HYDROCYCLONE FOR PRE-FILTERING OF IRRIGATION WATER

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ABSTRACT: The use of water containing suspended sediments causes serious problems to irrigation systems. Choosing the right filtering system type and capacity is essential to avoid increases in operational and maintenance costs of irrigation resulting from the need for cleaning and frequent component replacing. Pre-filters, such as the hydrocyclone, are important for their significant capability of retaining particles suspended in the water. Data on hydrocyclones performance for pre-filtering of irrigation water can be found in the literature, but research data in Brazil are scarce. Therefore, four Rietema type hydrocyclones (50 mm diameter) were constructed, one with circular-end and the other three presenting rectangular-end feeding tubes. The evaluation of hydrocyclones performance was conducted by using suspensions of fine sand and clay soil particles under varied pressure differentials. The comparison criteria were the discharge and the separation capability, given by total efficiency and reduced total efficiency. The hydrocyclone with circular-end feeding tube presented the highest indexes for the adopted criteria, considering sand and soil suspensions.
Key words: filtration, cyclones, centrifugal separator

HIDROCICLONE PARA PRÉ-FILTRAGEM DA ÁGUA DE IRRIGAÇÃO

RESUMO: A utilização de água contendo partículas sólidas em suspensão tem sido a causa de sérios problemas em sistemas de irrigação. A escolha do tipo e capacidade do sistema de filtragem é de fundamental importância para evitar aumento nos custos de operação e manutenção do sistema de irrigação. Pré-filtros, como os hidrociclones, caracterizam-se por significativo poder de separação de partículas presentes na água. Apesar de algumas referências feitas aos hidrociclones, não se dispõe no Brasil de resultados do desempenho dos mesmos, quando empregados em pré-filtragem da água utilizada nos sistemas de irrigação. Assim, um experimento compreendeu a construção e a avaliação do desempenho de quatro hidrociclones do tipo Rietema, utilizando-se suspensões de areia fina e de solo argiloso, sob diferentes diferenciais de pressão, e adotando-se como critério de comparação a capacidade de vazão e o poder de separação, medidos pela eficiência total e eficiência total reduzida. O hidrociclone dotado com bocal de alimentação circular apresentou os maiores índices nos critérios de comparação, com suspensão de areia e suspensão de solo.
Palavras-chave: filtração, ciclones, separador centrífugo

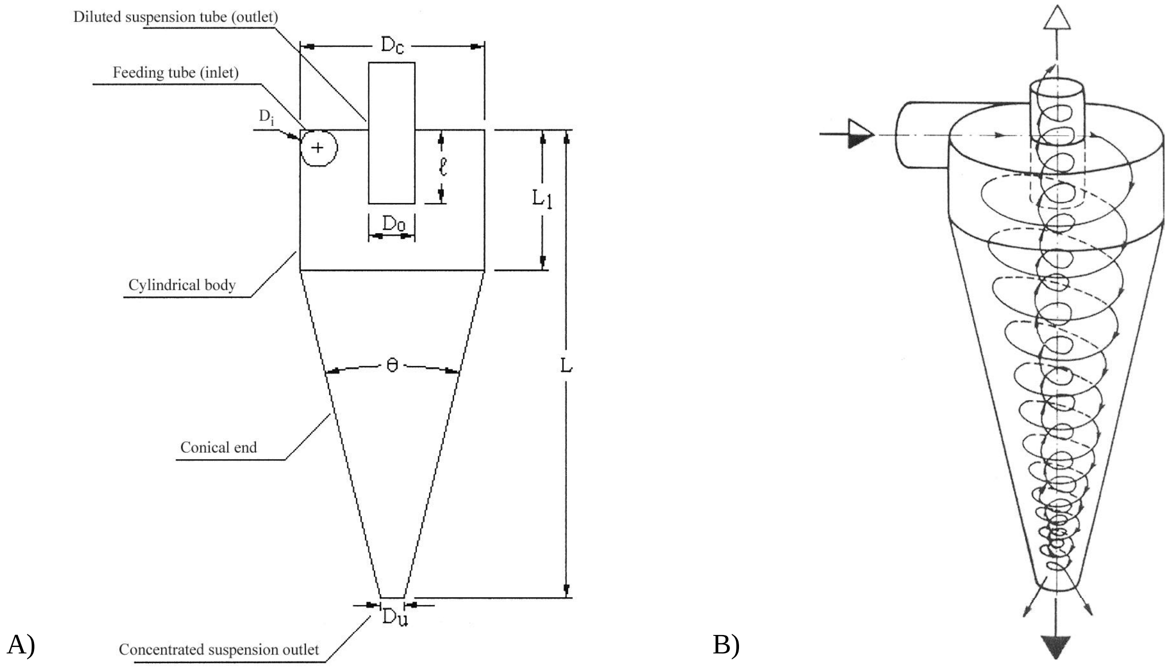
INTRODUCTION

Sediments present in the water usually reduce durability of irrigation system components such as pump rotors, feeding tubes and localized irrigation pipelines. Sedimentation basins and hydrocyclones can be used to reduce the size and costs of filtering systems (Keller & Bliesner, 1990).

The hydrocyclones are an important class of equipments destined to separation of solid-liquid suspension phases (Souza et al., 2000). An hydrocyclone consists of a conic end linked to a cylindrical body, in which there is a tangential entrance for the feeding suspension. The hydrocyclone has a tube in its upper part for the diluted suspension draining (overflow) and a hole in the under part for the concentrated suspension draining (underflow) (Figure 1 a). The suspension is pumped through the feeding tube and when entering the hydrocyclone it is activated by a rotational, descendent movement and tends towards the drainage point of the underflow (Flintoff et al., 1987) as shown in Figure 1b.

When the feeding suspension is introduced into the hydrocyclone, a fraction of the liquid and the higher velocity (heavier) particles are discharged through the concentrated underflow drain. The remaining liquid and the lower velocity (lighter) particles are discharged throughout the diluted overflow drain (Silva, 1989). Even though the hydrocyclone may not be separating by centrifugation, a certain amount of solids is removed with the concentrated in a rate that may be defined by the equation:

$$R_L = \frac{Q_u\left(1 - Cv_u\right)}{Q\left(1 - Cv\right)} \qquad (1)$$



D_C – Hydrocyclone diameter; D_i – feeding tube diameter; D_o – diluted overflow tube diameter; D_U – concentrated underflow tube diameter; L – hydrocyclone length; ℓ - diluted overflow tube reentrance; L_1 –hydrocyclone cylindrical part length; θ - cone angle.

Figure 1 - Diagram showing the main hydrocyclone dimensions (a) and the internal draining movement (b).

where: R_L – liquid ratio, non-dimensional; Q_u – concentrated suspension outflow, L T^{-1}; Q – feeding suspension outflow, L^3 T^{-1}; Cv_u – volumetric concentration of the concentrated suspension, non-dimensional; Cv - volumetric concentration of the feeding suspension, non-dimensional (Silva, 1989).

The total or global efficiency is defined as the ratio between the concentrated suspension solid mass outflow and the feeding suspension solid mass outflow:

$$E_T = \frac{Ws_u}{Ws} \quad (2)$$

where: E_T – total efficiency, non-dimensional; Ws - feeding suspension solid mass flow, M T^{-1}; Ws_u - concentrated suspension solid mass flow, M T^{-1}.

The reduced total efficiency is calculated by subtracting the "dead flow" contribution, thus resulting in the hydrocyclone actual performance, which has been calculated by the expression:

$$E_T^{'} = \frac{E_T - R_L}{1 - R_L} \quad (3)$$

where: E'_T – reduced total efficiency, non-dimensional; E_T – total efficiency, non-dimensional; R_L – liquid ratio, non-dimensional (Kelsall, 1953).

This work aimed to construct and evaluate four hydrocyclones with equal dimensions, but varying the form and dimension of the feeding tubes, operating with sand and soil suspensions, in order to obtain best performance parameters and efficiency on the removal of solid particles present in the water.

MATERIAL AND METHODS

Hydrocyclone assembly

Four 50 mm-diameter hydrocyclones were assembled for the experiment. Equipment dimensions followed recommendations of Rietema (1961), differing only regarding the shape and dimensions of the feeding tube. The hydrocyclone with circular-end feeding tube, Hydrocyclone I, the first to be dimensioned, had 13.99 mm internal diameter. The other three hydrocyclones were assembled with rectangular-end feeding tubes with different shapes and sizes (Table 1). For the circular-end feeding tube, the inflow rate established was equal to 2 m s^{-1}, and the outflow, defined by the continuity equation, was 0.31 L s^{-1}. Dimensions of the retangular-end feeding tube were calculated considering hydrocyclone pressure reduction of 50, 100 and 150 kPa, for hydrocyclones II, III and IV, respectively, using the continuity equation and an average discharge coefficient of convergent, conical-end feeding tube equal to 90% (Neves, 1979).

The feeding tubes were assembled using 15-mm nominal diameter (ND), commercial copper tubes, and the rectangular-ends were molded with the correspondent dimensions (Table 1).

Essay material

Fine sand and clayey-soil were used as sediment material (Kandiudalfic Eutrudox). After rinsing the fine sand, was sieved through a 1.19 mm screen to remove coarse particles. The soil was sieved through a 0.54 mm screen to remove small gravels. Density of sand and soil particles were determined by the Pycnometer (density bottle) method (Kiehl, 1979), resulting in values of 2.65 g cm^{-3} and 2.70 g cm^{-3}, for sand and soil, respectively. Soil fractions were also determined according to Kiehl (1979), and the following values were found: 73.55% clay, 18.26% silt, and 8.19% sand.

Experimental workbench

The experiment was performed in a workbench, in closed circuit (Figure 2):

1) Reservoir: For the sand-water or soil-water suspensions, 500 L capacity.

2) Motor-pump: Centrifugal pump with discharge flow of 4,500 L h^{-1} (0.00125 m^3 s^{-1}), pumping pressure of 340 kPa, and electrical motor with 1,470.60 W (2 HP) and 3,500 rpm.

3) Flowmeter: Electromagnetic flowmeter with nominal flow of 1,000 L h^{-1} (0,000278 m^3 s^{-1}).

4) Pressure sensor: The pressure-differential in the hydrocyclone was evaluated by pressure plugs installed into the feeding tube and diluted suspension, using differential-transducer pressure sensors with capacity within the range of 0 to 700 kPa and 2.5% error for temperatures between 0 and 85°C. When fed by a 5V c/c stabilized tension, the sensor emits analogical signals varying from 0.2 to 4.7V c/c, which are transformed in pressure readings. The pressure-transducer outputs were also linked to the digital analogical converser (DAC), allowing monitoring of the pressure reduction in the hydrocyclone.

5) Hydrocyclone: Sampling sites were installed close to the hydrocyclone, in the feeding tube (a) and in the diluted suspension (b).

6) Submersible shaker: Electrical motor, 1,102.90 W (1,5 HP) and 1,650 rpm, kept suspension homogeneous during samplings.

7) Microcomputer: Equipped with the software Aquidados (Vilela et al., 2001), to control the digital analogical converter by signals emitted through the computer parallel port. The software also controlled transmission of digital data to the CPU unity. Such information was processed and displayed in the video-monitor, at real time, and results were simultaneously stored in specific files, with respective reading date and time records.

Experimental procedures

Sand and soil suspensions were prepared by the addition of 20 kg of material, previously sieved, to 450 L of water, resulting in an initial sediments concentration of 44.44 g L^{-1}.

Table 1 - Characteristics of the feeding tubes used in the hydrocyclones.

Characteristic	Feeding-end			
	Circular	Rectangular		
	20 kPa (I)	50 kPa (II)	100 kPa (III)	150 kPa (IV)
Internal dimensions (mm)	d = 13.99	1.72 x 20.30	1.20 x 20.81	0.95 x 21.40
Section (mm^2)	153.77	34.92	24.97	19.99

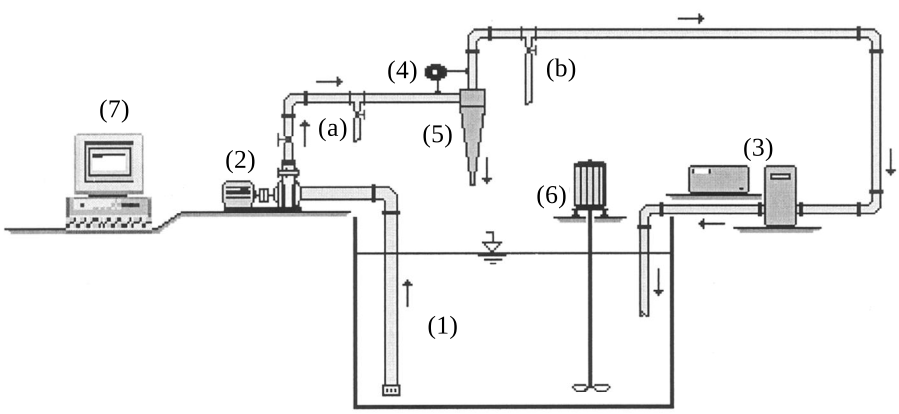


Figure 2 - Diagram of the experimental workbench and components.

Starting of system: The workbench system was set in motion by the motor-pump; the microcomputer, the flow-meter, the pressure-sensor and the submersible shaking were then turned on. The desired pressure reduction was adjusted by the software *through* a gate valve installed in the pump output. Pressure differentials were: 10, 20, 30, 40, 50, and 60 kPa, for the hydrocyclone I, operating with sand and soil suspensions; 20, 50, 100, and 150 kPa, for hydrocyclones II, III and IV, operating with soil suspension. After systems reached equilibrium, the temperature of the suspension was checked and data monitoring started. The liquid ratio (LR) was adjusted to 10% by the gate valve installed in the output of the concentrated suspension.

Data monitoring: The reading interval and data registration period were adjusted to 60 s in the initial display screen, and then the reading key was entered. During the flow and pressure reduction data-collecting period, aliquot samples of the concentrated suspension were taken at 30 s intervals and weighed, to obtain the sample mass. When the flow and pressure differential readings were finished, the feeding suspension sampling started. This procedure was repeated for each pressure differential point sampled.

Concentration measurements: The sample concentrations were determined using the gravimetric method. An aliquot sample (exact volume) was transferred to an aluminum recipient and oven dried at 110^{o}C for 24 hours. After evaporation, the residue was weighed for dry matter determination and expressed as g L^{-1}.

Analysis of particle size fraction: The determination of sand and soil particle size fraction followed distinct procedures, since the replications of each sample were pooled, due to small quantity of solids collected, mainly from the feeding flow. Determination of the sand fraction was done by the sieve method and determination of the soil fraction, by the sedimentation method (Allen, 1990). A kit of ten sieves, mesh 1,000, 590, 500, 420, 297, 250, 149, 105, 74, and 53 mm was used for the sand fraction analysis. The total amount of dry sand was weighed and three subsamples were taken; each subsample was set top the kit and sieved by shaking for 12 minutes. Sieves were then weighed to obtain the fraction mass (X), correspondent to each screen meshes.

For determination of the soil particle size fraction, the method used was based on the gravimetric sedimentation, and the variation on the sediment concentration of the collected samples at determined intervals, allowed to calculate the cumulative fraction, in a mass basis, lower than a certain diameter (d), determined by the Stoke´s law. The dried soil sample was weighed and transferred to a recipient with distilled water, let stand for 24 hours and stirred at 16,000 rpm for 20 minutes to disaggregate the particles. The suspension was then transferred to a 1,000-mL graduated cylinder, distilled water was added until completing the volume, and the suspension was manually stirred for 60 seconds, using a plain-disc. The sampling period was then started: 10-mL samples were taken, using a pipette plunged 10 cm into the suspension, after 10, 30, 60, 120, 180, 300, 600, 1,200, and 1,800 seconds. Samples were transferred to small vials and oven-dried at 110^{o}C for 24 hours. The dry residue was weighed in analytical balance to the nearest 0.0001 g, for the determination of mass fraction *X* lower than a certain Stokes diameter, using the Equation (4):

$$X = \frac{C}{C_o} \quad (4)$$

where: *X* – mass fraction lower than a certain diameter, non-dimensional; C – sample concentration collected at time t, M L^{-1}; C_o – initial concentration, M L^{-1}.

At the beginning of each essay, the suspension's temperature was monitored in the graduated cylinder. The correspondent Stokes' diameter was calculated by Equation (5), for each defined sampling period of time, and resulted approximately in 7, 8, 12, 17, 22, 27, 38, 54, and 93 mm, respectively.

$$ds_{tk} = \left[\frac{18mh}{gt(r_s - r)}\right]^{0,5} \quad (5)$$

where: ds_{tk} - Stokes' diameter, L; m - fluid absolute viscosity, M L^{-1} T^{-1}; h – pipette sampling depth, L; g – acceleration due to gravity, L T^{-2}; t – sampling time interval, T; ρ_s – solid density, M L^{-3}; ρ - fluid density, M L^{-3}.

RESULTS AND DISCUSSION

Hydrocyclones performance

Hydrocyclone I

Mean values on hydrocyclone I performance operating with sand and soil suspension are presented in Table 2. The suspension sediment concentration varied with increasing pressure differential. It was not possible to keep the suspension homogeneous in the input flow to the centrifugal pump at the same time that the workbench dynamic conditions were altered, since the stirring velocity of submersible shaker was at the limit above which the suspension started to be ejected out of the reservoir. As no other shaker was available, the test took into account differences in suspension concentrations.

The feeding flow varied from 1,159.9 L h^{-1} to 2,603.6 L h^{-1} and from 1,160.9 L h^{-1} to 2,534.8 L h^{-1}, for operation with sand and soil suspension respectively. The suspension temperature remained between 21^{o}C and 22^{o}C during the essays.

Table 2 - Average data of performance parameters of Hydrocyclone I operating with sand and soil suspension.

ΔP (kPa)	Q	Q_u	[A]	[C]	Cv	Cv_u	LR	Ws	Ws_u	ET	ET'
	------ L h^{-1} ------		------ g L^{-1} ------		------------- % ------------			----- kg h^{-1} -----		------- % -------	
Sand											
10.80	1159.9	133.5	2.81	23.26	0.106	0.879	11.42	3.265	3.104	95.08	94.45
22.30	1582.8	223.3	2.99	21.09	0.113	0.797	13.66	4.849	4.708	97.09	96.62
29.50	1826.8	133.7	6.19	69.34	0.234	2.627	7.14	11.314	9.269	81.93	80.54
40.40	2002.2	207.6	6.11	45.50	0.231	2.720	10.22	12.239	9.444	77.16	74.56
52.00	2386.2	249.4	5.93	42.99	0.224	1.625	10.25	14.139	10.273	72.79	69.99
62.70	2603.6	259.2	7.01	47.95	0.265	1.813	9.80	18.255	12.427	68.07	64.61
Soil											
11.90	1160.9	156.5	7.29	13.98	0.270	0.518	13.48	8.436	2.188	25.93	14.38
22.60	1595.1	143.9	11.46	51.10	0.424	1.893	8.89	18.279	7.356	40.29	34.46
29.60	1813.8	141.5	11.32	58.03	0.419	2.149	7.69	20.542	8.141	39.63	34.62
43.50	2128.9	201.2	11.10	51.68	0.411	1.914	9.31	23.643	10.403	43.94	38.19
51.90	2284.8	220.4	10.89	43.07	0.403	1.595	9.53	24.383	9.497	38.15	31.63
63.60	2534.8	244.7	12.12	48.24	0.449	1.787	9.52	30.727	11.796	38.42	31.94

ΔP – pressure differential in the hydrocyclone; Q – feeding flow; Q_u – concentrated flow; [A] – feeding solid concentration; [C] – concentrated suspension solid concentration; Cv – feeding volumetric concentration; Cv_u – concentrated volumetric concentration; LR – liquid ratio; Ws – feeding solid mass flow; Ws_u – concentrated solid mass flow; ET – total efficiency; ET' – reduced total efficiency.

For the sand suspension essays, the highest indices of total reduced efficiency *ET'* were 94.45% and 96.62%, obtained for pressure differences of 10.80 kPa and 22.30 kPa, respectively; the lowest was 64.61% for a 62.70 kPa difference. For the soil suspension essays, *ET'* varied from 14.38% to 38.19% for pressure differences of 11.90 kPa and 43.50 kPa, respectively, decreasing to 31.94% for a 63.60 kPa pressure difference.

When operating with sand, hydrocyclone I had always higher total reduced efficiency *ET'* for similar pressure differences, as expected, due to the sand particle size characteristics. The average *ET'*, for all the pressure differences, was 80.13% and 30.87% for the sand and soil tests, respectively. The hydrocyclone separation capacity depends on its size and geometry, particle size and geometry, solid concentration, inflow rate, liquid ratio and density difference between particles and fluid (Jacobs & Penney, 1987). The highest sand suspension concentrations, for pressure differences higher than 22.30 kPa, had no effect on hydrocyclone performance. Even for higher feeding flows there was no gain in efficiency, what might be consequence of a greater turbulence into the hydrocyclone. For the soil suspension, the lower efficiencies obtained may be explained by the smaller particle sizes.

Hydrocyclones II, III and IV

Significantly lower feeding suspension concentrations in hydrocyclones II, III and IV were observed in comparison to those in hydrocyclone I, mainly for the pressure differences of 20 kPa and 50 kPa (Tables 3, 4 and 5), what may be explained by a lower feeding flow and, consequently, lower suspension turbulence in the reservoir, for first ones. The feeding flows observed during the tests varied from 806.5 L h^{-1} to 2,028.4 L h^{-1}, 401.3 L h^{-1} to 1,095.3 L h^{-1} and 322.8 L h^{-1} to 847.7 L h^{-1} for hydrocyclones II, III and IV, respectively.

The reduced total efficiencies obtained for hydrocyclones II, III and IV were similar to the hydrocyclone I, and the highest values were observed in the sand suspension test, with the following average mean values, for all pressure differentials: hydrocyclone II - 52.99% and 21,45% for sand and soil suspension, respectively; hydrocyclone III – 36.69% and 17.25% for sand and soil suspension, respectively; hydrocyclone IV – 34.45% and 12.66% for sand and soil suspension, respectively.

Comparing the performance of the four hydrocyclones, using *ET'* as reference, and considering a common pressure differential of 50 kPa, decreasing flows were observed for the hydrocyclones II, III and IV of 51.04%, 73.92% and 78.38%, respectively, in relation to the hydrocyclone I. The flow reduction did not represent efficiency gains for these hydrocyclones, meaning that, at the same test conditions, the reduced total efficiency decreased 26.72%, 53.98% and 38.52% for the sand suspension, and 62.60%, 71.04% and 78.69% for the soil suspension, for hydrocyclones II, III and IV, respectively. Hydrocyclones III and IV showed feeding tube obstruction, what might be explained by the smaller feeding tube diameter (Table 1).

Table 3 - Average data of performance parameters of Hydrocyclone II operating with sand and soil suspension.

ΔP (kPa)	Q	Q_u	[A]	[C]	Cv	Cv_u	LR	Ws	Ws_u	ET	ET'
	------ L h^{-1} ------		------ g L^{-1} ------		------------- % -------------			----- kg h^{-1} -----		------- % -------	
Sand											
23.90	806.5	94.5	0.35	2.08	0.013	0.079	11.70	0.281	0.197	72.73	69.13
51.10	1165.0	155.5	0.91	3.48	0.034	0.132	13.30	1.063	0.541	57.79	51.29
99.60	1621.8	195.3	5.69	25.92	0.215	0.980	12.00	9.244	5.069	59.99	54.47
151.70	2017.0	250.4	7.95	30.63	0.301	1.159	12.30	16.059	7.222	44.84	37.08
Soil											
48.50	1121.9	203.7	6.94	10.64	0.257	0.394	18.23	7.721	2.157	27.90	11.83
104.60	1667.3	190.7	14.23	42.03	0.527	1.556	11.32	23.758	8.029	33.88	25.45
152.10	2028.4	195.3	12.30	46.80	0.456	1.733	9.50	24.954	8.509	33.97	27.08

ΔP – pressure differential in the hydrocyclone; Q – feeding flow; Q_u – concentrated flow; [A] – feeding solid concentration; [C] – concentrated suspension solid concentration; Cv – feeding volumetric concentration; Cv_u – concentrated volumetric concentration; LR – liquid ratio; Ws – feeding solid mass flow; Ws_u – concentrated solid mass flow; ET – total efficiency; ET' – reduced total efficiency.

Table 4 - Average data of performance parameters of Hydrocyclone III operating with sand and soil suspension.

ΔP (kPa)	Q	Q_u	[A]	[C]	Cv	Cv_u	RL	Ws	Ws_u	ET	ET'
	------ L h^{-1} ------		------ g L^{-1} ------		------------- % -------------			----- kg h^{-1} -----		------- % -------	
Sand											
23.90	401.3	53.0	0.11	0.35	0.004	0.013	13.10	0.042	0.019	43.86	35.46
54.30	602.9	92.8	0.18	0.50	0.007	0.019	15.40	0.108	0.046	42.64	32.21
102.20	842.6	122.6	0.40	1.16	0.015	0.044	14.50	0.339	0.143	42.09	32.23
151.10	1012.9	100.3	3.42	18.01	0.295	0.681	9.80	3.468	1.806	52.07	46.84
Soil											
48.90	615.4	113.1	7.37	10.05	0.273	0.372	18.36	4.491	1.141	25.84	9.16
104.20	891.6	116.6	5.75	14.69	0.213	0.544	13.04	5.169	1.708	34.25	24.40
152.00	1095.3	133.9	16.44	37.83	0.609	1.401	12.13	18.004	5.062	28.13	18.20

ΔP – pressure differential in the hydrocyclone; Q – feeding flow; Q_u – concentrated flow; [A] – feeding solid concentration; [C] – concentrated suspension solid concentration; Cv – feeding volumetric concentration; Cv_u – concentrated volumetric concentration; RL – liquid ratio; Ws – feeding solid mass flow; Ws_u – concentrated solid mass flow; ET – total efficiency; ET' – reduced total efficiency.

Table 5 - Average data of performance parameters of Hydrocyclone IV operating with sand and soil suspension.

ΔP (kPa)	Q	Q_u	[A]	[C]	Cv	Cv_u	LR	Ws	Ws_u	ET	ET'
	------ L h^{-1} ------		------ g L^{-1} ------		------------- % -------------			----- kg h^{-1} -----		------- % -------	
Sand											
28.00	322.8	39.6	0.02	0.04	0.001	0.002	12.30	0.007	0.002	24.76	14.25
54.90	497.6	51.3	0.35	1.67	0.013	0.063	10.30	0.174	0.086	49.26	43.03
101.00	631.9	72.1	1.62	6.77	0.061	0.256	11.40	1.024	0.489	47.72	41.00
148.80	829.9	91.5	11.87	49.60	0.449	1.875	10.90	9.848	4.537	46.07	39.50
Soil											
52.40	512.4	111.6	5.93	7.36	0.220	0.273	21.78	3.037	0.822	27.05	6.74
105.50	652.7	139.9	8.54	12.86	0.316	0.476	21.40	5.571	1.798	32.28	13.84
149.60	847.7	151.1	9.67	17.40	0.358	0.644	17.78	8.199	2.629	32.08	17.40

ΔP – pressure differential in the hydrocyclone; Q – feeding flow; Q_u – concentrated flow; [A] – feeding solid concentration; [C] – concentrated suspension solid concentration; Cv – feeding volumetric concentration; Cv_u – concentrated volumetric concentration; LR – liquid ratio; Ws – feeding solid mass flow; Ws_u – concentrated solid mass flow; ET – total efficiency; ET' – reduced total efficiency.

Total efficiency

The reduced total efficiency excludes the "dead flow" effect present in the hydrocyclones, that is, there is a minimal separation efficiency because part of the feeding flow escapes the hydrocyclone by the concentrated duct. Such procedure allows performance analysis without taking into account the liquid ratio, which showed a variation among the tests in consequence of the particle separation by the centrifugal force. For practical purposes the main interest in the use of hydrocyclones as water pre-filtering for irrigation, is the potential of removal of particles in suspension. Table 6 presents the average mean values for the total efficiency calculated from all the total efficiencies observed for each pressure differential used in the essays, and for the average pressure differential and the correspondent average feeding flow. Data in Table 6 represent the general behavior of each hydrocyclone, concerning separation potential power and the pressure differential necessary for best performance. In relation to the sand suspension tests, the highest efficiency value was obtained for the hydrocyclone I (82.02%), followed by lower values of 58.84%, 45.17%, and 41.95%, obtained for hydrocyclones II, III and IV, respectively. In the soil suspension tests, the highest efficiency was also obtained for the hydrocyclone I, with reduction 1/3 of the pressure differential. However, lower differences in efficiency with the other three hydrocyclones were observed.

The increasing pressure differential in the rectangular-end feeding tube hydrocyclones did not result in increased efficiency, but in lowering flows with consequent decreasing centrifugal forces generated in them. This evidenced the lower power of separation of these hydrocyclones when compared to the circular-end feeding tube hydrocyclone.

Although the tests were done with a high solid concentration in the suspensions, the hydrocyclones showed high performance, especially the hydrocyclone I, what demonstrates their relevance to the pre-filtering of water to be used for irrigation. Data presented in Table 6 show that, 4,732.6 g of sand could enter the system through irrigation during 1-hour operation without the help of a hydrocyclone; when a hydrocyclone is in operation, only 137.7 g 34.4-fold less of sand would enter the system, considering a homogeneous suspension. In another words, the irrigation system operating with the hydrocyclone I would take 34.4 hours to release the same amount of sand than released by an irrigation system in 1-hour without the hydrocyclone I. Test analysis with soil suspensions. Shows that 23,630.8 g and 13,248.1 g (1.78-fold less soil sediment) would be released from the system without and with the use of hydrocyclone I, respectively.

Table 6 - Mean values of total efficiency, pressure differential and feeding flow calculated from the results of all tests made with the hydrocyclones operating with the sand and soil suspensions.

Hydrocyclone	Suspension	$\overline{ET}$ %	$\overline{\Delta P}$ kPa	Q (L h^{-1})
I	sand	82.02	36.28	1926.92
	soil	37.73	37.23	1919.72
II	sand	58.84	81.58	1402.58
	soil	31.92	101.73	1605.87
III	sand	45.17	82.88	714.93
	soil	29.41	101.70	867.43
IV	sand	41.95	83.18	570.55
	soil	30.47	102.50	670.93

$\overline{ET}$- average total efficiency of all tests; $\overline{\Delta P}$ - average pressure differential of all tests; Q – feeding flow.

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Received January 23, 2003
Accepted February 12, 2004