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Research Paper :

Study on design and performance evaluation of hydrocyclone separators for micro-irrigation systems

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ABSTRACT

Hydrocyclone is a simple mechanical device, with no moving parts, where solid particles or immiscible liquids are separated from liquid. It is used as a primary filter for micro irrigation systems to remove floating particles as well as to remove high density particles from the irrigated water. In this study, the six hydrocyclone models were designed, fabricated and tested for its performance evaluation. The models were designed for the removal of particulate matter of size 48microns and larger sizes from irrigation water. The models were designed with combination of 20^0 and 26^0 cone angles and 0.04, 0.05 and 0.065m underflow cylinder diameters. These hydrocyclones were fabricated with 3mm thick mild steel sheet. The clean water pressure drop and the percentage of sand trapped in hydrocyclone were recorded. It was found that, the hydrocyclone model M_3 with 26^0 cone angle and 0.065m underflow cylinder diameter was the best model with the removal efficiency of 95.68% among all the six models.

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Key words : Hydrocyclone filter, Vortex finder, Micro irrigation, Cut size

Originally in the later part of the 19th century hydrocyclone was used as a solid/liquid separator to remove sand from well water. A typical hydrocyclone consists of a cylindrical section, a conical section, an underflow cylinder section and a sand collection basket is shown in Fig. 1. The separation is based on density difference between the liquid and the matter 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 larger sized particulate matter in irrigation water before it is passed through the screen filters or sand filters. These primary filters are basically meant to reduce the workload on the secondary filters. The hydrocyclones that are presently used in drip irrigation are those that have been designed and used in other industrial applications and there is a good scope for improving their efficiency. For this purpose, there is a need to design hydrocyclones that are meant to be specifically used in drip irrigation systems, taking into account the needs of the system.

METHODOLOGY

The present study on study on design and performance evaluation of hydrocyclone separators for micro-irrigation systems was conducted at Jain Irrigation systems Limited, Jalgaon, Maharashtra. A standard cyclone is defined as, a cyclone which has the proper geometrical relationship between the cyclone diameter, inlet area, vortex finder and apex orifice and has sufficient length to provide retention time in order to properly classify the particles. There are various design parameters of hydrocyclone which are as follows:

Cone angle:

For design purpose, 20^0 and 26^0 cone angles were chosen. Arterburn (1976) reported that the larger the hydrocyclone diameter, the coarser the separation. The included angle of the cone section is normally between 10^0 and 20^0.

Cone section length:

The length of cone depends upon the underflow cylinder diameter and cone angle.

Length of the underflow cylinder section:

The length of underflow cylinder section varies with the cone length and cone angle. The underflow cylinder section starts at the point where it joins the cone section at one end and ends where the apex of the imaginary cut

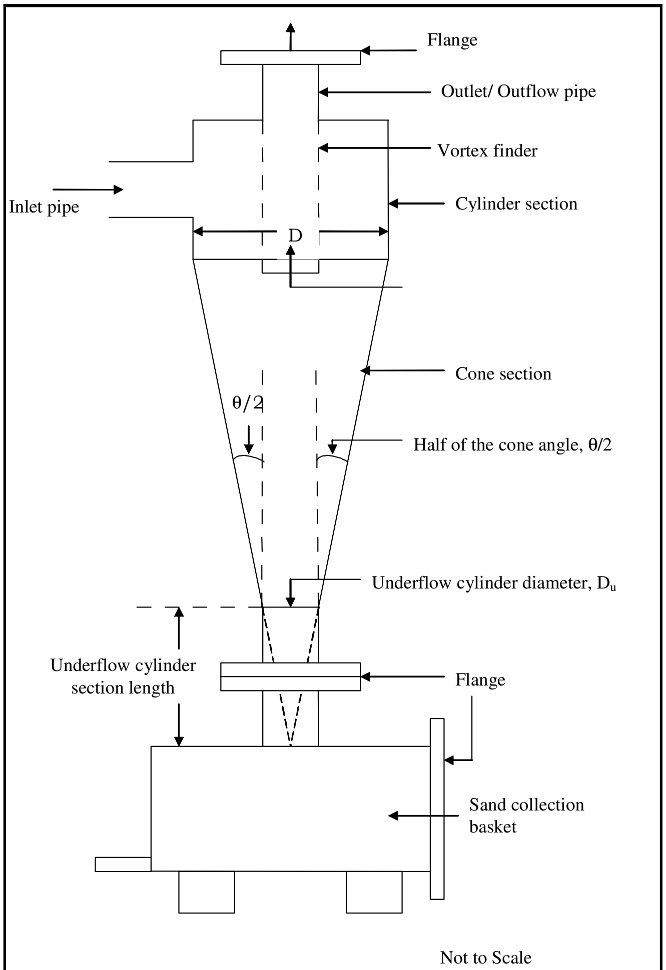

Fig. 1 : Typical hydrocyclone

off portion of the cone is located namely at the entrance of the sand collection basket. This cone was cut at the selected underflow cylinder section diameter values *i.e.* 0.04 m, 0.05 m and 0.065 m.

Underflow cylinder diameter:

To know the effect of change of underflow cylinder diameter on the performance efficiency of hydrocyclone, the three diameters of underflow cylinder section were chosen *i.e.* 0.04, 0.05 and 0.065 m.

Inlet and overflow section diameters:

The inlet and overflow pipe diameter values were fixed at 0.05 and 0.05m, respectively for a flow rate of 25m^3/h. Svarovsky (1984) reported that to increase the intake capacity of a hydrocyclone, its inlet diameter has to be increased.

Cylinder section diameter:

In the present study, all the six models including the control model had a diameter of 0.198 m (I.D.) which was 3.73 times the overflow pipe diameter. Zhao and Abrahamson (1999) reported on the dimensions of cyclone, wherein they suggested that the diameter of cylinder section of the cyclone should be 2 times the overflow pipe diameter.

Cylinder section length:

Typically hydrocyclones have a cylinder section length equal to or greater than the hydrocyclone diameter. Zhao and Abrahamson (1999) reported on the dimensions of cyclone, wherein they suggested that the length of cylinder section should be 3 times the overflow pipe diameter. In the present study, the cylinder section length was chosen as 3times the overflow pipe diameter for models M_1, M_2, M_3, M_4, M_5 and M_6 and the length of the cylinder section for the control model was 4.01 times the overflow pipe diameter.

Vortex finder design:

Vortex finder takes the clean water and delivers it to the outlet. If the length of vortex finder increases, it is likely to disturb the vortex and result in coarser separation of particles. So the length of the vortex finder should be optimum and is found by a trial and error method. In the study, the length of the vortex finder was kept at 0.398m for control model and 0.335m for the other six models. Arterburn (1976) reported that the diameter of the vortex finder was equal to 0.35 times the hydrocyclone diameter.

Height of hydrocyclone:

The height from the top of the outflow pipe to the end of the underflow cylinder section is referred to as total height of hydrocyclone.

Cut size:

The cut size is defined as the diameter (d_p) of a particle, which has a probability of n% to end up in the underflow section (Svarovsky, 1984). The design probability (n) of trapping of particles in the collection basket was taken as 95%. Particle separation is based on the density difference between the liquid and the matter to be separated. A higher density difference results in a finer separation. For this investigation, silica sand with a specific gravity of 2.65 g/cc was selected. The hydrocyclones were designed by using the mathematical expression given by Anonymous, (2005a).

$$\mathbf{dp} = \sqrt{\frac{\mathbf{n \times 0.01 \times 0.5(D - Do) \times 18\eta}}{\mathbf{(\rho s - \rho l)\lambda a}}} \tag{1}$$

where,

d_p = diameter of removed particles, m
n = probability, per cent.
D = diameter of the cylinder section, m.
D_o = diameter of the overflow pipe, m
η = dynamic viscosity of the liquid at room temperature, Pa-s
ρ_s = density of the solids, kg/m^3
ρ_l = density of liquid, kg/m^3
a = acceleration, m/s^2

$$a = \frac{u_i^2}{D/2}$$

where,
u_i = inlet velocity of fluid, m/s

$$u_i = \frac{Q}{A_c} \quad \text{and} \quad Ac = \frac{\pi}{4} \times D_1^2$$

where,
A_c = cross-sectional area of inlet pipe, m^2
Q = inlet flow rate, m^3/s
λ = residence time, s

$$\lambda = \frac{L}{\dfrac{Q}{\pi\left(\dfrac{D_2 - D_0^2}{4}\right)}} \qquad (2)$$

where,
L = length of the cyclone from the top of inlet pipe up to the end of cone section, m

Fabrication of hydrocyclone:

The cylinder section and cone section of the hydrocyclones were fabricated by using M.S. (mild steel) sheet of 3mm thickness. Commercially available 0.05m diameter, class-B mild steel pipe was used to fabricate the inlet and outlet sections of the hydrocyclone. To fabricate the underflow cylinder section, the commercially available 0.04, 0.05 and 0.065m diameter, class-B mild steel pipes were used as needed. All the hydrocyclones were coated with pure polyster powder.

Experimental procedure:

The clean water pressure drops for each model of hydrocyclone was recorded at discharge rates of 20, 25 and 30m^3/h. The pressure drop values in the hydrocyclones were tested according to IS: 14743:1999. The experimental set–up for testing the hydrocyclone performance is illustrated in the Fig. 2. The trapped silica sand material in collection baskets of respective hydrocyclone models were collected and analyzed for their particle size distribution by using motorized sieve shaker. These values were then compared with the particle size distribution of the sand sample that was fed into the system. Based on this, the hydrocyclone with the maximum trapping efficiency was selected as the best model and the dimensions of that model of the hydrocyclone were selected as the best combination of dimensions.

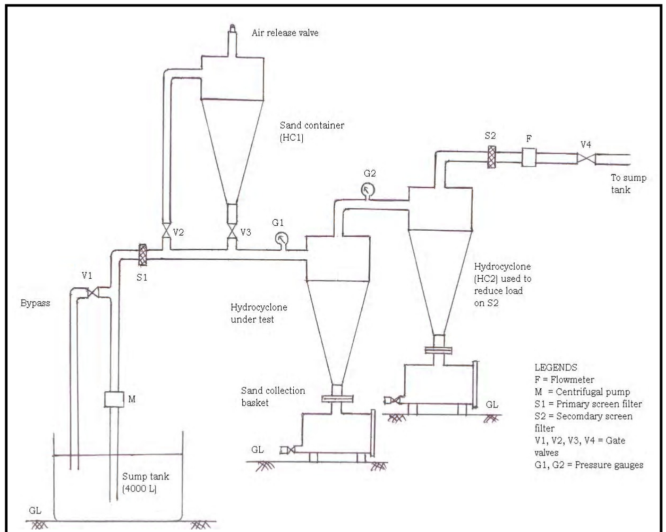

Fig. 2 : Typical hydrocyclone

The overall trapping efficiency of the hydrocyclone was calculated by using the following formula given by Anonymous, (2005a):

$$E = \frac{w_U}{w_F} x100 \qquad (3)$$

where,
E = trapping efficiency of hydrocyclone, dimensionless
w_F = mass fraction in the feed flow, dimensionless
w_U = mass fraction in the underflow, dimensionless

RESULTS AND DISCUSSION

The results obtained from the experiment on design, fabrication and testing of hydrocyclones are discussed in this section.

Design of hydrocyclone:

The design dimensions of the six hydrocyclone models (*i.e.* M_1, M_2, M_3, M_4, M_5 and M_6) calculated by using equation 1 (Anonymous 2005a) are presented in Table 1. It was observed that the cone angle and the underflow cylinder diameter were the main variables for the design of these hydrocyclones. The control model was the earlier model and the same is in use by the farmers in drip irrigation systems. The control model was

Table 1 : Design dimensions of hydrocyclone models

Model No.	Cone angle (θ/2), degrees	Flow, (Q), m³/h	Di, Do, m	Underflow cylinder dia. (Du), m	Cylinder dia. (D), m	Probability (π), %	Viscosity of water (μ), kg/m s	Flow velocity, (V), m/s	Acceleration of water at vortex, (a), m²/s	Cone length, m	Cylinder length, m	Cyclone height up to inlet, m	Residence time, (λ), s	ρs-ρ, kg/m³	D-Do, m	Particle diameter, dp, μ
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Control	10	25	0.053	0.053	0.198	95	0.00089	3.14	99.43	0.4412	0.213	0.6242	2.52	1650	0.1449	51.67
M_1	10	25	0.050	0.040	0.198	95	0.00089	3.54	126.48	0.4480	0.150	0.5480	2.24	1650	0.1480	48.73
M_2	10	25	0.050	0.050	0.198	95	0.00089	3.54	126.48	0.4197	0.150	0.5197	2.16	1650	0.1480	50.03
M_3	10	25	0.050	0.065	0.198	95	0.00089	3.54	126.48	0.3771	0.150	0.4771	1.98	1650	0.1480	52.21
M_4	13	25	0.050	0.040	0.198	95	0.00089	3.54	126.48	0.3422	0.150	0.4422	1.83	1650	0.1480	54.24
M_5	13	25	0.050	0.050	0.198	95	0.00089	3.54	126.48	0.3205	0.150	0.4205	1.74	1650	0.1480	55.61
M_6	13	25	0.050	0.065	0.198	95	0.00089	3.54	126.48	0.2880	0.150	0.3880	1.61	1650	0.1480	57.90

designed to remove particles of size 51.67microns and more. Likewise, the models M_1, M_2, M_3, M_4, M_5 and M_6 were designed to remove particles of 48.73, 50.03, 52.21, 54.24, 55.61 and 57.90microns and larger size particles, respectively.

Effect of change in cone angle on clean water pressure drop:

The clean water pressure drops were recorded for all the seven hydrocyclones at three flow rates namely 20, 25 and 30m³/h and the results are shown in Table 2. It was seen that at 25m³/h flow rate, the models M_1, M_2 and M_3 which had a lower cone angle of 20^0 had a lower pressure drop of 0.46, 0.47 and 0.43 kg/cm² and the models M_4, M_5 and M_6 which had a higher cone angle of 26^0 had a higher pressure drop of 0.50, 0.51 and 0.52 kg/cm², respectively. Hence, as the cone angle increases the pressure difference between inlet and outlet increases and hence, lower the cone angle, lower the pressure drop.

Table 2 : Clean water pressure drop for the seven hydrocyclone models

Model No.	Flow, m³/h	Pressure, kg/cm²		
		Inlet	Outlet	Drop
Control	20	1.04	0.72	0.32
	25	1.50	1.03	0.47
	30	2.10	1.42	0.68
M_1	20	0.99	0.69	0.30
	25	1.50	1.04	0.46
	30	2.18	1.51	0.67
M_2	20	1.04	0.72	0.32
	25	1.50	1.03	0.47
	30	2.10	1.42	0.68
M_3	20	1.02	0.74	0.28
	25	1.50	1.07	0.43
	30	2.31	1.64	0.67
M_4	20	0.94	0.63	0.31
	25	1.50	1.00	0.50
	30	2.17	1.41	0.76
M_5	20	0.98	0.65	0.33
	25	1.50	0.99	0.51
	30	2.15	1.40	0.75
M_6	20	0.95	0.62	0.33
	25	1.50	0.98	0.52
	30	2.16	1.40	0.76

Effect of change in cone angle on performance:

The experiment results are presented in Table 3 which showed that the models M_1, M_2 and M_3 with a cone angle of 20^0 had greater performance efficiency as compared with the models M_4, M_5 and M_6 which had

Table 3 : Cumulative average percentage of sand trapped in all hydrocyclone models

Mesh size	Particle size (micron)	Cumulative initial percentage of sand taken (%)	Average cumulative percentage of trapped sand (%)						
			20^0 cone angle				26^0 cone angle		
			Control	M_1	M_2	M_3	M_4	M_5	M_6
400-250	38-56	8	8.85	6.03	10.98	11.98	7.23	8.98	11.74
250-150	56-106	66	58.62	60.76	61.68	62.78	58.64	60.63	60.26
150-100	106-150	74	68.48	68.64	69.57	70.74	66.51	68.63	68.68
100-85	150-180	81	75.48	75.73	75.66	77.38	73.23	75.18	75.53
85-60	180-250	87	81.12	81.40	81.66	83.60	78.33	81.11	81.17
60-30	250-500	92	85.46	85.83	86.17	87.93	83.15	85.56	85.56
30-16	500-1000	96	89.38	89.64	89.96	91.83	86.81	89.38	89.54
16-8	1000-2000	100	93.22	93.32	93.73	95.68	90.43	93.18	93.33

cone angle of 26^0. The results of the hydrocyclone performance in terms of the cumulative sand trapping efficiency showed a decreasing trend with increasing cone angle. It was seen that the M_3 model with a cone angle of 20^0 could remove sand of 56-106microns range with the maximum efficiency of 62.78% among the models M_1, M_2 and M_3 with the same cone angle. The models M_4, M_5 and M_6 with the cone angle of 26^0 could remove the same size range particles with efficiencies of 58.64, 60.63 and 60.26%, respectively. This can be attributed to the fact that a smaller cone angle ensures a more gradual increase in the swirling velocity of water as it passes through the hydrocyclone, which in turn leads to a more perfect separation of larger particles.

Effect of change in underflow cylinder section on performance:

In the present experiment, the three different diameters (*i.e.* 0.04, 0.05 and 0.065m) were chosen to see the effect of change in underflow diameter on the performance of hydrocyclone. The results obtained are tabulated in Table 3. It was observed that the models with 0.04m underflow cylinder diameter (*i.e.* model M_1 and M_4) were less efficient (sand trapping efficiencies 93.32 and 90.43%, respectively) than the models with 0.05m underflow cylinder diameter (*i.e.* models M_2 and M_5 having sand trapping efficiencies 93.73 and 93.18%, respectively) followed by the models with 0.065m underflow cylinder diameter (*i.e.* models M_3 and M_6 having 95.68 and 93.33%, respectively). A larger diameter of underflow cylinder section increases the fluid flow out through the underflow cylinder section, carrying more of particulate matter to the collection basket. If the underflow cylinder diameter is larger than the vortex finder diameter, the cyclone will often drain itself through the underflow cylinder section and perform no separation function. However, if the underflow cylinder diameter is too small, much of the heavier particulate matter may discharge with the light particulate matter through the underflow cylinder section.

The percentage of trapped sand for the models M_1 and M_4 were recorded as 60.76 and 58.64%, respectively in the 56-106microns range particles. Similarly, it was for the models M_2 and M_5 were recorded as 61.68 and 60.63%, respectively and for the models M_3 and M_6 were recorded as 62.78 and 60.26% (Table 3), respectively in the 56-106 microns range particles.

Conclusion:

As the cone angle increases, the pressure difference between inlet and outlet increases and hence lower the cone angle, lower the pressure drop. The cone angle in the 20^0 to 26^0 range can be used to design a hydrocyclone used for micro-irrigation system.

Thus from the study, the following dimensions for a good hydrocyclone for the purpose of removal of solid particles from the water to be used for micro-irrigation:

Inlet and outlet diameter = 0.05 m (2”)
Cylinder section diameter = 0.198 m (I.D.)
Cylinder section height = 0.213 m
Vortex finder length = 0.335 m
Cone angle = 20^0
Cone section length = 0.3771 m
Underflow cylinder diameter = 0.065 m, if significant damage due to abrasion is expected (higher load of particulate matter in irrigation water).
= 0.05 m, if the excepted damage is insignificant.
Underflow cylinder length = 0.184 m (if underflow diameter is 0.065 m).

= 0.090 m (if underflow diameter is 0.05 m).

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