COMPARISON BETWEEN DISC AND NON-WOVEN SYNTHETIC FABRIC FILTER MEDIA TO PREVENT EMITTER CLOGGING

T. A. P. Ribeiro, J. E. S. Paterniani, R. P. S. Airoldi, M. J. M. Silva

ABSTRACT. *The aim of this research was to compare the evolution of head loss in disc (130 μm) and non-woven synthetic fabric filter media used to filter the water in drip irrigation systems. Two forms of treatment of the irrigation water were carried out: one with a chemical product (chlorine) and the other with none. The research used two different filter media: two for each treatment together with a fertigation technique with organic products in both types of treatment. The chemical treatment of the irrigation water was done by chlorination, in which the source of chlorine was sodium hypochlorite. Water from an open reservoir was used, in which a drip irrigation module was installed. The temporal variation in water quality over one year was analyzed, taking into consideration the physical, chemical, and biological parameters of water that can cause clogging problems in emitters. The results showed that, in irrigation water, the pH and iron chemical parameters presented an average risk of clogging, and the hydrogen sulfide parameters presented a high risk. The performance of the filters was analyzed by comparing the concentrations of the effluent on the disc and non-woven synthetic fabric filters in relation to the efffluent's physical and biological parameters. An attempt was made to follow head loss evolution in relation to the volume filtered by the filters so as to make a comparative analysis. It could be seen that the evolution of head loss was more significant and quicker with the non-woven synthetic fabric filter than with the disc filter. The level of clogging in the emitters was calculated by means of a uniform distribution index. The test area using the non-synthetic woven fiber filter presented the smallest level of clogging and the greatest water distribution index.*

Keywords. *Chlorination, Drip irrigation, Filtration, Non-woven synthetic fabric, Drip irrigation, Water quality.*

Irrigation is known as the human activity that consumes the most water, on average 70% of all water consumed (FAO, 2003). Among the various irrigation methods, drip irrigation is the method that has grown most in the last decades due to its economical use of water. However, for a drip irrigation system to achieve excellent performance, some fundamental factors must be considered, such as water quality and the presence of inorganic (sand, lime, clay) and organic (algae, herb seeds, insect parts, bacteria, fungi, protozoa, etc.) particles. The filtering system is therefore an important factor to prevent the intake of organic and inorganic particles and of chemical sediments that can cause partial or complete clogging of the emitters. For plant irrigation to be efficient, the drip irrigation system must have efficient water treatment.

The water treatment system can use both physical and chemical processes. Chlorination is a chemical process that is widely used to control algae and iron bacteria in drip irrigation systems. English (1985) recommended that chlorination be used on a continuous basis at a rate of 1 to 2 mg L^{-1} or at a weekly rate at a concentration of 10 to 20 mg L^{-1} for 30 to 60 min to prevent lime-forming bacteria. The latter rate is also recommended by English (1985) to treat algae.

The physical processes used to treat water in drip irrigation systems are filtering mechanisms that can be divided into two categories: (1) screen and disc filters, classified as mechanical or superficial filtering elements, in which the filtering process is based on the fact that the filter pores are smaller than the diameter of the particles to be filtered; and (2) granulated or sand filters, in which the particles to be removed are smaller that the pores of the filter element, and physical/chemical means are used also to hold back these particles (Adin and Alon, 1986).

The removal capacity of superficial filter media has not been well analyzed, and studies with non-woven synthetic fabrics have shown them to be more efficient filtering elements in the removal of suspended solids in drip irrigation filters (Paterniani and Silva, 1996). The parameters that determine the efficiency of a non-woven synthetic fabric filter are its porosity characteristics, the specific surface and thickness of the fabric, as well as the filtration rate, the quality of the water, and the filtering system used (Paterniani, 1991). Scatolini (2001), in experimental field assays, compared the efficiency of filtering between the filtering elements of a disc filter and 130 micron screen, and a non-woven synthetic fabric filter. In the assay, the fabric was significantly more efficient than the screen and disc elements, removing a greater quantity of the suspended solids and algae that were present in the irrigation water.

Submitted for review in December 2006 as manuscript number SW 6808; approved for publication by the Soil & Water Division of ASABE in January 2008.

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Transactions of the ASABE

Vol. 51(2): 441-453 ISSN 0001-2351

The aim of the present work was to compare the evolution of head loss in the filtered volume of two different filters when removing impurities from drip irrigation water. The filtering elements to be assayed were a commercially available 130 micron disc filter, currently used by farmers, and a non-woven synthetic fabric filter, which could become an alternative technology, being more accessible to the farmers and technically more viable. A fertigation technique was used together with chlorination as a chemical treatment to control algae and bacteria. A concentration of 2 mg L^{-1} of free chlorine in the drip line was used to prevent clogging in relation to algae and lime control (English, 1985).

The physical, chemical, and biological parameters of the irrigation water that could cause clogging in the emitters were specifically analyzed for a period of one year and included pH, turbidity, total suspended solids, dissolved solids, iron, sulfides, magnesium, algae, and bacteria.

MATERIAL AND METHODS

The experiment was carried out in the municipal area of Campinas in the state of São Paulo, Brazil. The evaluation criteria for impurities present in the irrigation water were based on studies carried out by Nakayama and Bucks (1986). The water used in the experiments was from a 2500 m^3 reservoir built in a small weir that is supplied by water pumped from a small dam, where there is a supply from other nearby sources.

EQUIPMENT

An irrigation system was set up in the experimental area and consisted of the following elements: a centrifuge pump, an automatic irrigation controller, four solenoid-controlled valves, four differential pressure transducers, four pressure regulators (103.4 kPa at 22.71 to 1817 L h^{-1}), five digital hydrometers (turbine type, 10 to 100 L min^{-1}), four Bourdon manometers, fertilization and chlorine injection systems consisting of piston dosing pumps, and a filtering system consisting of four filters, of which two were 130 micron disc filters (25.4 mm diameter, Amiad) and two were non-woven synthetic fabric filters of the same diameter. The pumping system supplied four areas of emitters. Each irrigated area had its own filter system (disc or non-woven synthetic fabric).

The irrigation system was totally automated, regulated by a programmable control panel, and linked to the solenoid valves by its own wiring. The control program determined the opening and closing of the solenoid valves, allowing either fertigation or irrigation without nutrients. The differential pressure transducers converted the pressure differentials at the filters into electrical signals. The readings were stored by a data acquisition system (datalogger). Figure 1 illustrates the experimental setup used in this research.

Each irrigated area had three lateral lines 3 m long with emitters located every 30 cm. Labyrinth-type emitters (Streamline model 80, Netafim, Tel Aviv, Israel) were used. The drip line piping had a 0.20 mm wall thickness and 16 mm internal diameter. For a service pressure of 100 kPa, the nominal flow was 1 L h^{-1}, per the manufacturer.

An organic mineral fertilizer was used for fertigation. The product is in liquid form and its composition, per the manufacturer, is 25% organic material, 3% total nitrogen, and 9% potassium in the form of K_2O. The fertilizing solution used was made once a month in a completely closed plastic container.

The choice of the type of non-woven synthetic fabric filter was based on studies by Scatolini (2001). The bodies of the four filters were identical to guarantee functional similarity among the filters. The non-woven synthetic fabric used as a filter medium had 0.5 cm s^{-1} normal permeability, 1.6 s^{-1} permissivity, 0.150 mm pore opening, 380 g m^{-2} gramature, and 3.8 mm thickness.

The filter assays used surface water from the reservoir, where a set of pumps was installed to supply the four filters placed in parallel and therefore under the same head loss con–

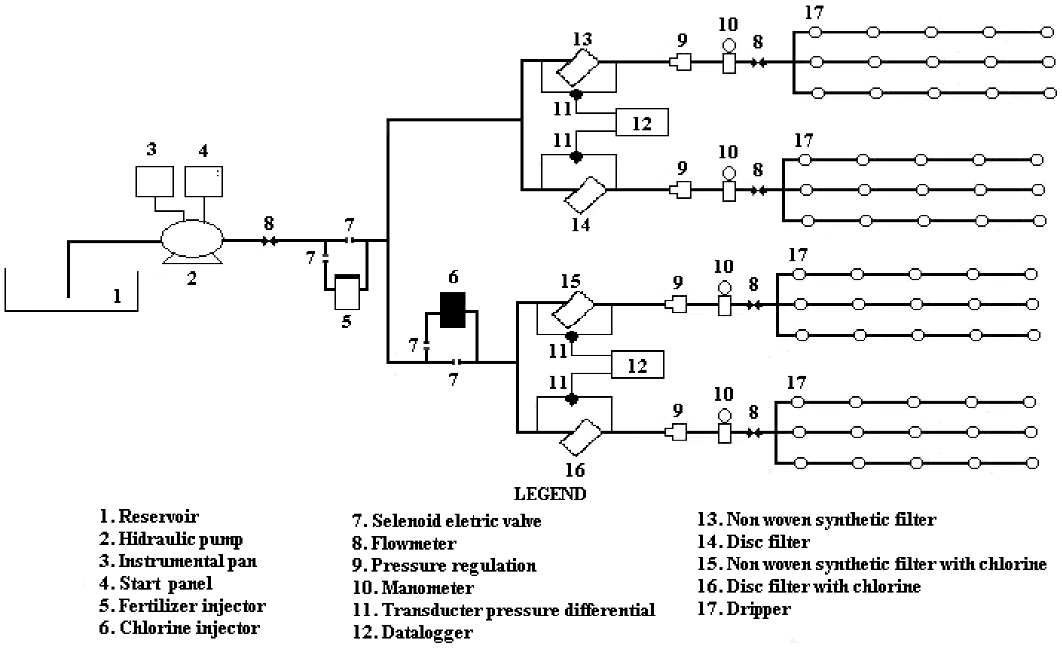

Figure 1. Irrigation system schematic.

ditions. The average flow in each filter was 600 L h^{-1}. To guarantee equal pressure in all four irrigated areas, 103.4 kPa pressure regulators were installed at the beginning of each area. An irrigation controller carried out the irrigation cycles and was programmed to turn the system on twice a day, i.e., in the morning and at the end of the afternoon. Irrigation time was 2 h. The fertilizer injection was in the main line of the system. Fertigation time was 1.5 h, while the remaining time was used for the application of water with chlorine. The source of chlorine was sodium hypochlorite (12%). The necessary chloride concentration value of 2 mg L^{-1} was adopted for the emitters.

Hydraulic characterization of the disc and non-woven synthetic fabric filter media was carried out. This was done to verify the evolution of head loss due to flow variations in the filters. In this way, a comparison of the performance of the filter media could be carried out. In this test, a filter was installed between two pressure measurement points, which were linked to a mercury differential manometer to measure the variation in head loss due to leakage. The water used to fill the reservoir was from the public water supply system. Figure 2 shows a schematic for this test.

A sampling point was located in the main irrigation line, after the pump system and before the fertilizer injector system (fig. 1). Water classification for the drip irrigation system regarding clogging problems (due to physical, chemical, and biological factors) followed the recommendations of Nakayama and Bucks (1986). Sampling from the water reservoir was carried out during all four seasons of the year. Factors related to water quality for drip irrigation and that could cause clogging of the emitters were determined by the field sampling. These factors included pH, suspended solids (SS), turbidity, dissolved solids, total iron (Fe), hydrogen sulfide (H_2S), and concentration of algae and bacteria. In each seasonal test phase, the system worked for a total of 120 h. There was a concern about stipulating a reasonable working period for the irrigation system (4 h a day) so that the clogging process could occur in the emitters.

Bacterial populations were determined by the counting method in a Petri dish, using agar (tryptone, glucose, and yeast extract) as a culture medium and a counting time of 48 h. The Sedgwick-Rafter method was used to count the algae, based on standard methods (APHA, 1992).

Microbiological analyses were carried out so as to characterize the types of algae and bacteria that were present in the samples of the material removed from the internal area of the hoses and emitters for six-month and one-year assays. The bacteria were classified according to *Bergey's Manual of Determinative Bacteriology* (Buchanan and Gibbons, 1974), and the algae were classified using the CETESB manual (CETESB, 1991).

Differential pressure transducers, with pressure taps situated before and after the filters, were used for monitoring the head loss. The data were stored in a data acquisition system (datalogger). The filters were cleaned if the pressure differential exceeded 40 kPa. The cleaning of the filter elements was carried out manually using water from the public water supply system. The increase of head loss due to the retention of impurities in the filter was determined based on the volume filtered.

To evaluate the performance of the filters and the efficiency of the chemical treatment (chlorination), the degree of emitter clogging was analyzed for the four irrigated areas according to the water distribution uniformity index in the field. The method used was proposed by Bralts and Kesner (1983). However, a computer program developed by Zazueta and Smajstrla (1991) was used for the calculation. A statistical method was used to calculate the water uniformity distribution of subareas or areas in the field based on the statistical uniformity coefficient (U_s, eq. 1) and on the coefficient of variation (CV, eq. 2):

$$U_s = 100\,(1 - \mathrm{CV}) \tag{1}$$

$$\mathrm{CV} = \frac{s}{\bar{q}} \tag{2}$$

where

U_s = emission statistical uniformity (%)
CV = statistical coefficient of emitter flow variation
s = standard deviation
$\bar{q}$ = total average flow (L h^{-1}).

Equation 1 shows that the larger the variation in the emitter flow values becomes, the smaller the application uniformity will be. In equation 2, the value of CV includes flow variation of the emitters due to all causes, including the effects of the piping, and the hydraulic characteristics of the emitters, including clogging. This method allows evaluation of the distribution uniformity not only for implanted systems but also for dimensioning effects (Favetta and Botrel, 2001).

The method recommends that at least 18 flow measurements be taken of the emitters for each area to be tested. In

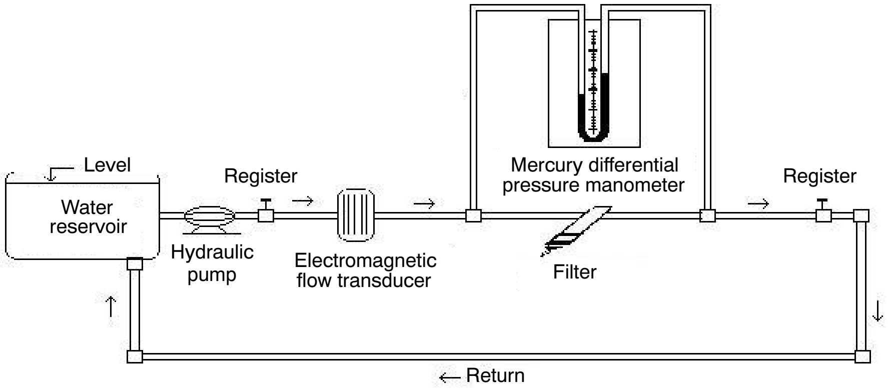

Figure 2. Experimental setup used to investigate the hydraulic characteristics of the filter elements.

this research, six emitters at the beginning, six in the middle, and six at the end of the lateral drip lines were selected.

Random blocks were used for the experimental outline. Three factor were considered: filter type (two levels: disc and non-woven synthetic fabric filters), chlorination (two levels: with or without chlorination), and season of the year considered as a homogeneous block (four levels: spring, summer, autumn, and winter). Analysis of variance of the data obtained by the two distinct water treatments was carried out to determine the significant difference between the treatments. The level of significance adopted for the analysis of variance was 5%. The averages of each analyzed factor for the treatment were compared based on the Tukey test. Pimentel (1982) stated that this test can be used to compare any contrasts between two treatment measures.

Result and Discussion

Reservoir Water

The results of the physical, chemical, and bacteriological parameter analyses of the reservoir water during the four research phases are presented in table 1. Each phase corresponds to a season of the year. An increase in the average values of turbidity and in the concentration of suspended solids in the irrigation water from the reservoir, apart from a correlation between the physical parameters analyzed, was observed. This correlation is important because as turbidity is an indicator of suspended solids, despite not being a precise parameter for determining the level of risk of emitter clogging for surface water sources, this physical parameter can be analyzed in the laboratory to determine the concentration of suspended solids and thus measure the potential risk of emitter clogging (table 1). Even after increasing, on average, about nine times from the first to the fourth phase, the concentration of suspended solids did not reach very high levels, which would present an average or high risk of emitter clogging. However, this implied a significant increase in the number of filter cleanings, of both the disk filters and the synthetic woven fiber filters, and a quicker increase in the evolution of head loss due to the volume filtered.

During the four phases, the pH values varied from 7.39 in the second phase (larger value) to 6.88 in the fourth phase (smaller value). In the first three phases, the values presented an average risk of clogging. The pH values found during this research are very similar to those in work done by Testezlaf

Table 1. Physical, chemical, and biological parameters of the irrigation water in the four phases.[a]

	Physical		Chemical							Biological	
	Susp. Solids (mg L^{-1})	Turbidity (NTU)	pH	Iron (mg L^{-1})	Sulfides (mg L^{-1})	EC (mS cm^{-1})	Diss. Solids (mgL^{-1})	Hardness (mg L^{-1})	Langelier Index	Algae (cfu cm^{-3})	Bacteria (cfu cm^{-3})
Phase 1											
Variation	1.0 to 5.0	1.82 to 3.88	7.1 to 7.5	0.4 to 1.0	1.0 to 2.0	0.045 to 0.076	28.8 to 48.64	20.22 to 26.63	(-2.07) to (-1.39)	165 to 1295	270 to 6500
Average	2.67	2.83	7.33	0.52	1.10	0.06	37.70	22.93	-1.95	497	2438
SD	1.51	0.68	0.23	0.18	0.32	0.01	6.33	2.14	0.30	345	2812
CV (%)	56.46	24.18	3.09	33.68	28.75	16.80	16.79	9.32	15.57	69.46	115.36
Risk of clogging[b]	L	N/C	M	M	M	N/C	L	N/C	N/C	N/C	L
Phase 2											
Variation	8.5 to 13.5	5.19 to 11.9	6.4 to 8.1	0.5 to 1.7	1.0 to 9.0	0.044 to 0.06	26.8 to 38.40	20.2 to 22.7	(-2.62) to (-1.90)	930 to 1820	1 to 7000
Average	10.96	8.27	7.39	1.10	2.42	0.05	32.21	20.71	-1.95	1377	1202
SD	1.37	1.91	0.46	0.38	2.27	0.01	3.68	1.04	0.42	287	2065
CV (%)	12.53	23.13	6.23	34.89	94.13	9.96	11.42	5.00	21.53	20.88	171.81
Risk of clogging[b]	L	N/C	M	M	H	N/C	L	N/C	N/C	N/C	L
Phase 3											
Variation	12.5 to 19	7.12 to 16.9	6.8 to 7.8	0.2 to 1.0	1.0 to 5.0	0.042 to 0.056	26.88 to 35.84	13.77 to 19.29	(-2.96) to (-0.98)	120 to 705	10 to 760
Average	17.61	11.30	7.13	0.74	2.83	0.05	31.72	17.96	-2.23	459	223
SD	4.17	2.93	0.42	0.26	1.17	0.01	2.64	1.96	0.66	179	236
CV (%)	23.66	25.95	5.86	34.97	41.39	8.33	8.33	10.90	29.76	38.97	105.74
Risk of clogging[b]	L	N/C	M	M	H	N/C	L	N/C	N/C	N/C	L
Phase 4											
Variation	16.0 to 23.5	7.45 to 14.5	6.6 to 7.3	0.0 to 1.0	2.0 to 16	0.032 to 0.090	20.48 to 57.60	20.68 to 22.96	(-3.63) to (-2.07)	205 to 950	200 to 5400
Average	19.7	10.14	6.88	0.48	3.50	0.059	38.02	21.25	-2.566	512	1702
SD	2.51	2.23	0.19	0.32	4.40	0.017	10.65	0.72	0.425	216	1798
CV (%)	12.78	21.97	2.89	66.46	125.81	28.00	28.00	3.37	16.57	42.12	105.62
Risk of clogging[b]	L	N/C	L	M	H	N/C	L	N/C	N/C	N/C	L

[a] EC = electric conductivity, SD = average standard deviation, and CV = coefficient of variation.

[b] L = low risk, M = average risk, H = high risk, and N/C = no classification.

et al. (1994), which verified the potential use of reservoir and river water for use in drip irrigations systems in rural vegetable-producing areas of the Campinas region: in 88.9% of the 27 water sources analyzed, the pH was alkaline and presented average risk of clogging, according to the same classification adopted in this research.

The average concentrations of sulfides varied from approximately 1.1 mg L^{-1} in the first phase to approximately 3.5 mg L^{-1} in the fourth phase (table 1). This increase is usually due to the amount of organic sediment, which flows into the lake that supplies the reservoir, and to indirect factors such as temperature and the amount of carbon dioxide or of oxygen, which increase or reduce sulfides solubility in the water.

The average concentration of total iron in the water increased from 0.52 to 1.1 mg L^{-1} from the first phase to the second phase because the rainy season began (November and December). This provoked great torrents with muddy soil that contained iron oxide in the areas near the lake that supplied the irrigation reservoir. In the third phase, the concentration of iron decreased to 0.74 mg L^{-1}, but at this time (end of February and March) it rained less and consequently there was a reduction in the contributions due to the superficial drainage to the lake, resulting in a reduction in the concentration of total iron. The same situation occurred in the last phase, which was the drought season (May and June), and the concentration decreased to 0.48 mg L^{-1}. Iron, at present, is one of the main problems in irrigation water, due to its capacity to clog the piping and emitters of drip irrigation systems. This happens because reduced, and therefore soluble, iron (Fe^{2+}) can oxidize and become insoluble (Fe^{3+}) when crossing the filtering system. After oxidation, iron stays on the walls of the pipe, creating an increase in head loss and jeopardizing the irrigation project (Hernandez et al., 2001).

According to Pitts et al. (1990), the values of water hardness of the reservoir in the four phases are considered to present low clogging potential in terms of $CaCO_3$ precipitate formation. This statement can be confirmed based on the results of the calculated Langelier index values, which were always negative (table 1), indicating that there is no problem in the formation of precipitates, which is in agreement with Ayers and Westcot (1985).

The electric conductivity values and the dissolved solid values both indicated that the water used for irrigation has very low salinity and varied little during the four phases of this research.

The average concentration of bacteria dropped significantly from the first phase to the third phase and increased in the last phase, as can be observed in table 1. A large variation in the bacterial concentrations was verified among the average values between one phase and another, which was caused by factors related to the environment and by pH variations in the water. According to Soares and Maia (1999), abrupt variations in bacterial growth are caused by different environmental conditions, such as temperature, pH, and need for oxygen and nutrients. These authors mentioned that, for most bacteria, good growth occurs between pH 6.5 and 7.5. Reservoir water pH varied on average from 7.39 (second phase) to 6.88 (fourth phase). The average algae concentration, after the great growth observed between the first and second phases (from 497 algae m L^{-1} to the about 1377 algae L^{-1}), decreased in the third and fourth phases, reaching values close to the first phase. Such changes are usually due to factors related to the environment.

Generally, we can say that the quality of the water used in the drip irrigation system varied during different times of the year, and the potential risk of emitter clogging was only average or high in relation to the chemical parameters (iron, sulfides, and pH).

EFFLUENT WATER OF THE FILTERING ELEMENTS

Samples were taken before and after the filters. Those taken before represent the water coming from the reservoir, and those taken after represent the water coming from the fabric and disc filters. In this way, the concentrations of algae, bacteria, turbidity, and total suspended solids in the water were determined. The areas were supplied by the water reservoir and experienced an influence of fertigation. Therefore, because the injection of fertilizer occurred at an intermediate point, the presence of the non-woven synthetic fabric and disc filters was not considered to account for the difference between the measurements of a specific water quality parameter taken before and after the filters. Thus, the comparison between the filtering elements was direct and was based on the measurements carried out after the filters. In general, it could not be imagined that the low concentration of fertilizer could cause significant changes in the parameters analyzed. Tables 2 and 3 show the variation of the average values of the suspended solids, turbidity, algae, and bacteria in the water samples taken after the disc and non-woven synthetic fabric filters in the four areas in the four phases of the research.

It can be seen in table 2 that in the first phase of the research, the synthetic woven fiber filtering element obtained better results both for turbidity and for the concentration of suspended solids, as it presented smaller values both in the average and in the standard deviation after the filter for these two physical parameters in the two areas that received treatment with chlorine. In the other two areas, where there was no treatment of the water with chlorine, the values were very similar. In the second phase, the average values, standard deviation, and coefficient of variation for the two filters that received chlorination presented practically the same values; therefore, the performances of both were very similar. The same happened for the filter areas that did not receive chlorination. In the third and fourth phases, for the four areas, the performance of the filters was similar because they presented practically the same values for average concentration values, standard deviation, and coefficient of variation (table 2).

In terms of biological parameters, the disk filter obtained better results than the non-synthetic woven filter in the first stage of the research (table 3) in the areas that received chlorination. However, for the areas without chlorination, the results were very similar. In the second phase, the performance of the two filtering elements in the areas that received chlorination was very similar, and the same happened for the areas that did not receive chlorination. The performance of the filters in the third phase, in relation to algae, for the four areas was similar because they presented practically the same values for average concentrations, standard deviation, and coefficient of variation. The performance did not vary much in relation to bacteria for the filters that received chlorination when the medium values were compared; however, the non-synthetic woven filter was superior to the disk filter in the third phase (table 3) when the filters did not receive chlorine.

Table 2. Results of the physical parameters of the water quality measured after the filters, in four phases.[a]

		Suspended Solids (mg L^{-1})				Turbidity (NTU)			
		Fabric Filter	Disc Filter	Fabric Filter Chlorine	Disc Filter Chlorine	Fabric Filter	Disc Filter	Fabric Filter Chlorine	Disc Filter Chlorine
Phase 1									
	Variation	0 to 5	0 to 5	0 to 3	0 to 4	1.65 to 5.37	1.84 to 3.71	1.57 to 9.68	2.47 to 14.9
	Average	1.90	1.90	0.90	1.75	2.81	2.83	3.22	5.03
	SD	1.97	1.97	1.10	1.87	1.04	0.64	2.33	4.13
	CV (%)	103.64	103.64	122.28	107.12	36.92	22.66	72.51	82.12
Phase 2									
	Variation	9.50 to 13	9.50 to 15	6.5 to 11	7 to 11.5	5.82 to 10.1	5.38 to 10.3	4.66 to 10.5	4.14 to 9.32
	Average	10.96	11.04	9.5	10	7.73	7.59	7.53	7.45
	SD	1.30	1.66	1.53	1.75	1.46	1.41	1.57	1.46
	CV (%)	11.91	15.01	16.10	17.50	18.95	18.54	20.84	19.59
Phase 3									
	Variation	14 to 25.5	12 to 27.5	12 to 23.5	11 to 26	6.58 to 15.3	8.65 to 15.8	9.57 to 13.9	9.13 to 16.4
	Average	17.89	18.78	16.61	17.76	10.76	11.67	11.76	12.05
	SD	5.05	5.04	3.33	4.71	2.90	2.55	1.89	2.77
	CV (%)	28.22	26.86	20.07	26.54	26.99	21.82	16.05	23.00
Phase 4									
	Variation	15.5 to 22.5	15.5 to 24	14 to 25.5	13.5 to 24.5	6.41 to 14.1	6.05 to 11.9	4.44 to 13.5	6.4 to 14.4
	Average	18.70	19.90	18.75	19.15	9.80	9.92	9.17	9.98
	SD	2.31	2.88	3.39	3.38	2.30	1.66	2.84	2.75
	CV (%)	12.36	14.50	18.10	17.62	23.44	16.75	30.93	27.53

[a] SD = average standard deviation, and CV = coefficient of variation.

Table 3. Results of the biological parameters of water quality measured after the filters, in four phases.[a]

		Algae (No. cm^{-3})				Bacteria (No. cm^{-3})			
		Fabric Filter	Disc Filter	Fabric Filter Chlorine	Disc Filter Chlorine	Fabric Filter	Disc Filter	Fabric Filter Chlorine	Disc Filter Chlorine
Phase 1									
	Variation	105 to 380	110 to 460	115 to 420	115 to 345	17 to 6500	10 to 5900	1 to 1500	2 to 1100
	Average	245.00	262.50	271.00	216.00	1290.70	1668.00	623.90	555.60
	SD	102	101	96.32	84.81	1873	1799	548.11	484.56
	CV (%)	41.72	38.50	35.54	39.27	145.11	107.88	87.85	87.21
Phase 2									
	Variation	445 to 1800	390 to 1155	375 to 925	405 to 1205	1 to 3000	1 to 4100	1 to 2000	1 to 2000
	Average	905.42	828.7	711.67	700.00	1261.9	1296.0	436.33	456.42
	SD	348	214	178.24	214.95	1159	1293	783.04	774.99
	CV (%)	38.39	25.78	25.04	30.70	91.88	99.77	179.46	169.72
Phase 3									
	Variation	330 to 1825	350 to 1210	310 to 1410	320 to 1405	10 to 1300	50 to 1800	6 to 600	3 to 500
	Average	800.00	720.56	830.00	801.67	622.22	615.56	121.89	118.11
	SD	438	275	396.64	416.78	520	576	202.13	171.49
	CV (%)	54.79	38.16	47.79	51.99	83.51	93.64	165.83	145.19
Phase 4									
	Variation	415 to 990	355 to 1025	325 to 1125	345 to 750	190 to 10000	650 to 23000	1 to 1900	10 to 2600
	Average	691.00	609.00	615.00	530.50	2348	4397	227.60	305
	SD	187.08	213.19	269.78	136.37	2852.23	6990.54	589.2	808.20
	CV (%)	27.07	35.01	43.87	25.71	121.48	158.98	258.8	264.98

[a] SD = average standard deviation, and CV = coefficient of variation.

In the last phase, the average concentrations of bacteria for the filters without chlorination presented differences among them, and the performance of the non-synthetic woven filter was superior to that of the disk. In relation to algae, the averages were similar in the areas that did not receive chlorine and in the ones that had the disk filter, which presented better results. The efficiency of chlorination in the removal of bacteria in all of the phases of the experiment is well known, but not always so regarding algae.

In all of the phases, the biological parameters were the ones that presented the largest coefficients of variation in the effluents of the analyzed filters, and the concentration of bacteria presented the largest value. According to Ravina et al. (1992), irrigation projects should possess a high-efficiency filtering system; however, from a microbiological point of view, using water of inferior quality created a frequent need to retrowash the system, which hindered the operation, especially when fertigation was used.

Table 4. Analysis of the variation of suspended solids, turbidity, algae, and bacteria measured after the filters.[a]

Cause of Variation	DF	MS	F-Value	Prob > F
Suspended solids				
Filter	1	15.9668065	1.8873	0.16823
Chlorination	1	27.6063799	3.2631	0.06944
Season	3	1982.7791123	234.3681	0.00001
Filter*chlorination	1	0.0262882	0.0031	0.95444
Residues	137	8.4601053		
Total	143			
Average (mg L^{-1})		12.712153		
CV (%)		22.881		
Turbidity				
Filter	1	7.4030360	1.9056	0.16615
Chlorination	1	1.7623558	0.4536	0.50890
Season	3	471.8125259	121.4457	0.00001
Filter*chlorination	1	1.6191569	0.4168	0.52682
Residues	137	3.8849681		
Total	143			
Average (mg L^{-1})		8.046319		
CV (%)		24.496		
Algae				
Filter	1	0.1022433	0.6837	0.58513
Chlorination	1	0.0531201	0.3552	0.55931
Season	3	36.1350121	80.5461	0.00001
Filter*chlorination	1	0.0523818	0.3503	0.56207
Residues	137	0.1495418		
Total	143			
Average (mg L^{-1})		6.239387		
CV (%)		6.198		
Bacteria				
Filter	1	1.2841490	0.3367	0.56980
Chlorination	1	203.5565549	53.3660	0.00001
Season	3	44.1963899	11.5869	0.00002
Filter*chlorination	1	0.0639745	0.0168	0.89251
Residues	137	3.8143484		
Total	143			
Average (mg L^{-1})		4.945137		
CV (%)		39.494		

[a] DF = degrees of freedom, MS = medium square, F-value was estimated for 5% probability level.

Table 5. Tukey test for the chlorination averages.

Variable	Chlorination	Repetition Number	Average	Original Average	5%
Suspended solids	Without	72	13.150000	13.150000	a
	With	72	12.274306	12.274306	a
Turbidity	Without	72	7.935694	7.935694	a
	With	72	8.156945	8.156945	a
Algae	Without	72	6.258546	521.458944	a
	With	72	6.220228	501.817960	a
Bacteria	Without	72	6.134081	460.314850	a
	With	72	3.756194	41.785258	b

Table 6. Tukey test for the season averages.

Variable	Season	Repetition Number	Average	Original Average	5%
Suspended solids	Winter	36	3.193056	3.193056	c
	Spring	36	10.527778	10.527778	b
	Summer	36	17.738889	17.738889	a
	Autumn	36	19.388889	19.388889	a
Turbidity	Winter	36	3.055555	3.055555	d
	Spring	36	7.984444	7..984444	c
	Summer	36	11.478611	11.478611	a
	Autumn	36	9.666667	9.666667	b
Algae	Winter	36	5.387249	217.601231	c
	Spring	36	6.639891	764.011756	a
	Summer	36	6.552421	699.939420	ab
	Autumn	36	6.377987	587.741573	b
Bacteria	Winter	36	5.952715	383.796696	a
	Spring	36	3.453725	30.617963	b
	Summer	36	4.783036	118.466503	a
	Autumn	36	5.591072	267.022837	a

The similarity among the final average results in each phase was proven based on the analysis of variance of the results (table 4), which confirmed that there was no significant difference at the 5% level among the treatments (disc filter and non-woven synthetic fabric filter) for any of the variables (suspended solids, turbidity, concentration of algae and bacteria). In tables 5 and 6, averages followed by different letters are significantly different at the level of significance indicated in the Tukey tests for filter type, chlorination, and season. There was a significant difference in chlorination only for bacteria (table 5), and significant differences occurred among all the variables in the different seasons of the year (table 6).

Microbiological Analyses of the Algae and Bacteria in the Hoses and Emitters

Algae

After one year of assays, microbiological analyses were carried out to determine the main genus of algae in the water samples collected from the hoses and emitters located in each of the areas with distinct irrigation water treatments (table 7). The *Chlorella*, *Selenastrum*, and *Scenedesmus* genera were also found by Scatolini (2001) in studies on the efficiency of the non-woven synthetic fabric filter in the removal of algae present in irrigation water.

Table 7. Results of the microbiological analysis of the hoses and emitters.

Chemical Treatment	Filter	Genus	
		Winter	Summer
No chlorination	Fabric	*Selenastrum* sp.	*Chlorella* sp., *Cylindrospermum* sp., *Nitzschia* sp., *Selenastrum* sp., *Synedra* sp., and *Staurastrum* sp.
	Disc, 130 micron	*Ankitrodemus* sp., *Selenastrum* sp., *Scenedesmus* sp., and *Microcystis* sp.	*Cylindrospermum* sp., *Dinobryon* sp., *Micrasteria* sp., *Phytoconis* sp., *Scenedesmus* sp., *Selenastrum* sp., *Synedra* sp., and *Staurastrum* sp.
Chlorination	Fabric	*Selenastrum* sp., *Scenedesmus* sp., *Uronema* sp., and *Microcystis* sp.	*Chlorella* sp., *Selenastrum* sp., *Staurastrum* sp., and *Pinnularia* sp.
	Disc, 130 micron	*Selenastrum* sp., *Scenedesmus* sp., *Asterococcus* sp., and *Microcystis* sp.	*Cylindrospermum* sp. and *Selenastrum* sp.

Table 8. Problems caused by algae and their control.[a]

Genus	Algae Group	Problem	Control
Asterococcus sp.	Green	Clogging of nylon filters with 80 μm openings, which can cause clogging in emitters. They are usually found in residual water.	Very resistant to copper sulfate and most of the other algaecides. Control treatment is considered non-economical.
Chlorella sp.	Green	Some species clog filters and they persist throughout the water distribution system. They develop a rich atmosphere in organic matter.	Sensitive to copper sulfate, but very resistant to the treatment with chlorine.
Cylindrospermum sp.	Blue	Clogging of filters	Sensitive to copper sulfate and can be controlled with doses smaller than 0.032 mg L^{-1}.
Microcystis sp.	Blue	They form slime that causes emitter and filter clogging. They are persistent in the distribution system (piping and hoses). They develop in a rich atmosphere in organic matter. They increase the risk of the formation of organochlorides in waters that are rich in organic matter and treated with chlorine.	Sensitive to copper sulfate and chlorine
Nitzschia sp.	Diatoms	Clogging of the filters	Copper sulfate and chlorine
Selenastrum sp.	Green	No problems	Chlorine
Scenedesmus sp.	Green	Persistent in water distribution system of iron piping, hoses) and they can clog emitters.	Resistant to the majority of the algaecides
Synedra sp.	Diatoms	High concentrations, of the order of thousands of cells per milliliter of water. Promotes filter clogging.	Copper sulfide and chlorine
Staurastrum sp.	Green	Emitter clogging	Chlorine

[a] The problems and the control procedure for algae in the clogging of filters and emitters are in agreement with Branco (1986).

The water that arrives at the filter frequently has a large number of algae, the majority of which are retained. The algae that can proliferate, causing, together with the impurities in the water, a biological layer in the filters and emitters, which can harm the performance of the equipment in question. According to Branco (1986), specific genera of algae are responsible for this clogging, as their cells are able to form groups of colonies, such as blue algae, which can grow with or without the presence of light.

The problems of clogging in the irrigated areas, due to the biological parameters of algae, show that those from the *Chlorella* sp. and *Microcystis* sp. genera may have developed from the use of fertilizer, as the product contained 25% organic material. The majority of the algae found in the areas where chlorination was used was due either to their being resistant to chlorine or because there was not enough concentration of free chlorine in the irrigation water to control their development. The characteristics of the algae, such as the genus, the algae group, the problems that they cause, and forms of control, are presented in table 8.

Bacteria

Using microbiological analyses, research was carried to identify the genus (*Pseudomonas* or *Microccoccus*) of the bacteria present in the entrance, in the internal parts, and in the exit of the emitters of the four filtering systems. An *a priori* test was carried out to determine if there was reductive sulfate and iron bacteria in the material collected; however, no identification was carried out. The results are presented in table 9.

The results showed that *Pseudomonas* and the iron bacteria were present in all the samples analyzed. This is due to the fact that the bacteria of the *Pseudomonas* genus oxidize Fe^{+2} and transform it into Fe^{+3}, which then precipitates. This in turn encourages the growth of iron bacterium, such as *Gallionella*, *Leptotrhix*, and *Crenothrix*, forming rust incrustations inside the piping, as well as the precipitation of iron hydroxide, which causes clogging in the emitters. Based on studies carried out by Gilbert et al. (1981), in which various types of chemical treatment were carried out on irrigation water with or without chlorine, and with chlorine and acid, for filtering systems with screen filters only and with sand and screen filters together, it could be observed that the biological factors were the greatest cause of emitter clogging and the *Pseudomonas* bacteria was more present. Ten different types of bacteria in emitters that received chemical treatment or not were identified, and it was verified that *Pseudomonas* was present in 89%.

Reddish-colored sediments were found at the end of all the drip lines in the filtering systems. According to Ford and Tucker (1986), these sediments can contain from 25% to 52% iron oxide and from 21% to 42% organic material. The sediment is formed by the oxidization of the soluble iron in the form of insoluble iron hydroxide. The iron complex can be carried by the irrigation lines and contribute to the iron clogging problem.

CHLORINATION EFFECT IN THE FILTERS

Water samples that had received chlorination were taken after the filters so as to determine the concentration of free

Table 9. Results of the microbiological analysis of the bacteria in the emitters and hoses for the four filtering systems.

	No Chlorine		With Chlorine	
Bacteria	Woven Filter	Disc Filter	Woven Filter	Disc Filter
Pseudomonas	1 cfu mL^{-1}	1 cfu mL^{-1}	1 cfu mL^{-1}	1 cfu mL^{-1}
Micrococcus	Not present in 10 mL	Not present in 10 mL	Not present in 10 mL	Not present in 10 mL
Sulfate reductions	Not present in 10 mL	Not present in 10 mL	Not present in 10 mL	Not present in 10 mL
Iron	Not present in 10 mL	Present in 10 mL	Present in 10 mL	Present in 10 mL

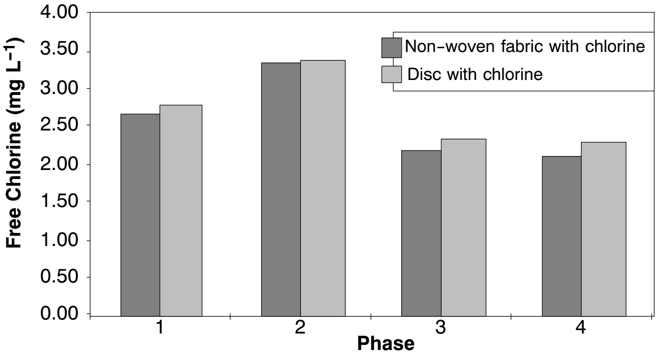

Figure 3. Average of the free chlorine concentration in the non-woven synthetic fabric and disc filters for the four phases.

chlorine and in this way determine which filtering elements had greater consumption. The concentrations were calculated to be approximately 2 mg L^{-1} free chlorine after the filters, per the methodology adopted in this research.

Figure 3 presents the average chlorine concentration results in the four phases of the research. In the first two phases, the free chlorine concentration averages were greater, and there was a reduction in the other two phases for both of the filters. The variation of free chlorine occurred due to the variation in the quality of the water throughout the year in relation to the concentration of algae and bacteria.

During all phases, the free chlorine concentrations were always greater in the effluents of the disc filters. This occurred because the filtering element of the non-woven synthetic fabric has greater permeability, causing a greater retention of impurities and consequently greater consumption of free chlorine.

HEAD LOSS VERSUS FLOW WITH CLEAN WATER

Figure 4 was set up based on the results obtained in the laboratory assay to compare which filter type presented a smaller head loss due to flow variation. It was observed that despite the similarity of the head losses among the filtering elements, the disk filter presented larger head loss values for flows of 0 to almost 5 $m^3\ h^{-1}$, changing this tendency to values up to 6 $m^3\ h^{-1}$.

In order to verify the mechanism of head loss evolution for the filtering elements, Boucher's law (eq. 3) was used, where the filterability index (*I*) of the equation for the filtering elements was verified. The filterability index (*I*) can be used as an index of the resistance to clogging of the filter. With an increase in *I*, filter clogging will occur faster (Adin and Alon, 1986):

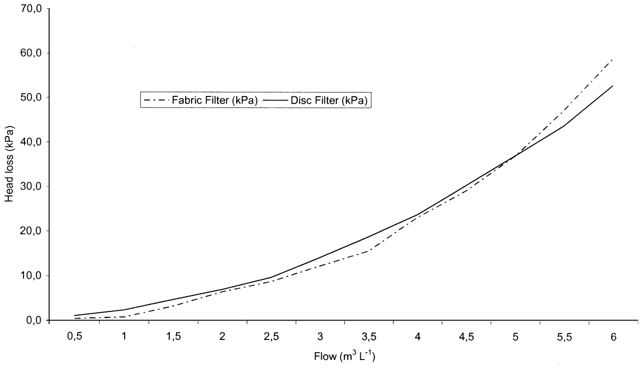

Figure 4. Evolution of the head loss for the disk and non-synthetic woven fiber filtering elements carried out in a laboratory with urban supply water.

$$H = H_0 * e^{(IV)} \quad (3)$$

where

H = head loss (kPa)

H_0 = initial head loss (kPa)

V = filtered volume (m^3)

I = filterability index.

Transforming Boucher's formula yields equation 4:

$$\mathrm{Ln}(H/H_0) = IV \quad (4)$$

The values of the experimental results are plotted figure 5, where the *x*-axis represents the filtered volume (m^3) and the *y*-axis represents the natural logarithm of H/H_0. The value of the filterability index (*I*) is determined by the value of the angular coefficient (inclination) of the straight line.

The linear equations for the two filtering elements, indicating the tendency of the experimental data, are also shown in figure 5. Thus, it is possible to discover which element clogs faster for the same filtered volume. The two linear equations presented a high value of the coefficient of determination (r^2). A greater tendency toward clogging in the non-synthetic woven fiber filter, which presented a larger value of the angular coefficient (0.3677 versus 0.2936 for the disk filter), is obvious. Therefore, the results indicated that there is a tendency toward enhanced performance of the non-synthetic woven fiber filter; however, both filters have similar behaviors.

HEAD LOSS VERSUS FILTERED VOLUME

Figures 6 through 9 show the results of the four phases of the research in terms of the evolution of head loss in the two irrigation filters. Head loss increases continuously up to a moment when there is an abrupt drop; after that, there is a new growth followed by a new drop, and so on successively. The more abrupt drops, in which the head loss falls to a value below 20 kPa, represent washing of the filtering element, whereas the lesser intensity drops represent only the transition between one irrigation shift and the next. The evolution of head loss in the non-woven synthetic fabric filters is much quicker than that observed in the disc filters in the first phase (fig. 6). The head loss in the fabric filter without chlorination at first presented greater growth with time. The growth of the head loss in the non-synthetic woven filter with chlorine became more expressive after the fourth washing of the filtering element (with a filtered volume in the order of 12.0 m^3). These values of head loss were due to the largest retention of

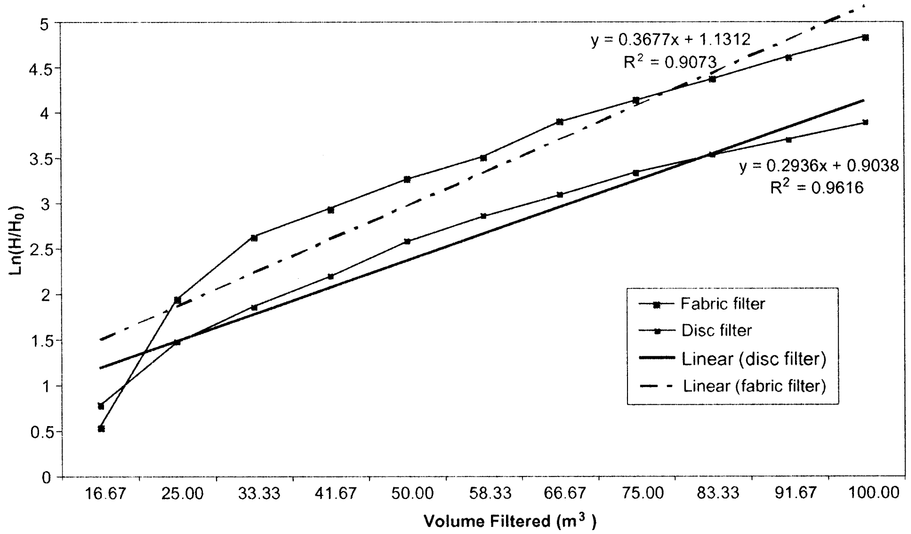

Figure 5. Relation of head loss in the filters due to filtered volume.

suspended and biological solids, which partially obstructed the filter medium.

In the first phase, the quality of the water from the reservoir was always good, with low concentrations of suspended solids, algae, and bacteria (table 1). It was not necessary to carry out any cleaning operation in the disc filters, and the head loss developed by the disc filters was practically stable and remained within the 5 to 10 kPa range for both treatments. However, there was a necessity to clean the non-woven synthetic fabric filters, with and without chlorine, 14 times. The cleaning of the filtering elements was carried out manually between watering shifts, using urban supply water.

In the second phase (fig. 7), there was a worsening of the quality of the water, as indicated by the increase in the average values of suspended solids, turbidity, and algae (table 2). Similar to what occurred in the first phase, in the second phase, the evolution of head loss occurred quicker in the fabric filter that in the disc filter. Once again, the fabric filter with chlorine presented a larger head loss in comparison to the other filter treatments. Eight washings of the fabric filter with chlorine and five of the fabric filter without chlorine were necessary, but no washings were needed for the disc filters. With the decreasing quality of the irrigation water, the head loss varied between 5 to 35 kPa in the disc filter; however, during the second phase, it was usually between 20 and 30 kPa. The evolution of head loss was never over 60 kPa in the second phase, while this happened several times in the first phase, in spite of the better quality of water. This happened because deformation of the non-synthetic woven fiber occurred in the second phase due to the pressure of the system, indicating the need for a more reinforced structure in the internal part of the filters as a support for the non-synthetic woven fiber.

The tendencies observed in the first and second phases were repeated in the third phase. In other words, there was a greater necessity for filter cleaning due to the decreasing water quality. Twelve cleaning operations were carried out in the non-woven synthetic fabric filters, where the head loss reached values of 110 kPa in some cases, due to the increase

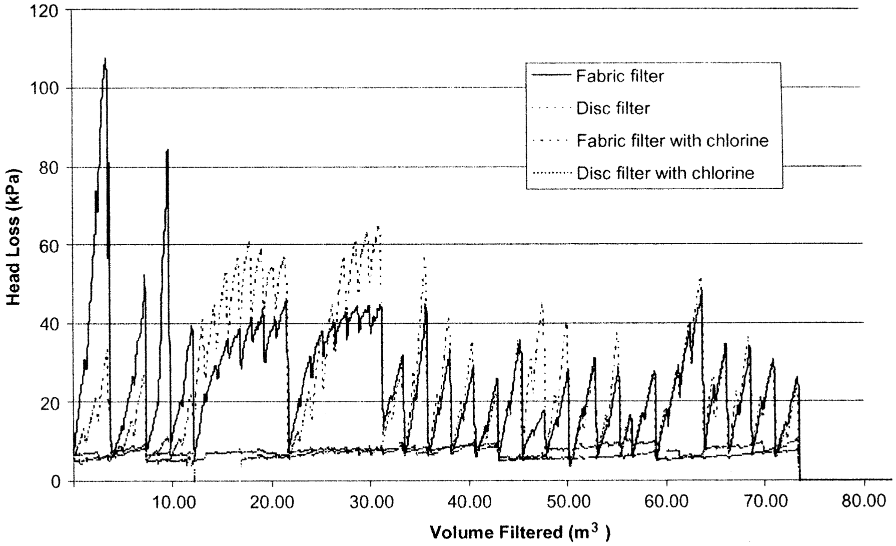

Figure 6. Variation of the head loss versus filtered volume for the disc and non-woven synthetic filters in the first phase.

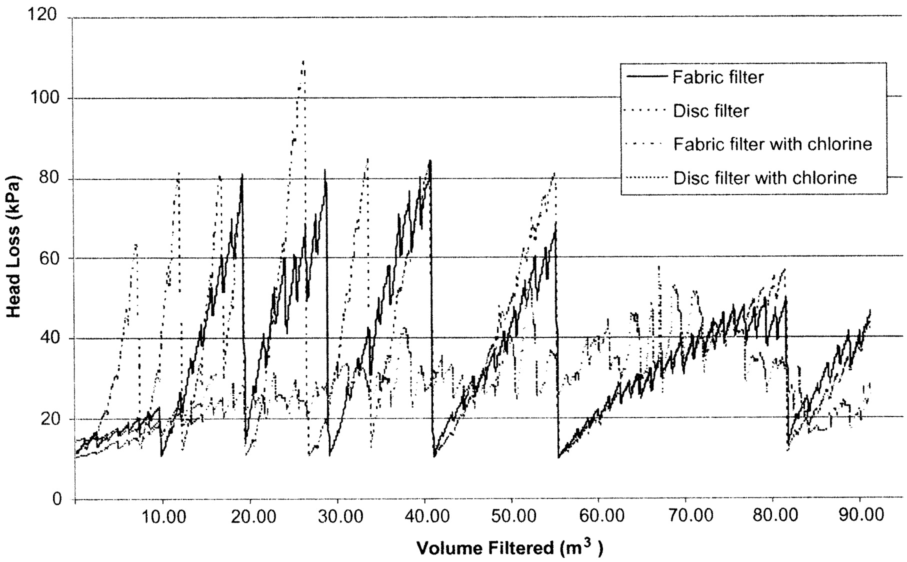

Figure 7. Variation of head loss versus filtered volume for the disc and non-woven synthetic fabric filters in the second phase.

in localized losses (fig. 8). Seven cleaning operations were necessary in the disc filters during this phase.

The worsening in the incoming water quality in the third phase could be seen due to the increase in the average concentration of suspended solids and turbidity (table 1), provoking the rapid increase in head loss in the filters. At various times, the head loss in the non-woven synthetic fabric filters exceeded 50 kPa due to the speed with which the suspended material in the water promoted clogging of the filtering elements. The proposal was to clean the filters whenever the localized head loss reached 40 kPa.

In the last phase (fig. 9), the average concentrations of the suspended solids and turbidity reached the highest values (table 1). Due to this, the filters worked under more severe conditions. Thus, similar to the previous phases, the evolution of head loss developed in the non-woven synthetic fabric filters was higher than that in the disc filters. At times, the head loss in the disc filter quickly passed the maximum allowed loss of 40 kPa. Twenty-three cleanings of the non-woven synthetic fabric filters with chlorine and 19 cleanings of the non-woven synthetic fabric filters without chlorine were necessary during this phase, while only five were necessary for the disc filters. The high frequency of washing of the non-woven synthetic fabric filters as well as the high loss values reached in the disc filters reflect the increase in the average concentrations of suspended solids and turbidity of the reservoir water.

After finishing the four phases of research, it could be stated that the evolution of head loss due to filtered volume was quicker in the non-woven synthetic fabric filters than in the disc filters. Therefore, a greater number of washing operations was needed in the non-woven synthetic fabric filters. The same problem occurred in the study carried out by Scatolini (2001), who concluded that the rapid increase of head loss in non-woven synthetic fabric filters was due to the greater retention of suspended solids that partially clogged the filter medium. This process is associated with the large adherence of impurities in the entangled fibers and with the formation

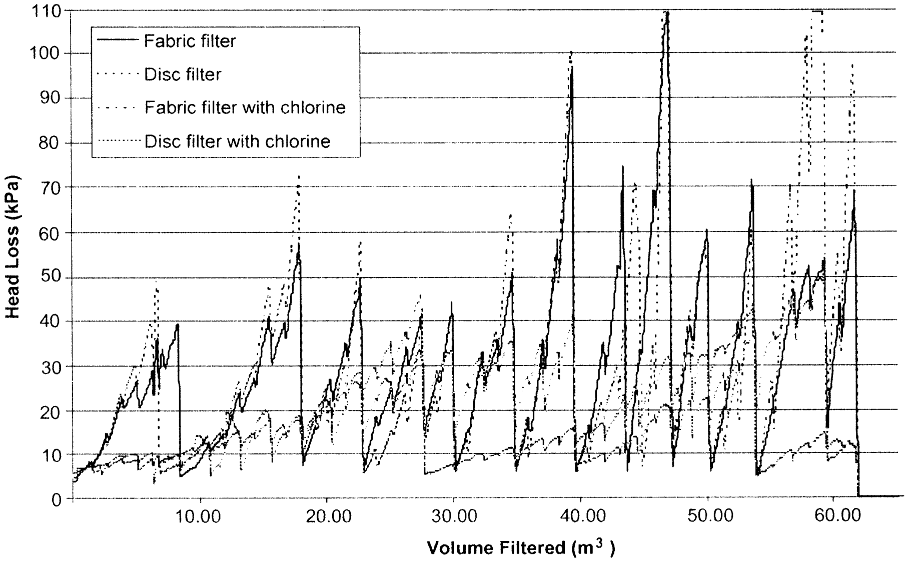

Figure 8. Variation of loss head versus filtered volume for the disc and non-woven synthetic fabric filters in the third phase.

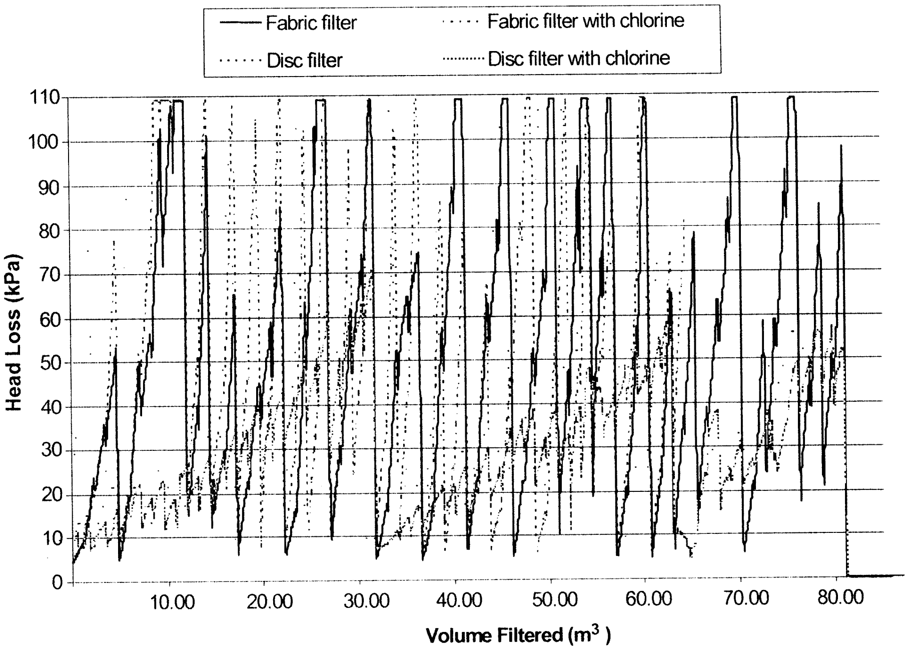

Figure 9. Variation of the head loss versus filtered volume for the disc and non-woven synthetic fabric filters in the fourth phase.

of a biological layer due to the removal of algae and bacteria from the water. The increase of head loss is directly related to the retention of solid particles in the filter medium: the greater the accumulation of solid particles in the filter, the smaller the space available for the water to pass through and consequently the greater water head loss.

According to Wilkinson (1986), diameters between 2 and 1.50 mm of a non-woven synthetic fiber are appropriate for the removal of 1 to 100 mm particles. As the non-woven synthetic fiber used in this research has a fiber diameter of 1.50 mm, it is capable of retaining particles between 1 to 100 mm, while the disk filter retains particles up to 130 mm. This explains why the evolution of head loss in the non-woven synthetic fiber filter was faster than in the disk filter.

Nakayama and Bucks (1991) reported that when high concentrations of suspended particles are present in irrigation water, there is a greater necessity to clean the filters of drip irrigation systems. The authors suggested the use of an automatic retrowashing filter to have better control of the removal of suspended particles.

ANALYSIS OF CLOGGING IN THE EMITTERS

It can be observed that, based on the values presented in table 10, there were no large variations in the uniformity indexes among the areas where the filters were tested. However, there was a decrease in the values over time, from the first phase to the fourth phase. This indicates that there was an emitter clogging tendency in the four areas, and the decrease in uniformity was more noticeable between the third and fourth phases. In agreement with the classification of Bralts and Kesner (1983), the indexes were considered excellent or very good depending on the time of the year. It can also be noted that, in each phase, the volume filtered in the areas varied from a minimum value of 62.29 (phase 3) to a maximum of 91.29 m^3 (phase 2). These variations caused a larger number of retrowashings due to the variation in the quality of the water throughout the year. However, they did always affect the clogging level of the emitters. This occurred due to good maintenance of the filters.

The causes of the variations through the year were due to time of use of the emitters, variations in the quality of the water during the year, lack of an automatic retrowashing system in the filters, and impurities in the water, mainly of biological origin.

The results for the water with and without chlorine, when comparing the uniformity indexes among the disk filters, indicated that chlorination was not that efficient (table 10). The same results occurred for the non-woven synthetic fiber filters. This might be because chlorine is not as efficient in the control of certain types of algae, such as *Asterococcus* sp., *Chlorella* sp., *Cylindrospermum* sp., and *Scenedesmus* sp. (Branco, 1986).

Table 10. Levels of emitter clogging in the four areas where the filtering element tests were carried out using average values of the water uniformity distribution index (WUI, %) during the four phases.

	First Phase (73.49 m^3 filtrate)		Second Phase (91.29 m^3 filtrate)		Third Phase (62.29 m^3 filtrate)		Fourth Phase (81.49 m^3 filtrate)	
Filter	WUI	Classification[a]	WUI	Classification	WUI	Classification	WUI	Classification
Fiber	98.08	Excellent	98.23	Excellent	97.30	Excellent	96.77	Excellent
Disk	97.83	Excellent	96.84	Excellent	96.15	Excellent	95.88	Excellent
Fiber, chlorination	97.55	Excellent	97.42	Excellent	97.19	Excellent	94.48	Excellent
Disk, chlorination	97.57	Excellent	97.14	Excellent	98.24	Excellent	87.79	Very good

[a] Classification system developed by Bralts and Kesner (1983).

During this research, the filter that presented a smaller level of clogging and greater water distribution index was the non-woven synthetic fiber without chlorine. There were no great differences in the level of clogging among the four areas. However, there were variations in the filtered volume.

CONCLUSION

The biological parameter presented the greatest coefficient of variation. This parameter analyzed the concentration of algae and bacteria, where the latter presented the greatest variation. The evolution of head loss in the non-woven synthetic fabric and disc filters was influenced by the water quality, and this influence was greater in the non-woven synthetic fabric filters, which led to a greater number of washing operations. For greater control of the retrowashing operations, and improvement in the filtering system efficiency, it would be important to install an automatic differential pressure retrowashing system in the non-woven synthetic fabric filters.

No significant differences were detected among the filtering elements of the disc and non-woven synthetic fabric filters in relation to removal of suspended solids, turbidity, algae, and bacteria at the 5% significance level. There were differences in filter performance in terms of the time of year for suspended solids, turbidity, algae, and bacteria and for the treatment with chlorine in terms the degree of bacteria concentration.

There were no great variations in the level of emitter clogging between the four areas analyzed. Future research altering the type of fabric, thickness, and filtering area could indicate the best characteristics of these filtering elements for use in drip irrigation systems.

ACKNOWLEDGEMENTS

The authors are grateful to FAPESP for the financial support to carry out this project (Process 00/01292-5) and for the study grants (Processes 01/02058-9 and 01/01719-1).

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