Journal of Agricultural Sciences
(Tarim Bilimleri Dergisi)

J Agr Sci-Tarim Bili
e-ISSN: 2148-9297
jas.ankara.edu.tr

JAS

Determination of Separation Efficiency of Hydrocyclone Used Pre-Filter in Micro Irrigation at Different Inlet Velocities and Sand Diameters

Cafer GENÇOĞLAN[a*], Hayri ŞAHAN[b], Serpil GENÇOĞLAN[a]

[a]*University of Kahramanmaraş Sütçü İmam, Faculty of Agriculture, Department of Biosystem, Kahramanmaraş TURKEY*

[b]*University of Kahramanmaraş Sütçü İmam, Graduate School of Natural and Applied Science, Biosystem Engineering, Kahramanmaraş TURKEY*

ARTICLE INFO
Research Article
Corresponding Author: Cafer GENÇOĞLAN, E-mail: gencoglan@ksu.edu.tr
Received: 16 August 2020 / Revised: 28 January 2020 / Accepted: 02 February 2020 / Online: 18 January 2023

Cite this article
GENÇOĞLAN C, ŞAHAN H, GENÇOĞLAN S (2023). Determination of Separation Efficiency of Hydrocyclone Used Pre-Filter in Micro Irrigation at Different Inlet Velocities and Sand Diameters. *Journal of Agricultural Sciences (Tarim Bilimleri Dergisi),* 29(1):60-67. DOI: 10.15832/ankutbd.983589

ABSTRACT

Hydrocyclones are used as pre-filter to reduce suspended particles in irrigation water on the subsequent filters. The aim of the study was to determine separation efficiency (SE) of hydrocyclones, called H1, H2 and H3 according to inlet/outlet diameters, at water velocities of 1.0 (V10), 1.5 (V15) and 2.0 (V20) ms^{-1}, and sands diameter of 0.5 (D05), 1.0 (D10), 1.5 (D15), 2.0 (D20) and 2.5 (D25) mm. Therefore, a hydrocyclone laboratory test system was constituted using a water tank, motor pump, inverter, flowmeter, valve, hydrocyclone, disk filter, and polythene pipe. Separation efficiencies were calculated by dividing amounts of sand collected in collection box by feeding amount of sand. The lowest average separation efficiency was determined as 37% at H1V10D05 treatment and the highest ones as 97% at both H2V20D10 and H3V20D20, and the other ones changed between two values. Average separation efficiencies resulted as 69%, 88% and 88% for H1, H2 and H3 hydrocyclones, and 71%, 84% and 90% for V10, V15 and V20 water velocities, and 78%, 82%, 82%, 83% and 84% for D05, D10, D15, D20 and D25 sand diameters, respectively. Besides these, average separation efficiency for three parameters was 82%. Since the inlet size of H2 is smaller than that of H3 and its SE was higher than that of H1 and equal to that of H3, the most suitable hydrocyclone was determined as H2 to be used in the micro irrigation. The highest average separation efficiency was 90% at a water velocity of 2.0 ms^{-1}. According to separation efficiency of the hydrocyclone, the optimum water velocity in the inlet of the hydrocyclone was determined as 2.0 ms^{-1}. The separation efficiency of hydrocyclone showed that the efficiencies increased with increasing water velocity from 0.5 ms^{-1} to 2.0 ms^{-1} and sand diameters from 0.5 to 2.5 mm. In separation efficiency for micro irrigation, water velocities and suspended materials play crucial roles as well as hydrocyclone mechanical properties.

Keywords: Micro irrigation, Hydrocyclone filter, Sand diameter, Water velocity, Efficiency

1. Introduction

The shortage of water resources has always been one of the main obstacles to the development of many sectors such as hydropower, agriculture, textile, mining, urban domestic water and so on (Feng et al. 2020). Due to the climate change and drought, the allocated irrigation water to the agriculture is getting decrease year by year and accordingly, to increase the use of micro irrigation systems that have higher irrigation efficiency (Goyal & Panigrahi 2015) and require higher initial capital investment have been supported by the government over the last few decades in Turkey (Ministry of Agriculture and Forestry 2021). On the other hand, water supplied from lakes, ponds, rivers, streams and canals may contain large amounts of organic and inorganic matter. Emitters with small orifices are used to deliver the required low irrigation flow rates and these small orifices can easily be clogged by particulate matter, biological growths, chemical precipitates or combination of these present in irrigation water (Keller & Bliesner 1990; Mailapalli et al. 2007). And also plant roots, sand, rust, microorganisms and dirt in the irrigation water could be the major sources of clogging for emitters (Adin & Sacks 1991) and solenoid valves in irrigation automation system (Feng et al. 2020). This shortens the economic life of the micro irrigation system. A clogged solenoid valve cannot function and accordingly irrigation automation cannot work. Besides, the partially or complete clogging of emitters can reduce or stop a system functioning, and thus, the clogging of the emitters may cause non-uniform water and nutrient (Nakayama & Bucks 1991), which can cause problems such as reduced plant growth, development, yield and variable product quality (Yurdem et al. 2010). The sustainability of the micro irrigation depends on the separation to prevent emitter clogging. Therefore, separation is necessary in the micro irrigation to prevent emitters and solenoid valve from clogging.

Since the later part of the 19th century, hydrocyclones, called cyclone separators have been utilized as a solid-liquid separator to remove sand from well water (Bernardo et al. 2006). They were also used solid-solid (Klima & Kim 1998), liquid-liquid (Smithy & Thew 1996) and gas-solid (Fıçıcı & Arı 2008). A typical hydrocyclone consists of a cylindrical section, a conical section, an underflow cylinder section and a sand collection box. The separation is based on density difference between the liquid/solid/gas and the material to be separated. The principle of centrifugal separation is used to remove or classify solid particles from a fluid, based on particle size, shape and density. Hydrocyclones are used as a primary filter for separation of coarse materials in irrigation water before it enters the screen or sand filters. So, these primary filters decrease the coarse suspended materials in irrigation water that passes the secondary filters such as media (gravel) and disc (screen) (Desai & Praveen 2011).

Hydrocyclone filters remove 98% of the sand particles (Keller & Bliesner 1990). It depends upon the centrifugal force to remove or eject high density particles from the water. Hydrocyclone filters cannot remove organic materials in irrigation water (Chauhdary et al. 2017).

Hydrocyclones have been extensively utilized as separation device in many areas such as the water treatment, air pollution control, agriculture, chemical, cement, power, milling and mining (Avcı & Erel 2003; Martinez et al. 2008; Yurdem et al. 2010; Desai & Praveen 2011; Parihar et al. 2012; Sakura & Leung 2015). There are many papers on the performance of hydrocyclone filters used in the industries areas (Dirgo & Leith 1985; Asomah & Napier-Munn 1997; Youngmin et al. 2000; Shukla et al. 2011; Cernecky & Plandorova 2013; Sakura & Leung 2015; Tan et al. 2015; Liu et al. 2016; Kenny et al. 2017). However, studies on hydrocyclones used as water filtration devices in the micro irrigation are limited (Yurdem et al. 2010; Feng et al. 2020).

At present, many domestic and foreign manufacturers have produced many kinds of filter products, and many experts and scholars have done a lot of research on the hydraulic performance and filtration ability of the filter, but there is no comprehensive report on the filter features and its performances (Feng et al. 2020). The most important parameters in cyclone operation are pressure drop (energy lost) and collection efficiency (Erence et al. 1994; Chauhan 1998; Fassani & Goldstein 2000; Erbaş et al. 2013). Chauhan (1998) tried to evaluate the performance of the hydrocyclone filter with clean water and with known concentration of impurities. The performance of the filter was studied by varying discharge, head loss, influent and effluent concentrations, and filtration efficiency with time of operation of the filter. Soccol & Botrel (2004) tested hydrocyclones in different sizes, using circular feeding (I) and rectangular feeding tubes (II, III and IV) for pre-filtering irrigation water under different pressure differential. In another study, Soccol et al. (2007) evaluated sand separation efficiency of hydrocyclone under varies pressure and concentration for micro irrigation system. Bulancak et al. (2006) studied to determine the efficiency of nine different filters (discs, screens, hydrocyclone, sand separator and media filter) used in drip irrigation systems. In a study of hydrocyclone filter by Mailapalli et al. (2007) studied, its performance for micro irrigation was evaluated by the variation of discharge, pressure drop, influent concentration. Firstly, the filter was tested with clean water to determine clean pressure drop and later it was tested with four concentrations of solid suspension. Results of this study showed that filtration efficiency increased with the increase of concentration. Srivastava et al. (1998) studied the hydraulic performance of commercially available drip irrigation hydrocyclone filter for various sets of discharge and pressure drop for two concentration. They found that the initial removal efficiency of higher concentration was more than lower concentration but final removal efficiency was not very much affected by the concentration of solid suspension. Desai & Praveen (2011) were designed and fabricated the six hydrocyclone models (M1 ... M6), and then tested for its performance evaluation for micro irrigation. They found that the hydrocyclone model M3 with 26° cone angle and 0.065 m underflow cylinder diameter was the best model with the removal efficiency of 95.68% among all the six models.

Since hydrocyclones have been designed in different size and shape, and produced for micro irrigation to prevent emitter clogging in many countries, further separation efficiency knowledge is needed in different hydraulic properties of hydrocyclones and size of the suspended material. For this purpose, a hydrocyclone test system was constituted in laboratory conditions.

So, the objective of the study was to determine separation efficiency for H1, H2 and H3 hydrocyclones at 3 different water velocities of 1.0, 1.5 and 2.0 ms^{-1} and sands diameter of 0.5, 1.0, 1.5, 2.0 and 2.5 mm.

2. Material and Methods

Since many kinds of hydrocyclones in different size and shape are produced for micro irrigation by many domestic manufacturers, further SE knowledge is needed in different hydraulic properties of hydrocyclones and size of the suspended material. In order to determine SE of these hydrocyclones, three widely used hydrocyclones in micro irrigation by the farmers, were chosen in the experiment. The SE of these three hydrocyclones was determined at 3 water speeds (1.0, 1.5 and 2.0 ms^{-1}, called as V10, V15 and V20, respectively) and 5 sand diameters (0.5, 1.0, 1.5, 2.0 and 2.5 mm called as D05, D10, D15, D20 and D25, respectively). Therefore, a workbench was assembled in the laboratory and it consists of reservoir (1), motor pump unit (2), inverter (3), flow meter (4), hydrocyclone (5), disc filter (6), fittings (7) and funnel (8) (Figure 1). The experiment was performed in the workbench.

1) Reservoir: Metal sheet of 2 mm, 1×1×1 m size, $1m^3$ capacity and painted to prevent rust and algae growth.

2) Motor pump: Centrifugal pump with discharge flow of 44 m^3h^{-1}, pumping hydraulic head of 24 m and electrical motor with 5.5 kW (3 phases 380 VAC, 11.3 A, 50 Hz) and 2870 rpm.

3) Inverter: Used to control the speed of the motor pump to drive variable flow rate in pipeline (6 kW).

4) Flowmeter: Electromagnetic flowmeter with nominal flow of 119.4555 $m^3 h^{-1}$.

5) Hydrocyclone: Three hydrocyclones having technical properties same, except inlet/outlet pipes, were utilized in the experiment.

6) Disc filter: Capacity of 38-50 m^3h^{-1}, filtration sensitivity of 130 µm. It was assembled to pipeline after hydrocyclones to prevent the return of sand.

7) Fittings: Ø75 polyethylene (PE) pipes, resisting 405 kPa, were used to connect each unit to each other in the workbench. Fittings consist of valves (2½"), couplings (2½") and reductions (from 3" to 2½").

8) Funnel: A 130 cm long polyethylene (PE) funnel (diameter of one end ∅6 cm and other end ∅3 cm) was used to discharge sand samples into inlet of the suction pipe of the motor pump.

Hydrocyclones were referred as H1, H2 and H3 according to the inlet (Di)/outlet (Do) diameters. While nominal inlet (Di)/outlet (Do) diameters of hydrocyclones were 2", 2½" and 3", their inside diameters were 50.8, 63.5 and 76.2 in mm, respectively. The properties of hydrocyclone were given in Table 1. As seen from Table 1 and as above, only diameter of Di/Do changed but other parameters were unchanged to determine effect of diameter on SE. Diagram of the experimental hydrocyclones was given in Figure 2. In these three hydrocyclones, length of the vortex finder pipe (Lv) was lesser than cylindrical section length (Lc) too.

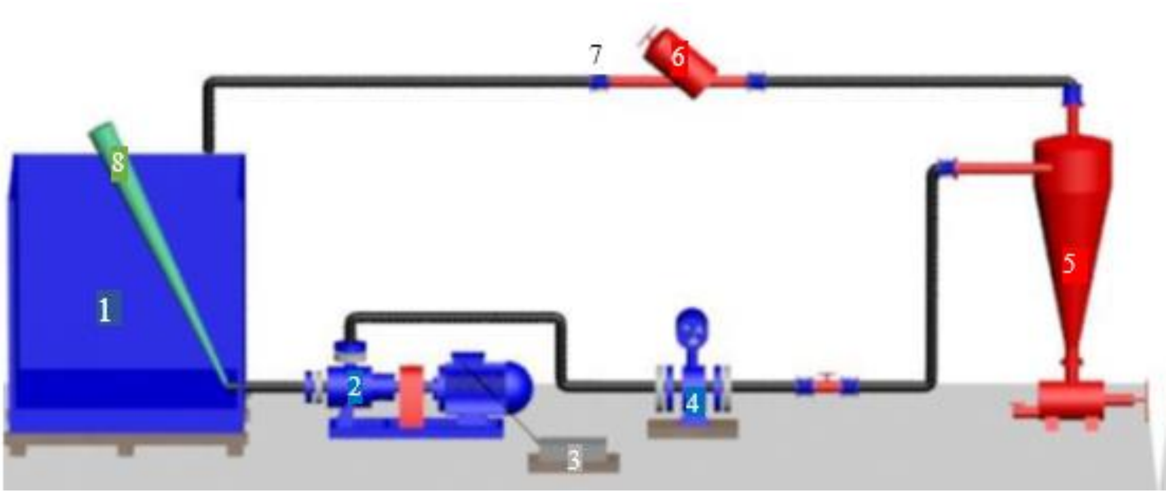

Figure 1- Diagram of the experimental workbench and components

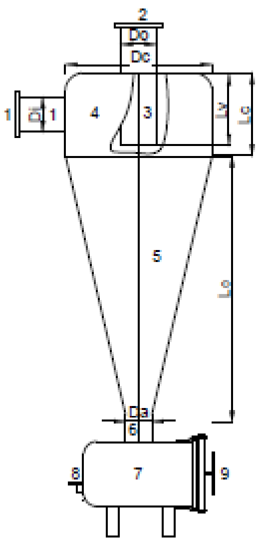

Figure 2- Diagram of the experimental hydrocyclone 1) inlet pipe, 2) outlet pipe, 3) vortex finder, 4) cylindrical section, 5) conical section, 6) apex, 7) collection box, 8) ball valve, 9) chamber cover

Table 1- Technical properties of hydrocyclone filters used in experiments

Elements of hydrocyclone	*Hydrocyclone types*		
	H1	*H2*	*H3*
Inside diameter of inlet/outlet pipe (Di/Do), mm	50.8	63.5	76.2
Cylindrical section diameter (Dc), mm	160	160	160
Cylindrical section length (Lc), mm	190	190	190
Conical section length (Lo), mm	490	490	490
Length of the vortex finder pipe (Lv), mm	150	150	150
Cone angle (ɵ°)	7.3	7.3	7.3
Apex diameter (Da), mm	35	35	35

The tests were created using 1.0, 1.5 and 2.0 ms^{-1} water velocities and 0.5, 1.0, 1.5, 2.0 and 2.5 mm sand diameters at the 2", 2.5" and 3" inlet diameters of the hydrocyclones. Each test was repeated 3 times and a total of 3*3*5*3=135 tests were conducted under 101.3 kPa therefore, a manometer of 400 kPa was mounted on pipeline. And also, the water temperature was measured as 20-22 ºC during the tests.

Although the water velocity in the main pipe in irrigation systems shows small changes according to the researchers, it was determined that the water velocity in the main pipe varies between 0.5 and 3 ms^{-1} (İşcanet al. 2001; Yıldırım 2003; Addink et al.1983). Therefore, in the hydrocyclone SE test, water velocities at inlet pipe of the hydrocyclone were chosen as 1.0, 1.5 and 2.0 ms^{-1}. The motor pump did not suck any sand at 0.5 ms^{-1} the inlet water velocity of hydrocyclone. Since flow meter available in laboratory displayed only flow rate (m^3h^{-1}), the flow rates at the inlet pipe of the hydrocyclone were calculated from Continuity Equation (Equation 1) using the water velocities (ms^{-1}) and cross section areas of inlet pipes (Table 2). The hydrocyclone inlet areas (m^2) were computed from pipe inside diameters of hydrocyclones. In order to adjust the water velocities in the inlet of the hydrocyclone, the motor pump, inverter, flowmeter and the flow rates were used. The motor pump was driven by an inverter. In this context, the velocity of the motor pump is adjusted by changing the inverter output frequency by the pot on the inverter. As the motor pump velocity was increased by inverter, so also in the system. For example, the output frequency of the inverter is gradually increased with the pot until the flow rate value on the flow meter display is equal to 14.59 m^3h^{-1}. Accordingly, this calculation the inlet water velocity of the H1 (0.0508) hydrocyclone will be equal to 2.0 ms^{-1}. The other velocities in Table 2 were set same way.

$$V = \frac{Q}{A*3600} \quad (1)$$

Where; V: Water velocity in the inlet pipe (ms^{-1}), Q: Flow rate (m^3h^{-1}), A: Pipe cross-sectional area (m^2).

Table 2- Inlet (Di)/outlet (Do) diameters and hydraulic properties of hydrocyclones

Hydrocyclones and their inlet diameters (m)	*Inlet water velocities (ms^{-1})*	*Inlet cross section area (m^2)*	*Flow rate (Q) m^3h^{-1}*
H1 (0.0508)	2.0	0.002026	14.59
	1.5		10.94
	1.0		7.29
H2 (0.0635)	2.0	0.003165	22.79
	1.5		17.09
	1.0		11.40
H3 (0.0762)	2.0	0.004558	32.82
	1.5		24.61
	1.0		16.41

Sand used in the test was obtained from a stream. Before determining the sand diameters, since the sand contained course and light materials, those course materials were removed from the sand and the sand was washed 4-5 times with tap water until light material such as silt, clay and other materials was cleared. The washed sand was dried at 105 ºC in the oven until being stable weight. In general, sand diameters vary between 0.074-2.0 mm (Kumsabar & Kip 1986). So, the dried sand was sieved on the kit of five sieves (0.5, 1.0, 1.5, 2.0 and 2.5 mm opening) to determine sand diameter of 0.5, 1.0, 1.5, 2.0 and 2.5 mm. The sand passing through sieve of 2.5 mm opening and collecting on sieve of 2.0 mm opening was referred as 2.5 mm sand and other sand diameters of 0.5, 1.0, 1.5 and 2.0 were determined using same method. Sands with different diameters were weighed at 500 g and 15 sand masses with 3 replications were formed and similarly, Tan et al. (2015) used 500 g dolomite in their study well.

There was no sand and smaller solid particles in the water and it was in the C_2S_1 class (USSL 1954). The water reservoir in the system was first filled with the water until 5-10 cm from the mouth level. Then, the valve placed on the water tank outlet pipe was opened and the motor pump was started. After the motor pump is started, the desired water velocity in the inlet of hydrocyclone is adjusted with the help of the pot on inverter. The pressure of the system was kept at 101.3 kPa in all tests. The sieved sand of different diameters was delivered through the funnel to the outlet pipe of the water reservoir (to the suction pipe of the motor pump). After the system was operated at the desired speed for 5 minutes, 500-grams-sands with the five different diameters were given to the system within 10 minutes of operation with the help of the funnel. After the sand transfer was finished, the system was operated at the same velocity for another 5 minutes. After the system was stopped, the sand in the collection box (underflow chamber) of the hydrocyclone was filtered and taken into the sample container. The collected wet sand was dried in an oven at 105º C until it reached a constant weight.

The SEs of the hydrocyclone at different water inlet velocities were calculated from Equation 2 (Soccol & Botrel 2004; Sakura & Leung 2015).

$$\mathrm{SE} = \frac{\mathrm{CS}}{\mathrm{FS}} * 100 \qquad (2)$$

Where; SE: Separation efficiency (%), FS: Feeding dry sand of 500 (g), CS: The collected dry sand in the hydrocyclone's collection box (g).

Hydrocyclone SE was evaluated using ANOVA and Duncan test in SPSS statistical software.

3. Results and Discussion

The laboratory tests were conducted with 3 replication using 500 g sand stacks to determine SE of H1, H2 and H3 hydrocyclones at water velocities of 1.0, 1.5 and 2.0 ms^{-1}, and sand diameter of 0.5, 1.0, 1.5, 2.0 and 2.5 mm for 10 minutes. The SEs of hydrocyclone were calculated as a percentage by dividing the dry weight of sand gathering in the collection box by the dry weight of sand supplied to the system. ANOVA test was performed using hydrocyclone efficiency values and effects of hydrocyclones, water inlet velocities and sand diameters on SE were found to be statistically significant ($P<0.05$). In addition, groups of SE of parameters were determined by Duncan test (Table 3).

SEs were determined taking into account three parameters that these were three hydrocyclones (H1, H2, and H3), three water velocities (V10, V15 and V20) and five sand diameters (D05, D10, D15, D20 and D25). The lowest average SE was resulted from 37% at H1V10D05 treatment and the highest ones from 97% at H2V20D10 and H3V20D20 and the other's changed between two values (Table 4). When averaged SE in H1, H2, and H3 treatments, their SE were 69%, 88% and 88%, respectively (Table 3) and the average SE of these three was 82%. When increased water velocity from 1.0 ms^{-1} to 2.0 ms^{-1}, SEs in H1, H2, and H3 treatments increased from 54 to 80%, 79% to 95%, and 79% from 95%, respectively. When raised sand diameters from 0.5 mm to 2.5 mm, SEs in H1, H2 and H3 changed between 59-76%, 87-89% and 86-90%, respectively (Table 4). The lowest SE was found out in H1 and the highest ones in both H2 and H3. There was significant difference statistically among SEs of the three hydrocyclones ($P<0.05$) and Duncan test divided hydrocyclones into 2 groups (Table 3). As can be seen from the Table 3, the SE of H2 and H3 constituting the first group is high and the SE of H1 constituting the second group is low. Since the size of H2 is smaller than H3 and its SE is higher than H1 and H3, the most suitable hydrocyclone was determined as H2 to be used in the micro irrigation.

In the V10, V15 and V20 treatments, the average SEs were calculated as 71%, 84% and 90%, respectively (Table 3) and the SE increases between V10 and V15, and V15 and V20, and V10 and V20 were 13%, 6% and 19%, respectively. When raised sand diameter from 0.5 mm to 2.5 mm, SE in V10, V15 and V20 changed between 65-74%, 80-86% and 87-92%, respectively (Table 4). The SE increased with both increasing water velocity (Sakura & Leung 2015) and sand diameter. The water inlet velocity had a statistically significant effect on the hydrocyclone SE ($P<0.05$). Duncan test divided SE of water speed into 3 groups (Table 3). It formed the 1st group of 2 ms^{-1}, the 2nd group of 1.5 ms^{-1} and the 3rd group of 1 ms^{-1}, respectively. The highest average SE was 90% at a water speed of 2 ms^{-1}. According to these SE, water velocity of 2.0 ms^{-1} was the optimum for the hydrocyclone.

Average hydrocyclone SEs at D05, D10, D15, D20 and D25 treatments were found to be 78%, 82%, 82%, 83% and 84%, respectively (Table 3 and Table 4). The increase in SE from D05 to D10 was of 4%, and from D10 to D20 not changed and there was an increase of 2% from D20 to D25. As sand diameter or weight increased from D05 to D25, SE increase was 6% some extent. The effect of sand diameters on SE was found to be statistically significant at $P<0.05$ level (Table 3). Duncan test divided sand diameters into 3 groups. The first group consisted of 2.5 mm sand, the second group consisted of 2.0, 1.5 and 1.0 mm, and the third group 0.5 mm sand. Hydrocyclone SE was found to be low in small sand diameters and high in large sand diameters.

The SEs in the treatments were given in Figure 3. As seen in Figure 3, SEs of H2 and H3 was close to each other and that's of H1 was lower than that's of H2 and H3. SE of H1 changed between 60% and 80% and that' of H2 and H3 changed between 80% and 97% and at five point such as 0.5, 2.0; 1.0, 2.0; 1.5, 2.0; 2.0, 2.0 and 2.5, 2.0 (sand diameter (mm), inlet velocity (ms^{-}

[1])) SE varied between 93-97% that their SEs were determined at 2.0 ms^{-1} inlet velocities. When three points (for example sand diameters and velocities= 0.5, 1.0; 0.5, 1.5; 0.5, 2.0) from the vertical axis are examined on clockwise, the SE increased as the inlet velocities and sand diameter (weight) increased. As stated by Silva (1989), when the suspension is entered the hydrocyclone, a fraction of the higher velocity of the irrigation water and heavier sands were discharged through apex. The remaining irrigation water and the lower velocity (lighter) sands were discharged throughout the vortex finder. Even though the hydrocyclone may not be separating by centrifugation all sands, a certain amount of sands was removed with 82% (all averages of the three parameters). The highest SE found out at 2.0 ms^{-1} at H2 and H3 that it was very important for choosing in water velocities for the hydrocyclones. In this subject, Addink et al. (1983) stated that the optimum flow velocity in main lines should be ranged 1–3 ms^{-1} from the point of construction and energy costs. Since our results and Addink et al. (1983)'s findings are parallel, so selection of 2 ms^{-1} is suitable for hydrocyclones of micro irrigation.

Table 3- Classification of SE in hydrocyclone, water inlet velocity and sand diameters by Duncan test

Hydrocyclones	*Mean Efficiency*
H1	$69^{b}\pm1.95$
H2	$88^{a}\pm1.06$
H3	$88^{a}\pm1.05$

Water inlet speeds (ms^{-1})	*Mean Efficiency*
V10	$71^{c}\pm1.98$
V15	$84^{b}\pm1.32$
V20	$90^{a}\pm1.18$

Sand diameters (mm)	*Mean Efficiency*
D05	$78^{c}\pm3.30$
D10	$82^{b}\pm2.53$
D15	$82^{b}\pm2.46$
D20	$82^{b}\pm2.07$
D25	$84^{a}\pm1.98$

Table 4- Average SEs for treatments

Sand diameters (mm)	*Water velocities (ms^{-1})*	*H1*	*H2*	*H3*
	V10	37	81	77
D05	V15	66	87	88
	V20	74	94	93
	V10	56	80	83
D10	V15	70	90	92
	V20	76	97	95
	V10	56	78	77
D15	V15	74	93	92
	V20	78	95	95
	V10	60	77	79
D20	V15	76	87	87
	V20	84	95	97
	V10	61	80	81
D25	V15	77	93	88
	V20	89	94	94

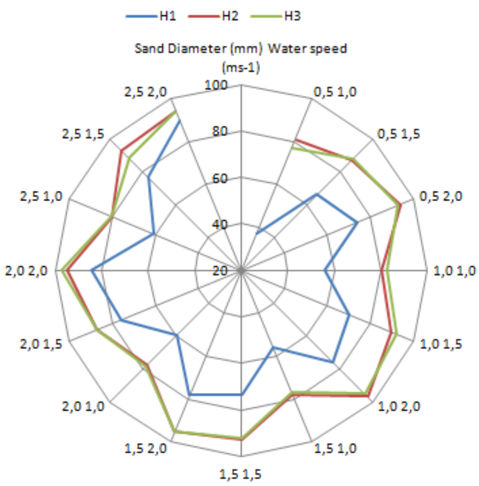

Figure 3- Effect of hydrocyclones, water velocities and sand diameters on SEs

The most upper limit of average SE with 90% was observed at water velocity treatments, and followed successively by that's SE of hydrocyclone (88%) and sand diameter (84%) treatments (Table 4). Since the highest SE was found out in water velocity treatment, it could be told that water velocity is most effective parameter in SE. Yurdem et al. (2010) reports that when the inflow rate increase, the tangential velocity of flow in the hydrocyclone increases. Thus, the centrifugal force on the water increases and giving a high radial velocity. This creates more turbulent kinetic energy in the cyclone and finally SEs increase.

SE given in the studies conducted so far for micro irrigation changed between 9% and 97%. Examples of the studies are as follows. In the study by Desai & Praveen (2011), the SE was 95.68% in the hydrocyclone model M3 with 26º cone angle and 0.065m underflow cylinder diameter. Keller & Bliesner (1990) reported that hydrocyclones could remove up to 98% of sand particles. Soccol & Botrel (2004) resulted that in relation to the sand suspension tests the highest SE of 82.02% was obtained for the hydrocyclone I. In another study, Soccol et al. (2007) concluded the highest SE were obtained 95.48 and 97.09% at 10.8 and 22.3 kPa pressure differential in hydrocyclone, respectively. Bulancak et al. (2006) found to be 37% and 36% efficiencies for the hydrocyclone and sand separator, respectively, in drip irrigation systems. In a study of micro irrigation hydrocyclone filter with 20 cm by Mailapalli et al. (2007), the minimum and maximum efficiencies of solid suspension were 9.91-30.3, 9.93-32.96, 9.62-43.89 and 9.9-52.5%. When SE results were compared, the results of this study correlate with the SE ranges reported in the existing studies. Since hydrocyclones are produced in different sizes and operated under different management conditions such as pressure, concentration, inlet water velocity and solid suspension, the lower and upper limits of the efficiency could vary in a wide range.

4. Conclusions

SEs were determined taking into account H1, H2, and H3 hydrocyclones, V10, V15 and V20 water velocities and D05, D10, D15, D20 and D25 sand diameters.

Average SEs resulted as 69%, 88% and 88% for H1, H2 and H3 hydrocyclones, and 71%, 84% and 90% for V10, V15 and V20 water velocities, and 78%, 82%, 82%, 83% and 84% for D05, D10, D15, D20 and D25 sand diameters, respectively and also all average of SE for three parameters was 82%. These three parameters were significantly affected the results of SE. Under the tests condition, SE increased with the increase of inlet diameter, water velocities and sand diameters. The most suitable inlet diameter and water velocity of hydrocyclones were determined as H2 (0.0635m) and 2.0 ms^{-1}, respectively.

Acknowledgments

This work was supported by Scientific Research Projects Coordination Unit, Kahramanmaraş Sütçü İmam University

References

Addink J W, Keller J, Pair CH, Sneed R E & Wolfe J W (1983). Design and operation of sprinkler systems. In: Design and Operation of Farm Irrigation Systems (Ed. M.E. Jensen), ASAE Monograph, No.3, Michigan, USA, pp. 621-660. https://doi.org/10.13031/2013.23705

Adin A & Sacks M (1991). Dripper-clogging factors in wastewater irrigation. *Journal of Irrigation and Drainage Engineering* 117(6):813-826. http://dx.doi.org/10.1061/(ASCE)0733-9437(1991)117:6(813)

Asomah I K & Napier-Munn T J (1997). An empirical model of hydrocyclones, incorporating angle of inclination. Minerals Engineering 10(3): 339–347. https://doi.org/10.1016/S0892-6875(97)00008-3

Avcı A & Erel G K (2003). The effect of length on efficiency and optimization in cyclone separators. *Uludağ University Journal of The Faculty of Engineering* 8(1):101-109. http://dx.doi.org/10.17482/uujfe.19578 (In Turkish)

Bernardo S, Mori M, Peres A P & Dionisio R P (2006). 3-D computational fluid dynamics for gas and gas-particle flows in a cyclone with different inlet section angles. Powder Technology 162(3): 190-200. https://doi.org/10.1016/j.powtec.2005.11.007

Bulancak S, Demir V, Yurdem H & Uz E (2006). Determination of the efficiencies of different types of filters and filter combinations used in drip irrigation systems in open channel. *Journal of Agricultural Faculty of Ege University* 43(1): 85-96. (In Turkish)

Cernecky J & Plandorova K (2013). The effect of the introduction of an exit tube on the separation efficiency in a cyclone. *Brazilian Journal of Chemical* Engineering 30(3): 627-641. http://dx.doi.org/10.1590/S0104-66322013000300020

Chauhdary J N, Shabbir G, Ahmed S & Waqas A (2017). Pressurized Irrigation Systems In: Applied Irrigation Engineering (Editors Bakhsh, A., Choudhry, M., R.,) p 275-306. University of Agriculture, Faisalabad, Pakistan.

Chauhan H S (1998). Product standardization in micro irrigation. In: Workshop on Micro irrigation& Sprinkler Irrigation Systems, 1, 1998, New Delhi. Proceedings New Delhi: Central Board of Irrigation and Power, pp. VI-3–VI-6.

Desai G A & Praveen G S (2011). Study on design and performance evaluation of hydrocyclone separators for micro-irrigation systems. *International Journal of Agricultural Engineering 4*(2): 200-205.

Dirgo J & Leith D (1985). Cyclone collection efficiency: comparison of experimental results with theoretical predictions. Aerosol science and technology 4(4): 401-415. https://doi.org/10.1080/02786828508959066

Erbaş M, Sofuoğlu A, Bıyıkoğlu A & Uslan İ (2013). Design and improvement of a dust trap cyclone separator using numerical methods. ULIBTK'13 19. Ulusal Isı Bilimi ve Tekniği Kongresi, 9-12 Eylül 2013, Samsun. (In Turkish)

Erence E, Kalafatoğlu E, Örs N & İzgi Y (1994). Cyclone design and simulation. TÜBİTAK-MAM Kimya Müh. Bölümü, Rappor No:255. (In Turkish)

Fassani F L & Goldstein Jr L (2000). A study of the effect of high inlet solids loading on a cyclone separator pressure drop and collection efficiency. Powder Technology, 107(1-2): 60-65. http://dx.doi.org/10.1016/S0032-5910(99)00091-1

Feng J, Xue S & Liu H (2020). Review of filter and its performance testing in agricultural efficient water-saving drip irrigation system. In IOP Conference Series: Earth and Environmental Science (Vol. 474, No. 7, p. 072032). IOP Publishing. http://dx.doi.org/10.1088/1755-1315/474/7/072032

Fıçıcı F & Arı V (2008). Experimental investigation of effect of vent pipe diameter changing in tangential inlet reverse flow cyclones on pressure drop. *Pamukkale University Journal of Engineering Sciences* 14(2): 205-211. (In Turkish)

Goyal M R & Panigrahi P (2015). Sustainable Micro Irrigation Design Systems for Agricultural Crops: Methods and Practices. CRC Press. https://doi.org/10.1201/b18770

İşcan S, Tepeli E, Uyan A, Yaşar M & Çavdar A (2001). Fundamentals of Irrigation I, T.C. Ministry of Agriculture and Rural Affairs, Adana Agricultural Production Enterprises and Mechanization Training Center Directorate, Adana. (In Turkish)

Keller J & Bliesner R D (1990). Sprinkle and trickle irrigation. An Avi book. New York, NY: Van Nostrand Reinhold, 651 pp. https://doi.org/10.1007/978-1-4757-1425-8

Kenny L C, Thorpe A & Stacey P (2017). A collection of experimental data for aerosol monitoring cyclones. Aerosol Science and Technology 51(10): 1190-1200. http://dx.doi.org/10.1080/02786826.2017.1341620

Klima M S & Kim B H (1998). Dense-medium separation of heavy metal particles from soil using a wide angle hydrocyclone. *Journal of Environmental Science and Health* 1325-1340. https://doi.org/10.1080/10934529809376791

Kumbasar V & Kip F (1986). Soil Mechanics Problems Book - Çağlayan Kitabevi, İstanbul. (In Turkish)

Liu L, Dou H S & Chen X (2016). Effect of particle diameter and injection position on the separation performance of cyclone separators. *The Journal of Computational Multiphase Flows* 8(1): 40-47. http://dx.doi.org/10.1177/1757482X16634199

Mailapalli D R, Marques P A A & Thomas K J (2007). Performance evaluation of hydrocyclone filter for micro irrigation. Eng. Agric., Jaboticabal 27(2):373-382. http://dx.doi.org/10.1590/S0100-69162007000300006

Martinez L F, Lavin A G, Mahamud M M & Bueno J L (2008). Vortex finder optimum length in hydrocyclone separation. Chemical Engineering and Processing 47(2): 192–199. doi:10.1016/ j.cep.2007.03.003

Nakayama F S & Bucks D A (1991). Water quality in drip/trickle irrigation: a review. Irrigation science 12(4): 187-192. https://doi.org/10.1007/BF00190522

Parihar A K S, Joshi C & Sridhar G (2012). The performance of cyclones in producer gas cleaning: experimental and modeling studies. Proceedings of the Institution of Mechanical Engineers, Part A: *Journal of Power and Energy* 226(6): 776-793. https://doi.org/10.1177/0957650912448333

Sakura G B & Leung A Y (2015). Experimental study of particle collection efficiency of cylindrical inlet type cyclone separator. *International Journal of Environmental Science and Development* 6(3): 160-164. http://dx.doi.org/10.7763/IJESD.2015.V6.581

Shukla S K, Shukla P & Ghosh P (2011). Evaluation of numerical schemes for dispersed phase modeling of cyclone separators. Engineering Applications of Computational Fluid Mechanics 5(2):235-246. https://doi.org/10.1080/19942060.2011.11015367

Silva M A P (1989). Hidrociclones de Bradley: dimensionamento e análise de desempenho. Rio de Janeiro: UFRJ, 81p. (Dissertação - Mestrado).

Smithy I C & Thew M T (1996). A study of effect of dissolved gas on operation of liquid-liquid separation. In: Claxton D, Svarovsky L & Thew M T (Eds.), Hydrocyclones, London and Bury Saint Edmunds London pp.357-368.

Soccol O J & Botrel T A (2004). Hydrocyclone for pre-filtering of irrigation water. Scientia Agricola 61(2): 134-140. http://dx.doi.org/10.1590/S0103-90162004000200002

Soccol O J, Rodrigues L N, Botrel T A & Ullmann M N (2007). Evaluation of hydrocyclone as pre-filter in irrigation system. Brazilian Archives of Biology and Technology 50:193-199. http://dx.doi.org/10.1590/S1516-89132007000200003

Srivastava S K, Singh K K, Singh P K & Singh R P (1998). Hydraulic performance study of drip irrigation hydrocyclone filter. In: Workshop on Micro irrigation& Sprinkler Irrigation Systems, 1, 1998, New Delhi. Proceedings. New Delhi: Central Board of Irrigation and Power, pp. III-33–III-38

Tan F, Karagöz İ & Avcı A (2015). Experimental investigation of performance characteristics in multiphase flows p:2783-2789, Ulusal Tesisat Mühendisliği Kongresi, 8-11 Nisan /İzmir. (In Turkish)

Ministry of Agriculture and Forestry (2021). Statement on Supporting Individual Irrigation Systems within the Scope of Rural Development Supports. Retrieved in September, 30, 2021 from https://www.resmigazete.gov.tr/eskiler/2021/02/20210225-3.htm (In Turkish)

USSL (1954). U.S. Salinity Lab. Staff. Diagnosis and Improvement Saline and Alkali Soils. Agriculture Handbook 60, USA.

Yıldırım O (2003). Design of Irrigation Systems. Ankara University Publication Number:1536, Faculty of Agriculture Publication Number:489. Ankara University, Faculty of Agriculture, Department of Agricultural Structures and Irrigation, Ankara. (In Turkish)

Youngmin J, Chi T & Madhumita B R (2000). Development of a post cyclone to improve the efficiency of reverse flow cyclones. Powder Technology 113(1-2): 97-108. https://doi.org/10.1016/S0032-5910(00)00206-0

Yurdem H, Demir V & Değirmencioğlu A (2010). Development of a mathematical model to predict clean water head losses in hydrocyclone filters in drip irrigation systems using dimensional analysis. Biosystems Engineering 105(4): 495-506. http://dx.doi.org/10.1016/j.biosystemseng.2010.02.001