SLOW SAND FILTRATION: MICROBIAL REMOVALS IN PRE-CHLORINATED SECONDARY EFFLUENT

Shaukat Farooq and Syed A. V. Imran
Department of Civil Engineering
King Fahd University of Petroleum & Minerals
Dhahran-31261, Saudi Arabia

Abstract

A two-year study was conducted to evaluate slow sand filtration as a tertiary treatment process for secondary wastewater effluents on a pilot scale under field conditions. The first phase of the study dealt with the identification of the optimum design parameters for the slow sand filters. The effects of flow rate, sand depth and sand size on removal of microorganisms, suspended solids and turbidity were investigated. These studies on pilot filters have shown some limitations in terms of short filter runs that result due to algal blooms and the uninhibited growth of the *schmutzedecke* layer. Especially so when the slow sand filter is being used to treat nutrient rich secondary effluent. Headloss minimization in slow sand filters was identified as one of the most important considerations for its longer, efficient and economic runs. Chlorination of the secondary effluent prior to slow sand filtration was studied as a solution to this problem. The second phase therefore involved the study of effect of pre-chlorination of secondary effluents on slow sand filtration. Removal of six different group of organisms was investigated in this study. Preliminary data shows 96.7-99.9% removal of standard plate counts, 95.8-99.7% removal of total coliforms, 94.2-99.5% removal of fecal coliforms, 93.1-99.6% removal of fecal streptococci, 77.4-96.3% removal of *Cl. perfringens* and 69.1-99.8% removal of coliphages in chlorinated secondary effluent after slow sand filtration. The filter was operated for over 100 days without interruption. Chlorination before slow sand filtration, seems to control the rapid growth of the *schmutzedecke* layer to an optimum limit that does not hinder microorganism removal and also control the head loss.

Keywords: Slow sand filters, prechlorination, headloss, colifoms, clostridium, coliphage, tertiary treatment.

Introduction

Slow sand filtration has long been recognized as an economic and reliable treatment process for potable water treatment. Recent studies have shown that it is equally reliable in the treatment of wastewater (Ellis, 1985; Farooq and Al-Yousef, 1993a; Farooq et. al., 1993b). But slow sand filters also have some inherent disadvantages like rapid headloss build-up, and time variant removal rates due to filter ripening and uncontrolled growth of the *schmutzedecke* layer. A coordinated effort is required to develop and modify slow sand filters for its effective performance in microbial removal in secondary effluents.

Pre-chlorination of the secondary effluent prior to filtration has been recommended as a measure to reduce headloss, achieve greater viral and bacterial removals, and reduce the fluctuations in the performance of the slow sand filter (Ellis, 1984). A pilot-scale study is conducted at the Al-Khobar Sewage Treatment Plant, Eastern Province, Saudi Arabia, in order to generate detailed information about the effect of pre-chlorination of secondary effluents on the performance of slow sand filters with respect to the removal of microbial indicator organisms. The main emphasis of the study is to investigate and monitor the bacterial and viral removals through slow sand filters due to pre-chlorination of the secondary effluents under field conditions. Six different microbial parameters have been selected, namely standard plate counts, total coliforms, fecal coliforms, fecal streptococcus, *Cl. perfringens*, and coliphages (Kott et al., 1974; Geldreich, 1978; Cabelli, 1978; Scarpino, 1978; Borrego et. al., 1987), as these are widely recommended as indicators of pathogens in waters and wastewater.

Literature Review

Ellis (1984), made an extensive review of the history, performance, influence of various physical, chemical and biological parameters, extent of research etc., on slow sand filters. He concluded that slow sand filters have all the advantages of being an efficient, economic and reliable water treatment process. The use of slow sand filters for treatment of secondary effluents is a recent concept that was examined and explored by Ellis (1985) in the mid 80's. Ellis found that results of previous studies on the viability of slow sand filtration as a tertiary treatment process gave a conservative picture of the treatment efficiency of slow sand filters. Studies using a slow sand filtration unit of 140 mm dia. perspex cylinder, 2.65m in height and 950 mm sand depth of fine sand was used. The sand size was initially 0.3 mm and later changed to 0.6 mm. At flow rates of 3.5 md^{-1} and 7.5 d^{-1} the slow sand filter was able to remove at least 90% of suspended solids, more than 65% of the remaining BOD and over 95% of the coliforms.

A comprehensive study on the effect of sand sizes and filter depths on the treatment efficiency of slow sand filters was conducted by S. Farooq et al. (1993b). The filter depths investigated were 135, 105, 55 cm and two sand sizes of 0.31 and 0.56 mm effective size. It was found that the removals of BOD, COD, standard plate counts, nitrate, phosphate, and sulfate vary from 79-92%, 40-60%, 88-93%, 17-30%, 8.3-84% and 5-10% respectively at various sand depths for two different sizes of sand. They concluded that the percent removals of different parameters investigated in the study decreased by decreasing the sand depth and/or by increasing the sand size. Therefore it was suggested that sand of coarser size with deeper bed be used in contrast to finer sand of shallow bed in order to get desired efficiency.

Surprisingly there is no single study that deals with the direct comparison of the microbial removals in slow sand filters with and without pre-chlorination. Historically chlorination of the supernatant waters, in a slow sand filter, have generally been restrained because of its perceived detrimental effect on the *schmutzedecke* layer (Ellis, 1984; Reisenberg et. al., 1995). Ellis, however, recommends pre-chlorination in situations where the chlorine demand is sufficiently high enough, so as not to effect the *schmutzedecke*. Pre-chlorination has also been used to prevent algal blooms in the filters, as a shock treatment to clean filter media and prevent fouling-up (Schuler et al., 1991), or as a means of suppressing biological activity (Bellamy et. al., 1985).

Materials and Methods

Two modular slow sand filters, one settling tank and one chlorination tank were constructed in the field at the Al-Khobar Sewage Treatment Plant. Their layout is shown in Fig 1. The pilot slow sand filters has been described elsewhere, along with the methods for the collection and enumeration of the samples [Farooq S. and Imran S.A.V, 1997]. Table 1 gives the characteristics of the secondary effluent from the sewage treatment plant. The design parameters for the pilot slow sand filters are given in Table 2.

Results and Discussion

Four different set of conditions, i.e., (i) disinfection at a chlorine dosage of 5 mg/l,
(ii) microbial removal in control filter, (iii) microbial removal in test filter, and (iv) the overall microbial removal in the test filter incorporating the combined effect of chlorination and slow sand filtration were evaluated for the removal microbial indicators. The results in terms of average percent removals along with their ranges for all organisms under four conditions are given in Table 3. However, their variations with respect to time are shown in respective Figs. 2-5. In the case of the control filter, percent values were calculated using the difference in microbial populations in the settled secondary effluent and at the filter outlet.(Fig 3) The effect of chlorination is obtained as the percentage difference of the microbial parameters in the settled secondary effluent and at the outlet of the chlorination tank.(Fig 2) The chlorinated secondary effluents then formed the influent to the test filter. The removals in the test filter were calculated as the percentage difference of the microbial populations in the chlorinated secondary effluents and at the outlet of the test filter.(Fig 4) The overall microbial removal in the test filter is evaluated as the percent difference of the microbial populations in the settled secondary effluent and at the outlet of the test filter (Fig 5).

Effect of Chlorination Alone

In the present study, pre-chlorination was achieved at the rate of 5 mg/l, in a separate chlorination tank, before being introduced into the test filter. This had the dual purpose of utilizing the available chlorine exclusively towards meeting the chlorine demand of the secondary effluents, and thereby causing minimal harm to the *schmutzedecke*. The residual chlorine if any would be utilized in controlling the *schmutzedecke* population. In the present study a residual chlorine of 0.5-1.0 mg/l was observed on some occasions, indicating a large chlorine demand. This dose of chlorine was effective in removing most of the bacterial species. The standard plate count removals ranged from 64.3-98.8% with an average removal of 87.32%. Total and fecal coliforms had removals ranging from 68.2-89.6% and 65.4-94.2%, and averaged at 76.6 and 84.9% respectively (Fig. 2). Chlorination showed variable removals in the case of fecal streptococci having a range of 38.9-94.6% with an average around 72.6% (Fig 2). Removals of *Cl. perfringens* showed marked variability with a range of 12.9-80.8% and averaged around 44.5% (Fig 2). This is an expected result as *Cl. Perfringens* is a spore-former and has high resistance to disinfectants. Due to its exceptional resistance to chlorination it has been recommended by Cabelli (1978) as an indicator of fecal pollution in extreme environments, where the traditional indicators like coliforms are likely to give erroneous interpretations.

The coliphage inactivation data showed marked variability with a range of 24.4-80.6% and an average around 49.2% (Fig 2). Coliphages are more resistant to chlorination than most enteroviruses. Kott et al.(1974), in a study of the chlorination experiments on f2 and MS_2 coliphages, and Polio I strain, have reported that the coliphages were more resistant than the attenuated Polio I virus. This study recommends that bacteriophages, particularly coliphages serve as viral pollution indicators in wastewater treatment involving chlorination. Thus chlorination alone is inadequate for the removal/inactivation of viruses. The large fluctuations in the removal percentages, could be due to the large chlorine demand of the secondary effluents, and the protection offered to the micro-organisms by turbidity and flocs.

Effect of Pre-chlorination on Filter Efficiency

The microbial removal efficiencies in the test and control filters were compared. Though these comparisons cannot be precise, due to the different microbial influents at the head of each filter and the effect of residual chlorine, they provide a reasonable estimate of the performance of the filters. The average removal ranges for standard plate count, total coliforms, fecal coliforms, fecal streptococcus, *Cl. Perfringens* and coliphages were 87.8%, 83.4%, 86.0%, 82.3%, 78.1% and 80.1% in the control filter, whereas in the test filter they were 88.2%, 92.9%, 86.4%, 88.1%, 78.9%, and 79.3% respectively, (Figs 3,4). The removal efficiencies of all the micro-organisms was similar in both the filters except perhaps for the total and fecal coliforms. This may be due to the fact that the coliforms are more readily inactivated than other indicator organisms. This has lead to a demand for viral indicators other than coliforms in chlorination studies. Ellis (1984) has reported that a pre-chlorination dose of even 8.8 mg/l did not significantly change the performance of a slow sand filter. This is reflected in the similar removal rates in both the test and control filters. It is assumed that the action of residual chlorine compensates for the loss of *schmutzedecke* in the test filter. The average removal rates of chlorine resistant indicators, that is, *Cl.*

Perfringens and coliphage, in the test and control filter are nearly equal. This indicates that the test filter is performing at par with the control filter.

The major difference was observed in the length of the operations of the filter fed with the chlorinated influent as compared to the control filter with no pre-chlorination. The test filter had a continuous run, without reaching headloss even after a period of 100 days. The control filter on the other hand, had a run time of 48 days, after which a five day period was required for its cleaning and maturation (Fig 6). These can be compared with the typical headloss variations which were encountered in a previous study (Fig 7). This particular phase shown in Figure 7 was one of the worst case and had an average period of operation of 10 days.

Overall Microbial Removal in Test and Control Filters

The overall average removals, including chlorination and slow sand filtration, in the test filter for standard plate count, total coliforms, fecal coliforms, fecal streptococcus, *Cl. Perfringens* and coliphages were 98.6%, 98.2%, 98.1%, 97.6%, 89.5% and 91.3%, respectively compared to 93.6%, 82.8%, 82.8%, 87.3%, 78.1% and 80.1% in the control filter . The overall microbial removals in the test filter by far better and more consistent than the removal rates in the control filter. This was especially so for *Cl. perfringens* and coliphages, indicating that a combined disinfection and filtration action was more efficient than disinfection or filtration alone. This is in conformance with the study carried out by Goldgrabe et.al., (1993), on the particle removal efficiencies in prechlorinated and nonchlorinated filters. She reports the particle removals in pre-chlorinated filters (1 mg/l residual chlorine) to be greater than the non-chlorinated filter by log 0.5-0.6. In a comparative study of pre-ozonation, pre-chlorination and pre-chloramination, Le Chavellier et.al, (1992), found that AOC (Assimilable Organic Carbon) reduction occurred even in the presence of a disinfectant residual. This implies AOC utilization by the indigenous filter biota even in the presence of disinfectants. However, the impermeable gelatinous slime formation on pre-chlorinated filters that were reported by Ellis (1984) was never observed throughout the filter run. This may have been due to the absence of clay particles in the filter influents.

Conclusion

The following specific conclusions may be drawn from the results of the operation of the pilot plant with respect to pre-chlorination studies in slow sand filters.

- Chlorination of secondary effluents alone, as is commonly practiced , is highly inadequate for the removal of spore former like *Cl. Perfringens* and chlorine resistant viruses like coliphage. This is evident from their highly variable removal efficiencies.

- The efficiencies of microbial removals in the test and control filter were similar. This indicates that a pre-chlorination dose of 5 mg/l does not adversely effect the filter operations or the *schmutzedecke* layer.

- The overall microbial removals in the test filter, that incorporates chlorination and slow sand filtration, were better and more consistent than chlorination or slow sand filtration alone.

- The run time of the test filter was more than 100 days compared to 48 days for the control filter. The longer runtimes will help maintain the economy and efficiency of operation and maintenance.

- Based on the superior results obtained by pre-chlorinating the secondary effluents, it is recommended to incorporate chlorination as a pre-treatment measure in the tertiary treatment of wastewaters by slow sand filtration.

Acknowledgment

The authors are grateful to KACST for funding the Slow Sand Filtration study at King Fahd University of Petroleum & Minerals (KFUPM), and also to the Department of Civil Engineering for providing the necessary facilities and support. Thanks are also extended to Al-Khobar Treatment Plant personnel and its management for extending full cooperation in conducting this study at the site.

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Parameter	Minimum	Maximum	Average
Temperature °C	10.0	39.0	28.2
Conductivity µmhos/cm	2800	3600	3447
pH	7.3	7.7	7.5
Alkalinity mg/l as $CaCO_3$	95	160	125
DO mg/l	5.0	7.1	6.0
Turbidity NTU	0.20	0.95	0.70
BOD mg/l	2.80	6.10	4.78
COD mg/l	32.0	57.6	41.04
TOC mg/l	11.7	16.8	14.1
Suspended Solids mg/l	8.0	88.4	14.7
TKN mg/l	0	6.16	3.20
Organic-N mg/l	0	6.16	2.70
NO_3 mg/l	0.05	1.30	0.38
NO_2 mg/l	0	1.15	0.56
Total-PO_4 mg/l	0	1.98	1.18
Ortho-PO_4 mg/l	0	1.55	0.63
Chlorides mg/l	424	1119	713
Sulfates mg/l	227	590	285
Total Coliform MPN/100ml	3100	1700000	369000
Fecal Coliform MPN/100ml	0	940000	153000
Standard Plate Count /ml	3200	820000	238000
Coliphage PFU/100ml	100	6200	577
Lead mg/l	0.001	0.132	0.043
Cadmium mg/l	0.004	0.170	0.070
Zinc mg/l	0.193	0.500	0.28
Iron mg/l	0.12	0.30	0.20
Copper mg/l	0.006	0.100	0.056
Nickel mg/l	0.005	0.100	0.034

Table 1: Characteristics of Unchlorinated Secondary Effluent from Al-Khobar Sewage Treatment Plant

Criterion	
Design Period	-
Period of Operation	24 hr
Filtration Rate	0.2 m/hr
Height of Underdrains (Including Gravel)	0.7 m
Height of Supernatent Water	1.0 m
Number of Filter Bed Units	2 Units
Filter Bed Depth	1.0 m
Filter Bed Area	3.14 m^2
Sand Specification	
Effective Size	0.5 mm
Uniformity Coefficient	1.6

Table 2:Design Parameters for Pilot Slow Sand Filters

Microbial Parameters	Population in Settled Secondary Effluent	Percent Removal/Inactivation							
		Chlorination (5mg/l)		Control Filter		Test Filter		Overall Test Filter Chlorine+Filtration	
		Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.
1. Standard Plate Count	$1.7*10^4$ /ml	64.3-98.8	87.3	80.5-92.4	87.8	80.0-99.3	88.2	96.7-99.9	98.6
2. Total Coliform	$3.47*10^5$ MPN/100ml	68.2-89.6	76.6	63.4-92.6	83.4	87.0-97.4	92.9	95.8-99.6	98.2
3. Fecal Coliform	$1.85*10^5$ MPN/100ml	65.4-94.7	84.9	75.0-94.2	86.0	74.0-95.8	86.4	94.2-99.5	98.1
4. Fecal Streptococcus	$1.56*10^4$ MPN/100ml	38.9-94.6	72.6	72.2-95.4	82.3	71.4-99.1	88.1	93.1-99.5	97.6
5. *Cl. Perfringens*	$1.24*10^2$ /100ml	12.9-80.8	44.5	47.4-91.3	78.1	44.8-90.7	78.9	77.4-96.3	89.5
6. Coliphages	$7.7*10^2$ /100ml	24.4-80.6	49.2	60.3-94.5	80.1	36.2-99.7	79.3	69.1-99.8	91.3

Table 3: Microbial Removal Efficiencies in Chlorination, Control Filter, Test Filter and Overall Test Filter

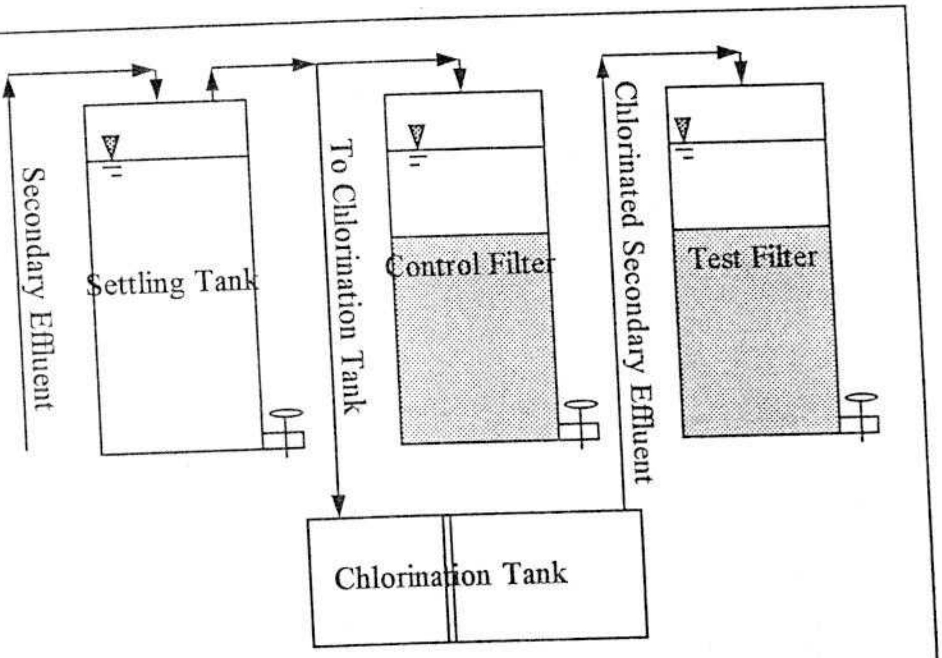

Fig 1: Schematic Layout of Pilot Slow Sand Filters

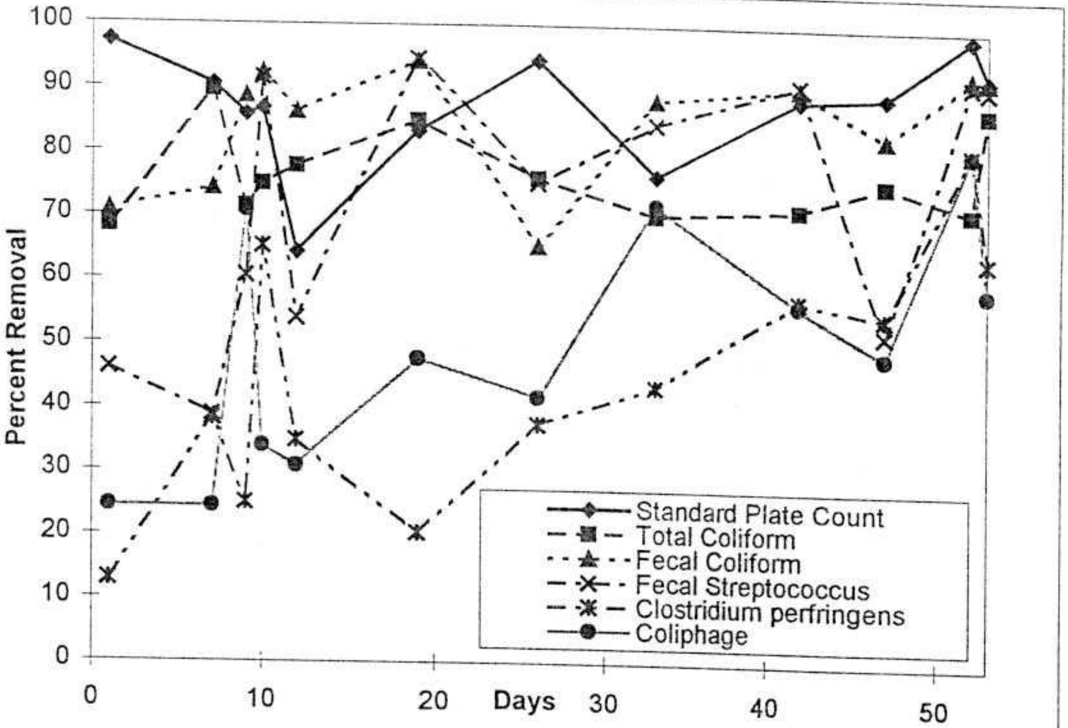

Fig 2: Percent Removal of Microbial Indicators After Chlorination Only

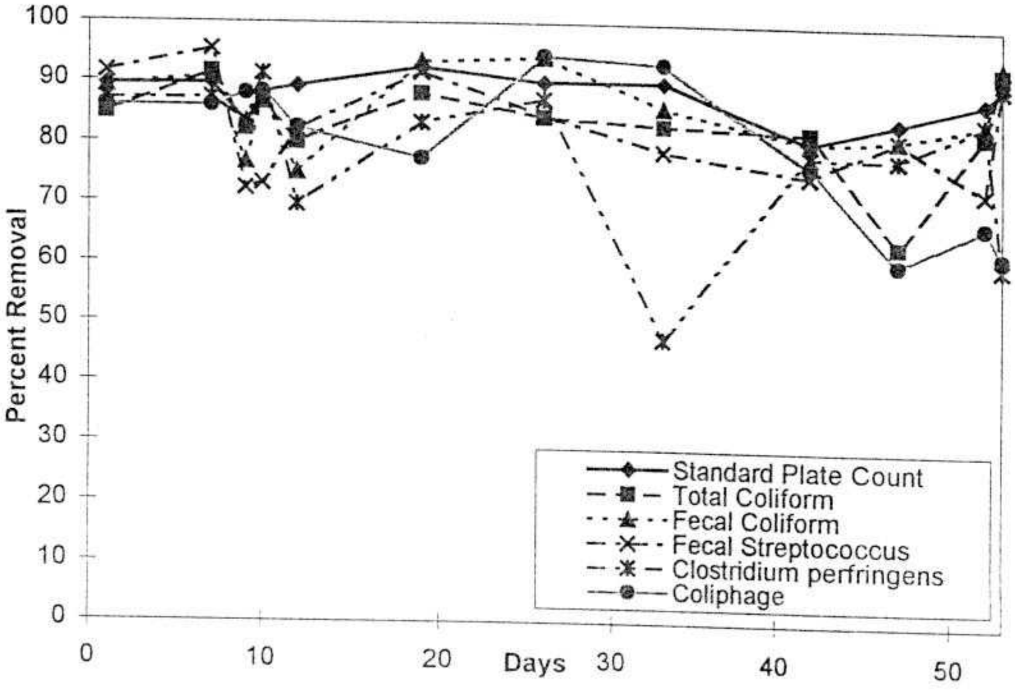

Fig 3: Percent Removal of Microbial Indicators in Control Filter

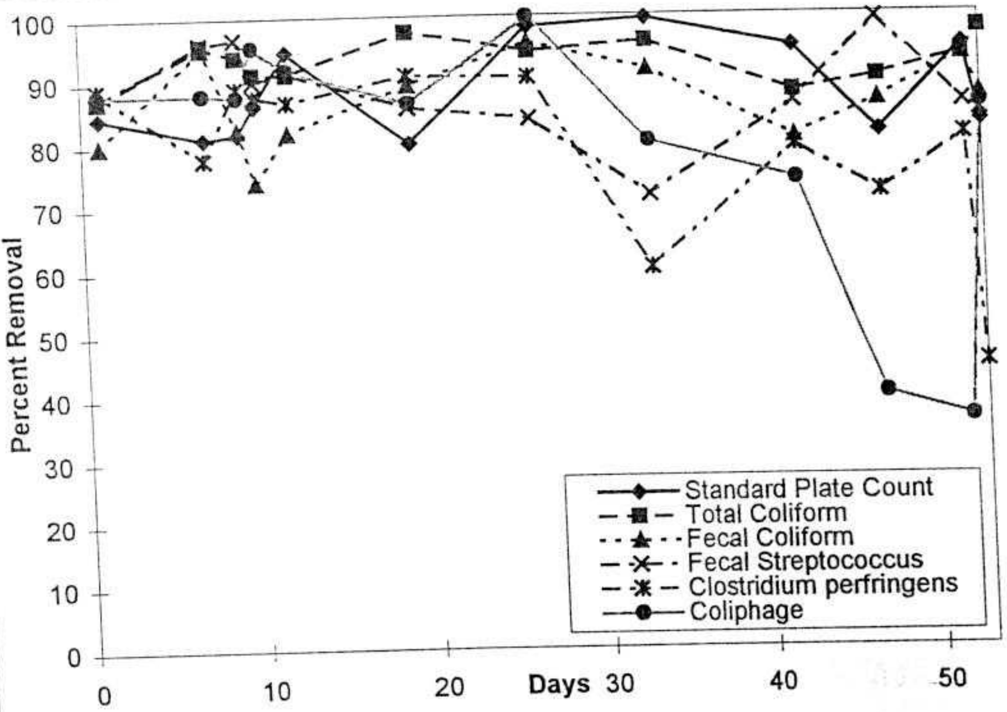

Fig 4: Percent Removal of Microbial Indicators Due to Filtration of Chlorinated Effluent Alone

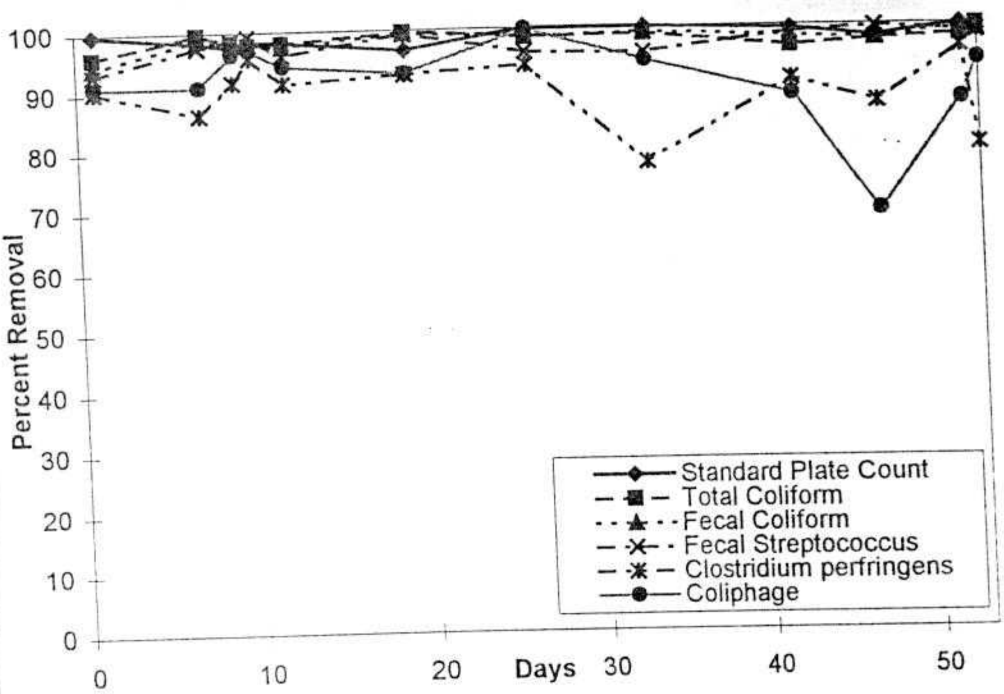

Fig 5: Percent Removal of Microbial Indicators Due to Combined Chlorination and Test Filtration

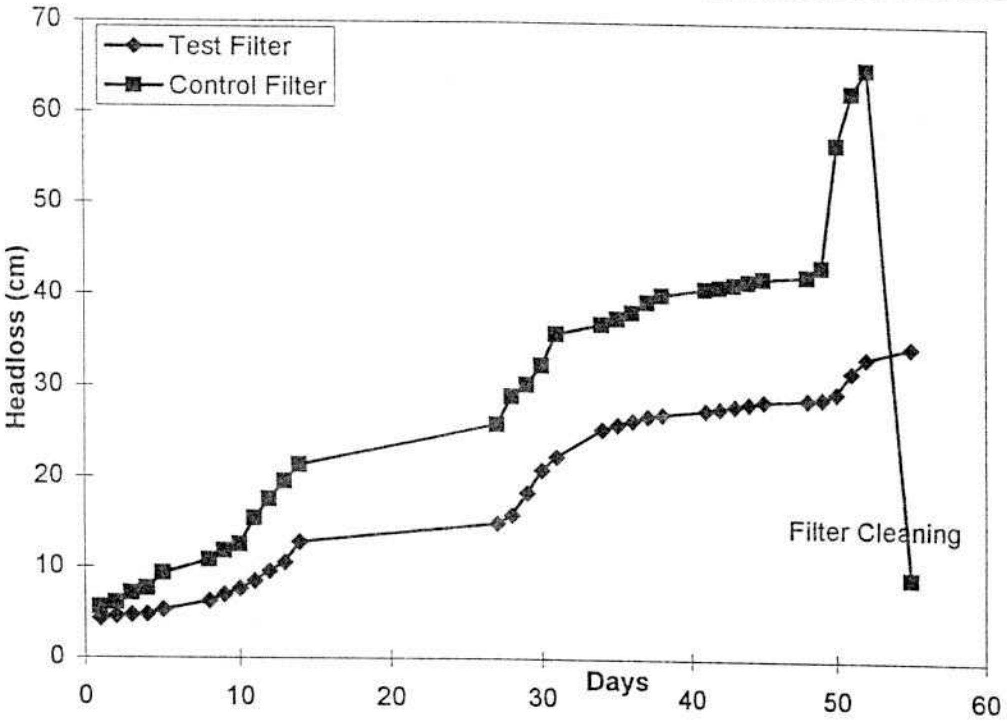

Fig 6: Variation of Headloss in Test and Control Filters

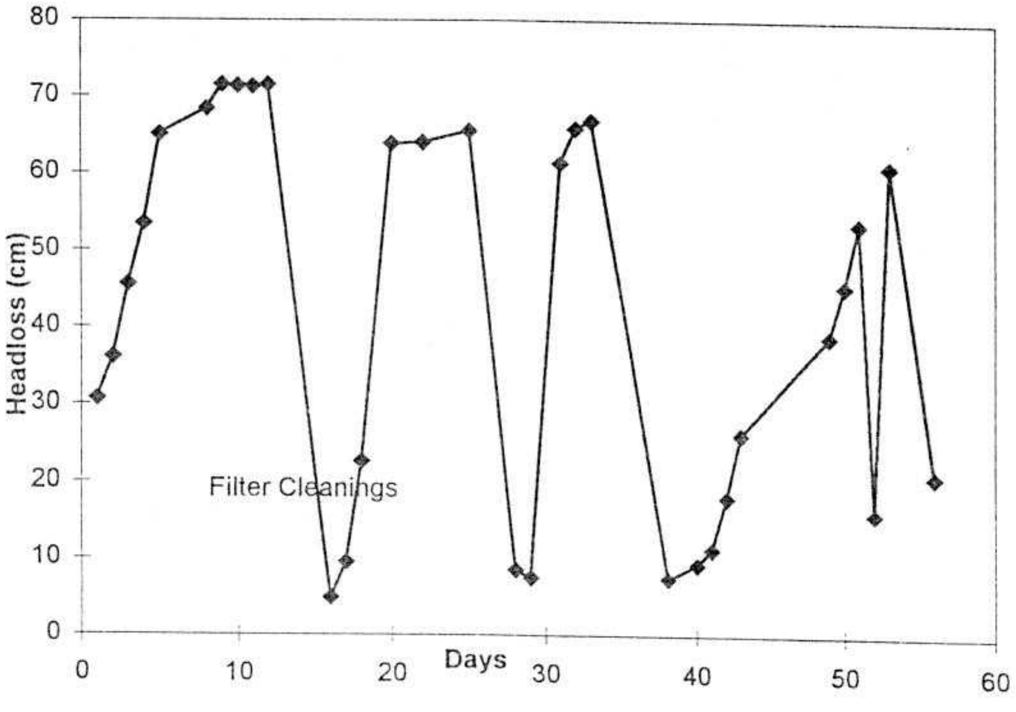

Fig 7: Typical Variation of Headloss in Filters Treating Secondary Effluents