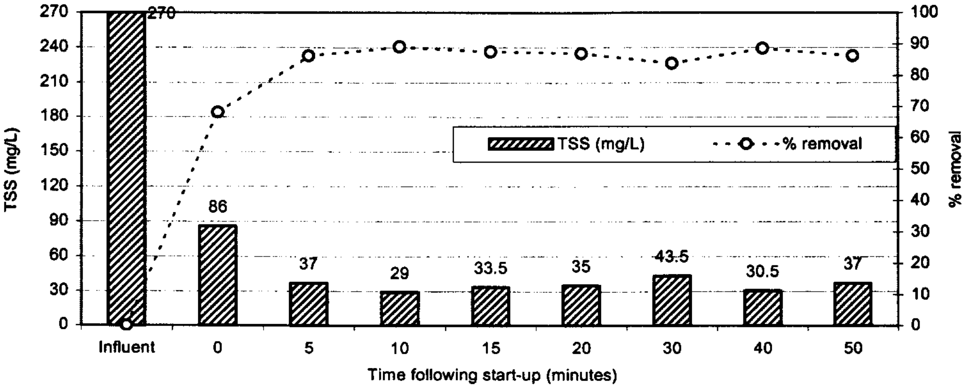

Figure 3. ACTIFLO performance in start-up at 120 m/h (2880 m^3/m^2.d)

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Study of various sedimentation rates

Figure 4 shows the variation in TSS quality of the influents and effluents for all the sedimentation rates analyzed. The ACTIFLO® system produced effluents of a constant quality (27 ± 16 mg TSS/L) regardless of the influent quality (117 to 680 mg/L), with rates from 90 to 180 m/h (1344-4320 m^3/m^2.d). This is, in fact, 44 times higher than rates described elsewhere (ASCE and AWWA, 1990; Metcalf and Eddy, 1991 and WEF, 1992). It may be concluded that using sand combined with a specific optimum flocculation stage for the production of heavy flocs with lamellar settling, the design of very compact sedimentation units is possible.

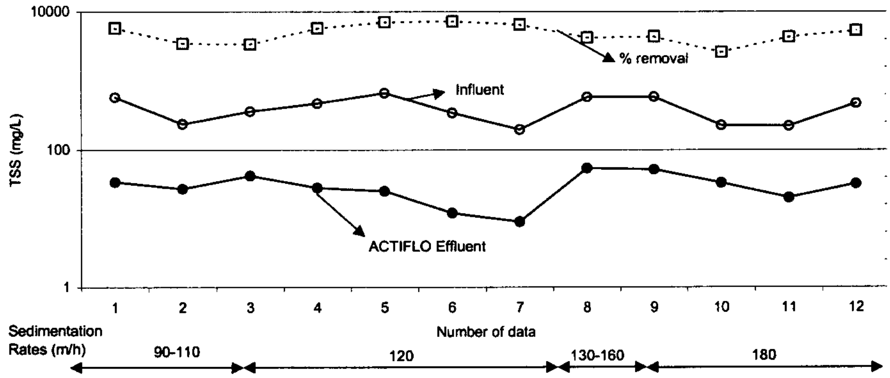

Figure 4. TSS content in the influent and the ATP effluent related to the sedimentation rate.

The results of the main parameters at each rate are shown in Table 4. At the highest rate, 180 m/h or 4320 m^3/m^2.d, a reduction in helminth eggs of 97% was obtained (from 27 ± 11 to 0.8 ± 0.5 HE/L) whilst TSS were reduced by 95.8% (from 486 to 20 ± 19 mg/L).

Table 4. Water quality leaving the ACTIFLO with sedimentation rates from 90 to 180 m/h. (1344 - 4320 $m^3.m^2/d$)

Parameters (mg/L)		Sedimentation rate (m/h)											
		90		100		120		130		160		180	
		Inf	Eff	Inf	Eff	Inf	Eff	Inf	Eff	Inf	Eff	Inf	Eff
TSS	MEAN	208	59	328	24.3	435	33	287	32	396	22	486	20
	S. D.	49	46	390	12	415	22	99	20	259	16	377	19
HE*	MEAN	21.5		27.6	2.2	28.5	1.2	29.7	2.4	23.5	0.7	27	0.8
	S. D.	10.6		13	2.8	22	0.8	11.6	2.3	5.1	0.1	11	0.5
TotalCOD	MEAN	499	265	555	192	454	197	498	254	462	186	373	171
	S. D.	30	29	229	50	184	72	15.5	36	94	62	92	77
TKN	MEAN	37.3	35	25.6	23	18.9	15.7	27	21.5	14	12.8	14	12
	S. D.	18	14	1.7	3.6	3.5	4.0	3.0		1.6	2.4	2.0	2.1
TP-P	MEAN	5.1	1.5	10	2.0	10.4	4.8	8.9	3.5	6	1.1	9	1.6
	S. D.	4.6	0.5	5.4	1.2	7.5	7.0	4.0		0.7	0.7	4.1	1.8

* He/L S.D. Standard Deviation

Filtration of the ACTIFLO effluent

Since the APT effluent does not comply with standards for HE concentration for crops consumed raw, filtration is desirable. In order to compare two types of filters (single-medium and multi-medium), the effluent was passed through two filters working in parallel. As can be seen in Figure 5, the HE concentration never exceeded the accepted limits, ranging from 0.0 to 0.8 HE/L.

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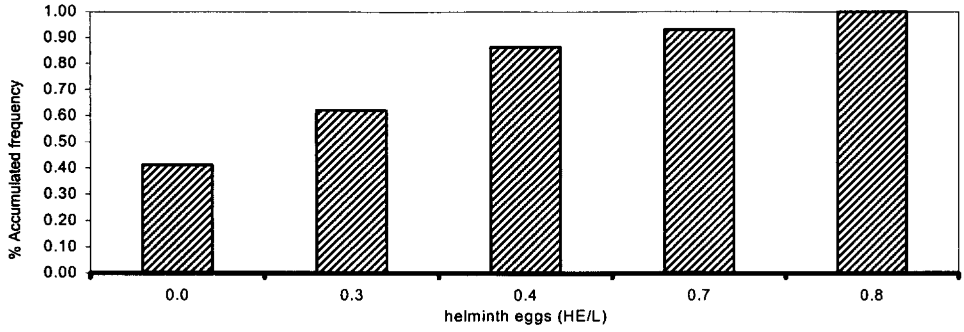

Figure 5. Cumulative percentage of samples with helminth eggs concentration less than or equal to the indicated value for the sand filters effluent.

The results for each of the filter rates studied are shown in Figure 6. For the single medium filter, 11 m/h was the best rate, giving an average run of 16.4 hours. The TSS measured in this case were of 18.0±10.5 mg/L, the HE were of 0.18±0.2 HE/L and CODt of 150±52 mg/L. Rates of up to 40 m/h (see Figure 6) were also studied and it was found that the length of run decreased in proportion to the increase in rate, to values of 8 hours.

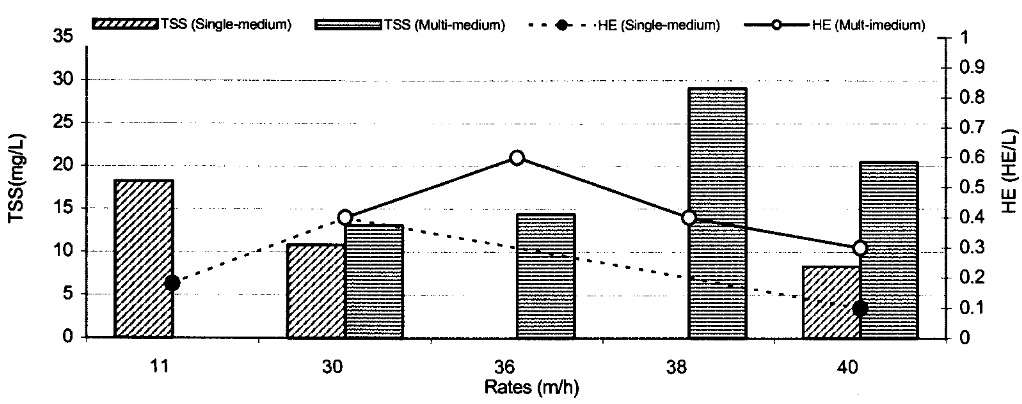

Figure 6. TSS and HE results related to filter rates in each of the filters.

Regarding the multi-medium filter the best performance was given at 40 m/h with an average run length of 20.7 h. Here TSS results in the final effluent were 20.6±13.5 mg/L, HE of 0.28 ± 0.31 HE/L, CODt of 53.7± 41.5 mg/L, TKN of 9.94±0.74 mg/L and 0.26±0.21mg/L for TP-P. The length of run in this case was predetermined as an operational condition not as the result of achieving an acceptable head loss or having excessive TSS in the effluent. Hence given the efficiency obtained and the high filtration speeds used, the multi-medium filter gave the better results.

Helminth eggs range from 20 to 80 μm in size (Ayres, 1989). Figure 7 shows the distribution of particle size in each phase of the process. Based on this data it was concluded that 26% of the solids found in the influent were of this size. This percentage falls to 1.7% for the APT effluent, 1.12% and 1.52% respectively, for the single-medium and multi-medium filters. In other words, the probability of finding HE in these effluents is minimal.

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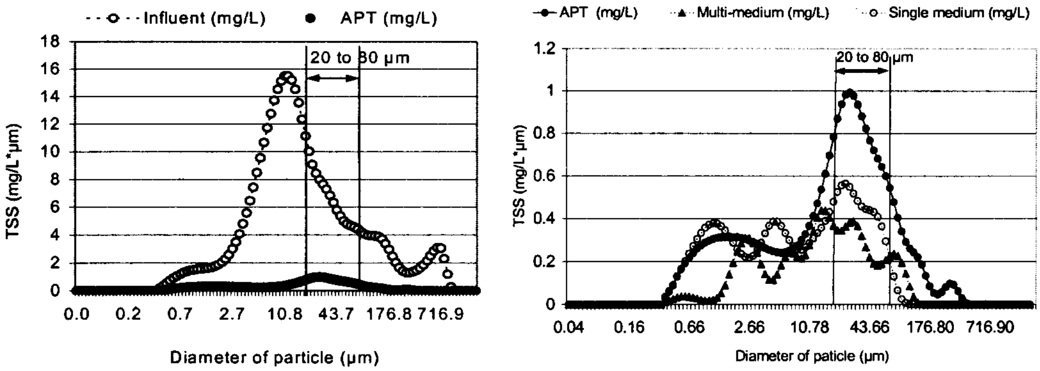

Figure 7. Distribution of particle size in the influent, APT effluent and filtered effluent.

Disinfection

To control other microorganisms in the effluent, disinfection is recommended as part of the system. In this case the filtered effluent was passed through a contact tank of chlorine gas where the contact time (0.5, 1, 2 and 3h) and the doses (10, 11 and 12 mg/L) were analyzed. With a dose of 10 mg/L of chlorine and a contact time of 3 hours the fecal coliforms were reduced from 4.9 x 10^8 to 340 MPN/100 mL leaving 0.64 mg/L of residual chlorine. Increasing the dose of chlorine brings down the contact time (2 hours) with no change in the results.The possible regrowth of bacteria was examined since the effluent will irrigate 90 000 ha, up to 24 hours distant from the plant. It was found that up to 32 hours after treatment there was no need for postchlorination, fecal coliforms being present at 9.3 x 10^2 MPN/100 mL, which is below the established limits. Levels of 1.9 x 10^5 in *Salmonella sp* and of 3.6 x 10^4 in *Pseudomonas* were measured in the influent, and neither species was detected in the disinfected effluent.

CONCLUSIONS

As a result of the studies undertaken it may be concluded that an APT followed by filtration and chlorination will produce effluents suitable for agricultural irrigation without restriction which provide an additional contribution in organic material, TKN and TP-P (169 kg N/ha/year and 32.3 kg P/ha/year).

The ACTIFLO® process was shown capable of working at sedimentation rates far higher than those previously described (180 m/h or 4320 m^3/m^2.d) producing an effluent of constant quality (27 ±16 mg TSS/L). It also provides a rapid start-up (10 minutes). The highest HE value in the ACTIFLO® effluent was 3.4 HE/L (1.2 HE/L average) which corresponds to 55 mg/L TSS (27 mg/L average).

For the filtration process two filter types can be used. In the case of the single-medium filter the best filtration performance was obtained at 11 m/h. The multi-medium filter performed best at 40 m/h. From an economic point of view the latter is the more highly recommended. In both cases minimum values of 1 HE/L in the effluent (0.28 HE/L average) are assured, 98.9% efficiency.

In the chlorination a doses of 10 mg/L is recommended with a contact time of 3 hours, with which fecal coliforms are reduced from 4.9X10^8 to 340 MPN/100 mL. This doses presents no risk of bacterial regrowth in the 32 hours following chlorination.

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