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Evaluation of Hydrocyclone as Pre-filter in Irrigation System

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ABSTRACT

The objective of this work was to evaluate the efficiency of a hydrocyclone to separate sand in irrigation water. To do this, it an experiment was conducted where the hydrocyclone was operated with pressures and discharge that varied from 10 to 60 kPa and from 1,159.90 L h^{-1} to 2,603.60 L h^{-1}, respectively. During the tests, the sand concentration in suspension varied from 2.81 g L^{-1} to 7.01 g L^{-1}. The results showed that the best efficiency was obtained with pressure differentials of 10 and 30 kPa, with cut size (d_{70}) of 50 μm.

Key words: Water quality, pre-filters, efficiency

INTRODUCTION

Irrigated agriculture depends on both water quantities and qualities. In the past, the quality of water used for irrigation was good, but in the past few years it has decreased due to the intensification of agriculture. To minimize problems that might occur owing to the use of water of low quality, one must conduct an effective planning in order to guarantee that the water is being used according with its quality (Ayers and Westcot, 1991). The situations where the quality of irrigated water is low that which contain several kinds of physical contaminants and organic particles that might damage the irrigation system, it is necessary to the use the filter systems. Sediments carried by the water decrease the system life time, and in some cases it is necessary to replace some components of the irrigation system each year (Lopez, 1998).

The hydrocyclones is an equipment which separates suspended solid-liquids (Souza et al., 2000). Although the first patent for hydrocyclones appeared in 1891, it only began to be used after the Second World War by industries involved in extraction and processing of minerals (Rietema, 1961). Since then, the hydrocyclones are used in industries in diverse ways, such as chemical, metallurgic, textile, petrochemical, food, bioengineering (Chu et al., 2002; Dai et al., 1999; Rovinsky, 1995; Silva, 1989). Although hydrocyclones were originally designed to separate suspended solid-liquids, they have also been used for solid-solid (Klima and Kim, 1998), liquid-liquid (Smyth and Thew, 1996) and gas-liquid separations (Marti, 1996). They are based on the same basic principles as centrifuge. In other

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words, the particles in suspension are placed in a centrifuge, where the fluid is separated. On the other hand, they have no moveable parts, what result in low costs of installation and maintenance (Souza et al., 2000).

Hydrocyclones consist of a conical part, attached to a cylindrical with a tangential opening for the feeding suspension. The upper portion of the hydrocyclone has an exit tube for the diluted substance (overflow) and in the lower portion, there is an orifice where the concentrated substance leaves (underflow). The suspension is pumped by a tube that enters the hydrocyclone, and is animated by a downward rotation that attempts to exit the orifice. Since this opening is relatively small, only the liquid can exit, taking with it the larger particles. The liquid does not leave know causes a downward vortex that escapes through the tube where there is diluted suspension, along with the finer particles (Flintoff et al., 1987). The majority of the suspension leaves the hydrocyclone via the dilution tube. Fig. 1 shows the liquid's trajectory.

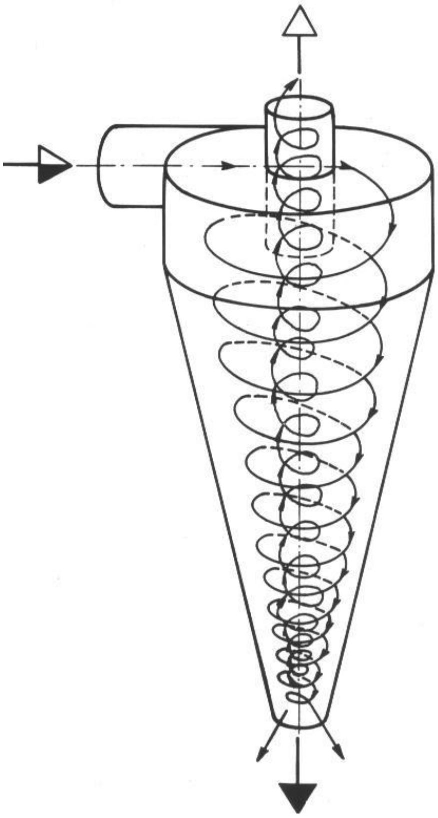

Figure 1 - Visual of the internal functioning of the hydrocyclone.

While using a hydrocyclone, when the suspension is introduced, a fraction of the liquid, along with the particles that have the highest terminal velocity is discharged through an exit orifice. The rest of the liquid with slower particles is discharged via a dilution tube (Silva, 1989). Also separation does not take place. If the hydrocyclone is not separating, due to the centrifuge's action, a certain quantity of solids is removed in the concentrate, for the same ratio as the liquid R_L. This occurs because the hydrocyclone also acts as a flow divider, just as a connection *T* in pipings.

The liquid ratio (R_L) can be defined using Equation 1:

$$R_L = \frac{Q_u(1 - Cv_u)}{Q(1 - Cv)} \quad (1)$$

where:

Q_u – concentrated suspension outflow ($L^3\ T^{-1}$)

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

Consider the simplified framework of a hydrocyclone shown in Fig. 2, in which Q is the suspension flow, *X* is the fraction mass of the smaller particles with a given diameter d and Ws is the feeding suspension solid mass flow. The subscripts "*o*" and "*u*" denote diluted and concentrated, respectively. The global mass balance for the hydrocyclone, assuming there is no accumulation within, is given by:

$$Ws = Ws_o + Ws_u \tag{2}$$

where:

Ws – feeding solid mass flow (M T^{-1})

Ws_o – overflow solid mass flow (M T^{-1})

Ws_u – underflow solid mass flow (M T^{-1})

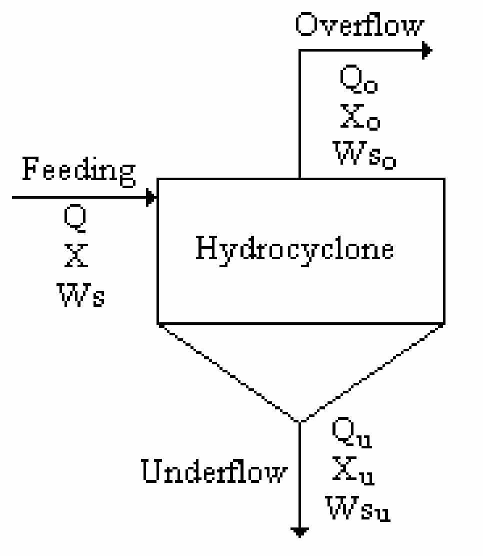

Figure 2 - Simplified framework of hydrocyclone.

According to Scheid (1992), the same balance can be made with smaller particles with a certain diameter, d, that are present in the feeding, as long as there has been no change in the size of the same particles within the hydrocyclone.

$$WsX = Ws_o X_o + Ws_u X_u \tag{3}$$

or,

$$X = \frac{Ws_o}{Ws} X_o + \frac{Ws_u}{Ws} X_u \tag{4}$$

where:

X – mass fraction of particle lower certain diameter *d* in the feeding, (non-dimensional)

X_o - mass fraction of particle lower certain diameter *d* in the overflow, (non-dimensional)

X_u - mass fraction of particle lower certain diameter *d* in the underflow, (non-dimensional)

The total efficiency (E_T) of the separation of the hydrocyclone is defined the rate of mass recovery into the concentrate as a fraction of the feed mass in the feeding (Equation 5) (Svarovsky, 1984).

$$E_T = \frac{Ws_u}{Ws} \tag{5}$$

The granulometric efficiency is defined in a similar way as the total efficiency, except that its value corresponds to one particle size only. This definition is similar to the total efficiency, except for the fact that the value corresponds to a particular sized particle, known as individual efficiency or size-based efficiency. Therefore, the mass flow for a given diameter is given by the product of the solid mass flow in the current in question, and the corresponding fraction *dX/dd* (Svarovsky, 1984), thus:

$$G = \frac{Ws_u}{Ws}\,\frac{dX_u/dd}{dX/dd} \tag{5}$$

substituting Equation 6 in Equation 5, one obtains:

$$G = E_T\,\frac{dX_u}{dX} \tag{7}$$

which in integral forms results in,

$$E_T = \int_0^1 G\,dX \tag{8}$$

where:
G – granulometric efficiency (non-dimensional)

Equation 7 allows for a determination of the granulometric efficiency of the hydrocyclone, by understanding the global efficiency and the distribution of feeding currents and concentrated. The results are usually analyzed by the intermediate curve that relates the granulometric efficiency with the diameter of the particle, denoted the granulometric efficiency curve. In this efficiency curve, the particle's diameter, which possess an efficiency of 50%, is denoted by cut size d_{50}. The cut size is a diameter for a particle whose form represents the potential for a separation by the hydrocyclone. The smaller the diameter, the better the hydrocyclone functions. The cumulative fraction (mass) corresponds to the adjusted granulometric distribution for the Rosin-Rammler-Bennet model, show in Equation 9 (Scheid, 1992).

$$X = 1 - e^{\left[-\left(\frac{d}{d*}\right)^n\right]} \tag{9}$$

where:

d – particle diameter (μm)
d* e n – constants in the model

The objective this study was to evaluate the hydrocyclone's capacity to retain sand particles in irrigation water, using parameters: such as total efficiency and granulometric efficiency.

MATERIALS AND METHODS

The hydrocyclone used was type Rietema (1961), with a diameter of 50 mm, constructed of PVC and glass fiber. The particulate matter consisted of fine sand, with a specific mass of 2.65 g cm^{-3}. During the trial runs, a workbench was used, with a closed circuit, composed of a 500 liters (L) reservoir, along with a pump with a 4,500 L h^{-1} discharge flow and elevation height as 340 kPa, electromagnetic flowmeter with nominal flow of 1,000 L h^{-1}, differential-transducer pressure sensors with capacity within the range of 0 to 700 kPa to evaluate the pressure-differential in the hydrocyclone, submersible shaker, 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 experimental workbench of trials was placed in operation by the motor-pump, microcomputer, flowmeter, pressure-sensor and submersible shaking. The desired pressure reduction in the hydrocyclone, was adjusted by means of software *Aquidados* through a gate valve installed in the pump output. The tests were conducted for differential pressures of 10, 20, 30, 40, 50 and 60 kPa, the liquid ratio was adjusted to 10% by the gate valve installed at then the output of the concentrated suspension. The reading interval and data registration period were adjusted to 60 s in the initial display screen, and the reading key was entered. During the flow and pressure reduction data-collecting period, samples of the concentrated suspension were taken at 30 s intervals and weighed. When the flow and pressure-differential readings were finished, the feeding suspension sampling started. This procedure was repeated two times obtaining average of three subsamples for each pressure-differential point sampled. The sample concentrations were determined using the gravimetric method and the determination of particle size distributions of sand, in few and concentrated suspension was done by the sieve method (Allen, 1990), using a kit of 10 sieves, mesh 1000, 590, 500, 420, 297, 250, 149, 105, 74 and 53 μm.

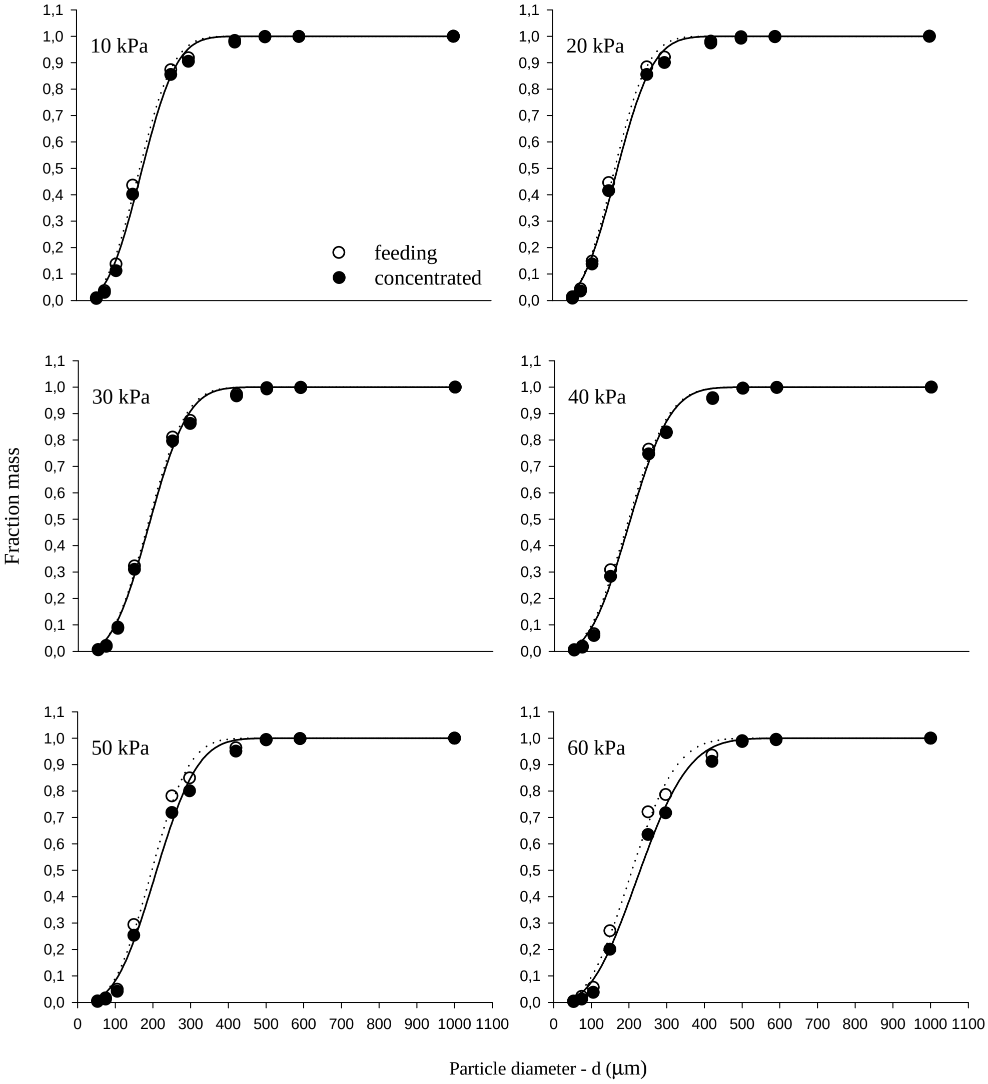

Figure 3 - Granulometric distribution of sand, experimental points and adjusted curves, in the feeding and the concentrate, for differentials of 10, 20, 30, 40, 50 and 60 kPa.

Table 1 - Average data for experimental trials realized by the hydrocyclones.

ΔP (kPa)	**Q ($L\ h^{-1}$)**	**Q_u ($L\ h^{-1}$)**	**[A] ($g\ L^{-1}$)**	**[C] ($g\ L^{-1}$)**	**Cv (%)**	**Cv_u (%)**	**RL (%)**	**Ws ($kg\ h^{-1}$)**	**Ws_u ($kg\ h^{-1}$)**	**ET (%)**
10.80	1159.9	133.5	2.81	23.26	0.106	0.879	11.42	3.265	3.104	95.08
22.30	1582.8	233.3	2.99	21.09	0.113	0.797	13.66	4.849	4.708	97.09
29.50	1826.8	133.7	6.19	69.34	0.234	2.627	7.14	11.314	9.269	81.93
40.40	2002.2	207.6	6.11	45.50	0.231	2.720	10.22	12.239	9.444	77.16
52.00	2386.2	249.4	5.93	42.99	0.224	1.625	10.25	14.139	10.273	72.79
62.70	2603.6	259.2	7.01	47.95	0.265	1.813	9.80	18.255	12.427	68.07

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

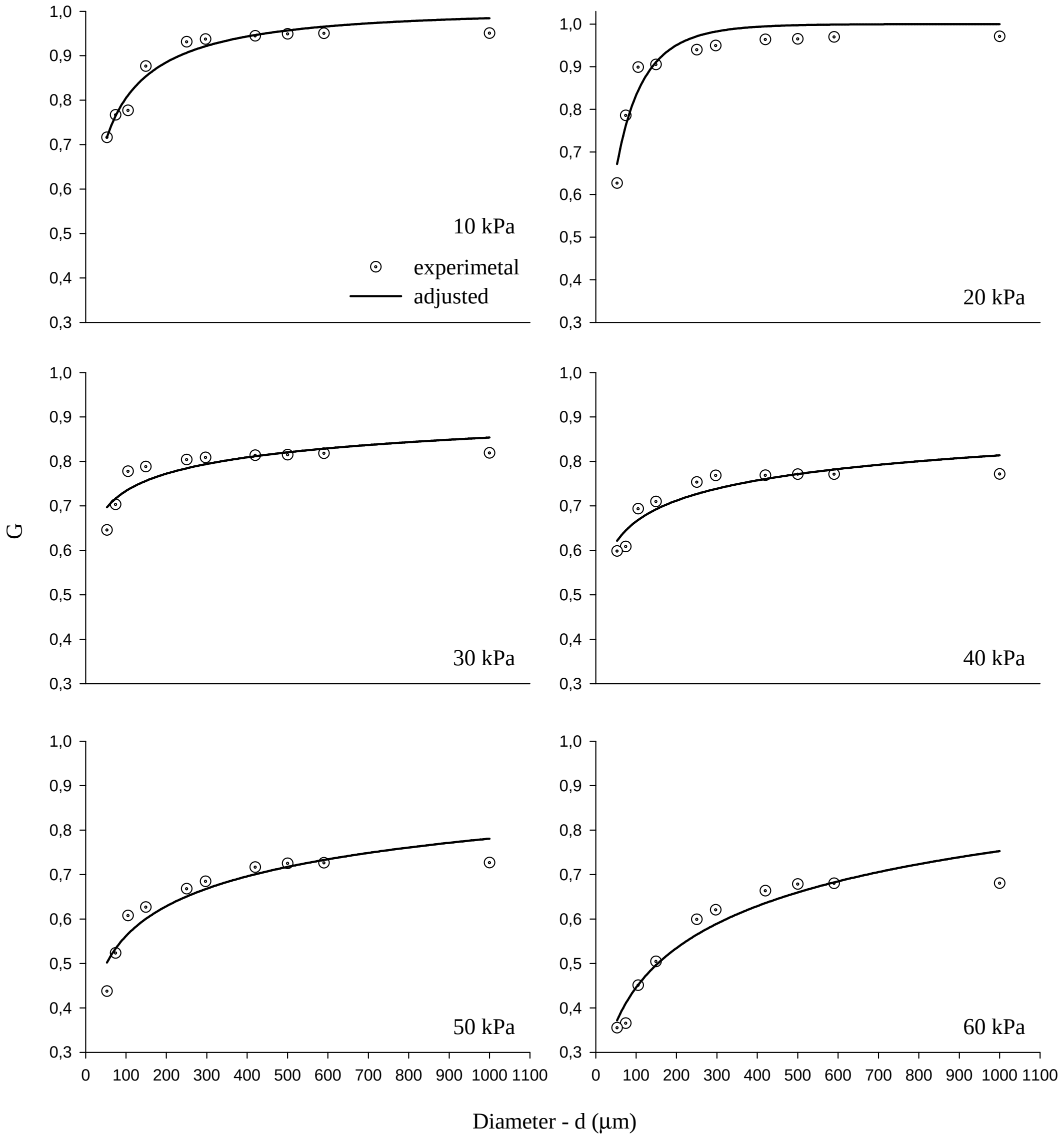

Figure 4 - Granulometric efficiency of the hydrocyclone operating at different pressure differentials, of 10, 20, 30, 40, 50 and 60 kPa.

RESULTS AND DISCUSSION

The granulometric distributions in suspension of feeding suspension and of the concentrate practically did not vary. This also occurred for the differences in pressure (Fig. 1). The Rosin-Rammler-Bennet model adjusted well to the experimental data with a granulometric distribution, with an r^2 of 0.99 for all differences in pressure. The average diameter for the sand particles in the feed varied between approximately 160 and 200 μm and from 175 to 215 μm in the concentrate.

Table 1 shows the data given by the hydrocyclone, as well as the flow and the concentrations of feed and concentrated suspensions for each pressure-differential point sampled. Total efficiency of the removal by hydrocyclone gave the highest values for the differentials between approximately 10 and 20 kPa, diminishing with the larger differentials. This decrease in the total efficiency canned be explained by the lesser amount of residence time available to the particles in the interior of the hydrocyclone, or by the occurrence of higher turbulence in the interior, when operating above the stated pressure differentials. In terms of the granulometric efficiency, there was a decrease (Fig. 2) in the curves with an increase in the pressure differential. For a granulometric efficiency of 70%, the approximate diameters of the particles varied by 50 µm for differentials between 10, 20 and 30 kPa, and between 150, 400 and 650, respectively. This showed that when the hydrocyclone operated between differentials of 10 to 30 kPa, it had the capacity to extract 70% of the sand particles with a diameter greater or equal to 50 µm.

RESUMO

Neste trabalho, o principal objetivo foi avaliar a capacidade de um hidrociclone em reter areia suspensa na água de irrigação. O hidrociclone operou com diferenciais de pressão que variaram de 10 a 60 kPa e vazões entre 1.159,90 a 2.603,60 L h^{-1}. A concentração de areia na suspensão variou de 2,81 a 7,01 g L^{-1}. Os resultados mostraram que as melhores eficiências de remoção foram obtidas para os diferenciais de pressão de 10 e 30 kPa, e diâmetros de corte (d_{70}) de 50 µm.

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