An Improved Design of Irrigation Centrifugal Filter for Separating Water and Fine Sediment: Appropriately Increase Head Loss for High Efficiency

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Abstract: Centrifugal filters commonly used in irrigation systems are able to separate coarse-grained sediments larger than 100 μm. Improving the filter structural characteristics and separation efficiency of fine-grained sediment has become an issue that needs to be solved. Therefore, a combination of experiment and numerical simulation was used to assess the effect of volute optimized design and semi-closed inlets on centrifugal filter separation efficiency and energy consumption. The results show that, balancing the relationship between the separation efficiency and head loss, the improvement of the filter structure optimizes its internal flow field, and the filter head loss can be appropriately increased to greatly improve the separation efficiency of fine sediment. Compared with a conventional centrifugal filter, the volute-optimized centrifugal filter synergistically improved the fine particle separation efficiency (22.83%-123.19%) and reduced the head loss (39.06%-45.98%), while the semi-closed inlet improved the separation efficiency of particle diameters above 30 μm by 14.29%-60.56% and increased the head loss (18.73%-28.16%). The combination of the two previous improvements and the reduction of the filter volume further improved the separation efficiency (21.99%-65.10%) but gradually increased the head loss. This study provides a new perspective for improved centrifugal filters with an efficient, broadly applicable experimental design for studying the potential implications for highly Turbidity water utilization in irrigation.

Keywords: turbidity water, separation efficiency, structure optimization, irrigation water treatment

1. Introduction

The reasonable use of turbidity water for agricultural irrigation has become an effective way to alleviate the global water scarcity issue (Skaggs et al., 2000). The quality of sediment treatment directly affects the use of irrigation systems (Zhou et al., 2017; Han et al., 2017; Adin et al.,1986). However, a relative mature filtration protection has been used for high-sediment water dominated by coarse-grained sediments (Bové et al., 2017; Li et al., 2015; Puig-Bargués et al., 2013). No successful and economical solution for filtering high sediment water resources, such as Yellow River water, which mainly contains fine-grained sediments, has been investigated (Salem et al., 2014). The slow sedimentation speed of fine sediments leads to large sedimentation basins and high costs (Tao, 2014), making it difficult to use sedimentation and screen, disc or sand/gravel filters (Qi et al., 2014; Salem et al., 2011; Capra et al., 2004) to effectively treat high-concentration fine-grained sediments. In addition, a large number of filter screens are required for fine-particle sediment filtration, leading to frequent automatic self-cleaning and high energy consumption issues (Zhang, 2015). Therefore, the development of an accurate filtration system to efficiently separate fine particle sediment has great significance for both the application and promotion of Turbidity water in irrigation.

Centrifugal filters separate particles denser than water， and are considered to be the primary treatment facility for Turbidity water irrigation, mainly because their effect is better for coarse sediment above 100 μm; however, their performance for fine particle viscous sediment is poor (Soccol et al., 1993). In fact, centrifugal filters are the common equipment used for solid-liquid separation according to particle size and density (Svarovsky et al., 2000) and are widely used in food, chemicals, textiles and other fields. Under the conditions of a high energy consumption and low flow rate, the median particle size of centrifugal filter separation can reach 5 μm or less (Yu et al., 2015; Neesse et al., 2015; Vakamalla et al., 2014;Yang et al., 2013).

For example, Williamson et al. (1983) used a micro hydrocyclone of 15 mm diameter under a high energy consumption and low viscosity operating conditions to effectively separate hematite, magnetite and silica fume with a size of approximately 2 μm. Lv (2015) et al. used a centrifugal filter with a 10 mm diameter under high inlet pressure conditions to separate median particles ≥ 0.5 μm. The diverse performance of the centrifugal filters used in the aforementioned works were mainly caused by their structures and designs.

In the chemical industry with its obvious input and output benefits, their main consideration is only how to improve efficiency, with less consideration given to the filter energy consumption. Thus, the separation efficiency it has been improved by optimizing the inlet form of the centrifugal filter (Noroozi et al., 2009), overflow pipe (Martinez et al., 1993) and volume (Vakamalla et al., 2018), as well as other structural and size improvements. However, for the agricultural field the input and operating costs of the entire irrigation system must be considered comprehensively; that is, the separation efficiency of the filter and the energy consumption of the system must be considered (Yurdem et al., 2010).

Therefore, can we change our thinking and increase the separation efficiency of the centrifugal filter for fine sediment by appropriately increasing the energy consumption and reducing the cost of the filtration system? At present, a comprehensive research on the improvement of centrifugal filters and the balance of energy consumption caused by separation efficiency and head loss has not been reported.

Based on these hypotheses, this study uses a combined method of practical experiments and computational fluid dynamics (CFD) analysis to study the influence of the optimized design of volutes and semi-closed inlets on the separation efficiency and head loss of centrifugal filters. The objectives were: 1) to clarify the effects of two improvements on filter inlet on the separation efficiency and the head loss of different sediment sizes; 2) to reveal the hydrodynamics of the two inlet improvements affecting the hydraulic performance of the filter; and 3) to explore ways of further improving the separation efficiency of fine sediment and the impact of an increased head loss. This study might provide guidance for an improved method of centrifugal filters for fine particle sediments.

2. Material and Methods

2.1 Test arrangement

An outdoor filter test platform was built at the Beijing Tongzhou experimental station, China Agricultural University. This test platform (Fig. 1b) includes material handling devices, water supply devices, filtration systems, measuring devices and connecting pipes. The test platform consisted of three different types of filters, including two inlet optimized forms: a casing inlet (CI), a semi-closed inlet (SI), and a conventional inlet cone type (CK), using the same water source. The filter maximum flow rate was 50 m^3/h, and the main structural diagram and parameters are shown in Fig. 1a and Table 1:

< # Fig. 1 approximately here # >

< # Table 1 approximately here # >

2.2 Test treatment

2.2.1. Single particle size gradation

Undisturbed sediment was collected from the Yellow River irrigation area (continuous irrigation channel-Wushen Main Canal), and an ultrasonic rotary vibrating screen was used for the screening treatment under five different particle diameter ranges (0-20 μm, 20-40 μm, 40-60 μm, 60-80 μm, and 80-100 μm) for testing.

< # Table 2 approximately here # >

2.2.2 Gradation of mixed particle sizes in typical irrigation areas

The sediments from the three typical irrigation areas of Ningxia, Neimeng, and Shanxi in the middle and upper reaches of the Yellow River were selected for making the particle gradations. As shown in Table 2, five concentration conditions (1, 2, 3, 4, 5 g/L) were set to simulate the mixed grain size sand-containing water in typical irrigation areas. Turbidity water was simulated with mixed particle sizes and tested under the conditions of eight operating flow rates (15, 20, 25, 30, 35, 40, 45, 50 m^3/h).

2.3 Test indicators

2.3.1 Sediment distribution test and volume fraction extraction

The sediment particle sizes were tested before and after filtration using a laser particle size analyzer (Mastersizer2000, Malvern, UK). The agitator speed of the analyzer and the shading range were maintained at 2500 rpm and 10%-20%, respectively. Before the test, 0.3-0.4 g of the sample were placed into a 50 mL Erlenmeyer flask, few drops of deionized water were added to infiltrate the sample, and H_2O_2 and sand bath heating were added. One mL of dispersant (sodium hexaphosphate) and 35 mL of deionized water were added to the cooled Erlenmeyer flask, and the particle size distribution was tested after standing.

2.3.2 Sediment removal rate

The pycnometer method was used to calculate the sediment removal rate according to the following formula:

$$V_s = \frac{W_3 - W_2}{\rho_s - \rho} \tag{1}$$

$$V = \frac{W_2 - W_1}{\rho} \tag{2}$$

$$S = \frac{\rho_s \times V_s}{V} = \frac{\rho \times \rho_s}{\rho_s - \rho} \times \frac{W_3 - W_2}{W_2 - W_1} \times 1000 \tag{3}$$

W_1; weight of the pycnometer, g, W_2; weight of distilled water and pycnometer, g, W_3; weight of the water sample and specific gravity of bottle, g, ρ; density of water; g/cm^3, ρ_s; density of sand in the Yellow River, 2.74 g/cm^3.

The separation efficiency of the centrifugal filter was characterized by the difference in the water source concentration before and after filtration, with the following formula:

$$E = \frac{C_2 - C_1}{C_2} \times 100 \tag{4}$$

E; separation efficiency (%), C_2; the filter inlet concentration (g/ml), C_1; the filter outlet concentration (g/ml).

2.4 Numerical simulation method

2.4.1. Meshing

The NX UG 8.0 software was used to establish an isometric three-dimensional model of the three centrifugal filters' internal watershed. (Zhou et al., 2021) The structural parameters of the filters are shown in Table 1. The ICEM was used as the pre-processing software to mesh the imported water in the three-dimensional model. The overall mesh is an unstructured grid with a size of 0.5 mm, where the water inlet and overflow are partially densified with a grid size of 0.3 mm. The quality of the grid passes the irrelevance test, as shown in Fig.S1.

2.4.2. Simulation model

The RNG k-ε model was selected as the turbulence model, and the water inlet was set as a velocity inlet, with the overflow port of the pressure outlet and the nonslip wall. The SIMPLEC algorithm was used to solve the pressure-velocity coupling, where the difference format was the second-order upwind style, and the calculation accuracy was 10^{-4}. The DPM model was selected for the discrete phase numerical calculation, and the mixed particle size of the sediment was fitted to the Rosin-Rammler function according to the undisturbed sediment particle data, with a spread parameter 1.30. The selected density of the discrete phase was 2740 kg/m^3 of calcium carbonate, the wall condition overflow port escaped, and the other walls were reflected. The fitted formula is shown in equation 5. Taking the CI filter as an example for model correction, see Supplementary Material Fig. S2 for details. Under different flow conditions, numerical simulations and experimental tests of the head loss, the separation efficiency and head loss fitting of numerical simulation and experimental test were both within 5%.

$$Y_d = \exp\left[-\left(\frac{d}{61}\right)^{1.30}\right] \quad (5)$$

In the formula: Y_d is the mass fraction of particles larger than the specified particle size d; d is the particle size, μm.

2.5 Statistical analysis

Regression analysis was used to quantify the correlations between separation efficiency and head loss. The significance of the independent variable was determined at $P<0.01$. The statistical analysis was carried out using SPSS (ver. 17.0, IBM Analytics).

3. Results

3.1 Separation efficiency

The separation efficiency of centrifugal filters of different structures under single particle size and mixed particle size obtained are shown in Figs. 2, S3 and S4. Compared with the CK, the average separation efficiency of the SI filter with the semi-closed inlet and CI filters with the casing inlet were increased by 47.36%-257.55% and 22.83%-123.19%, respectively. Moreover, a significant (*P* < 0.01) correlation was found among the 40-100 μm particle sizes, where the trend was $E_{SI}>E_{CI}>E_{CK}$, and as the particle size increased, the separation efficiency difference of different filters gradually decreased. When the particle size increased from 40-60 μm to 80-100 μm, the separation efficiency of SI and CI filters were reduced from 2.86 and 1.43 times to 2.05 and 1.21 times, respectively, compared to CK filters. Under the conditions of a particle size of 40-100 μm, the separation efficiency showed an obvious upward trend. The separation efficiency for sediments in the particle size of 0-20 μm ranged between 1.81%-11.82%, with a particle size of 80-100 μm between 18.85%-66.41%, and under a mixed size particle was between 7.26%-40.95%.

< # Fig. 2 approximately here # >

3.2 Head loss

The head loss correlation of the different centrifugal filters considering the different experimental flow rates and concentrations is shown in Fig 3. Compared with the CK filter, the average head loss of the SI filter with the semi-closed inlet optimized form was increased by 18.73%-28.16%, while the average head loss of the CI filter was reduced by 39.06%-45.98%. Moreover, the head loss of three different filters under different particle size conditions had a significant linear correlation (*P* < 0.01). With the change in the particle size, the head loss of the

CK, SI, and CI filters did not present obvious changes, reported as 1.70 m-13.78 m, 2.56 m-20.63 m, and 0.99 m-8.28 m respectively. However, the different structures showed a significant difference in head loss among the three different centrifugal filters ($P < 0.01$), and ranked as $\Delta H_{SI} > \Delta H_{CK} > \Delta H_{CI}$.

< # Fig. 3 approximately here # >

3.3 Correlation between the separation efficiency and head loss

The correlations between the head loss and separation efficiency of the three different types of centrifugal filters at 1 g/L and 5 g/L are shown in Figs. 4, S5 and S6. When the particle size ranged between 40-100 μm, under the various flow rates the head loss and separation efficiency of different centrifugal filters and flow rates showed a significant quadratic correlation ($P < 0.05$). With an increasing separation efficiency, the head loss shows a gradual increase at the initial stage and a sharp increase in the later stage. At the same time, with an increasing particle size, the change of head loss decreases with an increasing separation efficiency. When the particle size increased from 40-60 μm to 80-100 μm, the average regression slopes of the three centrifugal filters of CK, SI and CI decreased by 65.17%-77.44%, 12.50%-37.57% and 25.02%-55.07%, respectively.

< # Fig. 4 approximately here # >

3.4 Flow and sediment movement characteristics inside the filter

The internal flow conditions of the three types of centrifugal filters are shown in Figs. 5 and S7. The cross-sectional flow field (Fig. 5a, h, j) shows that the tangential velocities of the three filter cross sections gradually decrease from the sidewall to the center and from top to bottom. The average flow rates of the two improved filters SI and CI were 2.20- and 1.47-fold higher than that of CK. For the longitudinal cross-section flow field (Fig. 5b), the CK and SI filters had secondary eddy currents on both sides of the zero-speed envelope surface, the short-circuit flow phenomenon of CK was more obvious, the center point of the secondary vortex of the CI filter part was at the center, and the zero-axis speed envelope surface was irregular.

For the movement of different sizes particles, there were more particles in the sedimentation tank within the 80-100 μm range compared to 0-20 μm particles under the same number of particles filled. As for SI filter, the height of the trajectory concentration area in the cylindrical section gradually reduced with an increase in the particle size and a decrease of sediment particles number in overflow pipe. But for CI filter, the short-circuit flow effect was more obvious with a smaller trajectory difference in sand collection tank. As the particle size increased, the chance of particles depositing in the sand collecting tank increased. Among them, the 0-20 μm particle size sediment only entered the overflow after the cylindrical section and the cone end moved. Silt with a particle size of 80-100 μm entered the sand-collecting tank, and only a small part was discharged with the action of the internal swirling flow.

< # Fig. 5 approximately here # >

4. Discussion

4.1 Centrifugal filter inlet improvement effects on fine sediment separation efficiency and head loss

The optimized semi-closed inlet of the SI filter increased on average the separation efficiency and increased the head loss respectively. The main reason is that, compared with the CK filter, the SI had a semi-closed inlet, and an arc baffle was installed at the inlet near the axis, which played a role in diversion and rotation. As shown in Fig. 5a, the flow velocity difference between the cross section axis and the edge area was relatively large, pushing the filtered fluid closer to the wall of the filter. The centrifugal effect of the filter as a whole was strong, and the separation efficiency was enhanced (Tang et al., 2015), but at the same time the head loss is increased.

The average separation efficiency of the CI filter with the optimized volute inlet increased, and the head loss was reduced. The main reason is that, the CI filter adopted a volute-shaped inlet for diversion, which prevented the fluid from directly impacting the wall of the filter after entering the filter barrel (Chiné and Concha., 2000), increasing the internal flow velocity of the filter and improving the separation efficiency; but the diversion effect reduced the head loss. Patra et al. (2017) also showed that a hydrocyclone with a spiral in the cylindrical section has a better efficiency than conventional hydrocyclones under the same geometric and operational conditions.

The main improvement of both SI and CI filters was their much smaller size, comparing to the CK filter. Under the same flow conditions, the internal flow rate of the filter increased, which increased the cyclone separation effect of the water flow, thereby increasing the separation efficiency (Qian et al., 2016; Liu et al., 2014). However, at the same time the head loss caused by the frictional force under the action of viscosity also increased. This is also consistent with the study by Neesse et al. (2015). When the diameter of the centrifugal filter is reduced to approximately 10 mm, under high pressure conditions the separation particle size D50 reaches 0.5-2.8 μm.

4.2 Ways to improve the separation efficiency of fine sediments by optimizing the structure of centrifugal filters

Compared with others filter, the separation efficiency of the CI filter with an increasing volute inlet increased by 22.83%-123.19%, but its head loss was reduced by 39.06%-45.98%. Therefore, CI filter was used as the basic optimized filter configuration. The separation efficiency and the head loss of the SI filter with a semi-closed inlet increased by 18.73%-28.16% and 47.36%-257.55%, respectively. Fig. 6a shows that this research added a semi-closed inlet based on the CI filter to form a new filter structure, CI-SI, in order to improve the separation efficiency. Under the condition of a flow rate of 1 g/L and a sediment concentration of 50 m^3/h, the separation efficiencies of the new filter CI-SI and the three-structure filter are shown in Fig. 6b. Compared with the SI filter, its separation efficiency for sediments of approximately 10 μm was not noticeable improved, but the separation efficiency for 30 μm particles was further improved by 14.29%-60.56%. Compared with the CK filter, the overall separation efficiency was increased by 50.24%- 550.17%.

< # Fig. 6 approximately here # >

For the same filter structure, operating parameters such as the inlet flow rate also have a significant impact on the separation efficiency and head loss (Patra et al., 2017; Zhang et al., 2017; Vieira et al., 2016;). as shown in Fig. 7c, the head loss of the same centrifugal filter increases rapidly first and then slowly with the separation efficiency because the head loss generally increases with an increase in the flow rate. When the flow rate is low, the centrifugal force in the filter is small, which is not sufficient to effectively separate the mixture, and the separation efficiency is poor. As the flow rate increases, the separation efficiency increases. When the flow rate increases to a certain value, the separation efficiency tends to stabilize, or even decrease. On one hand, when the flow rate is too high, the residence time of the solid particles in the filter is reduced, which is not conducive to full separation.

As a result, it also leads to a discharge of the remaining particles in the sand collecting tank with the internal swirl flow (Wang, 2019). Therefore, for the same filter the treatment flow can be optimized to achieve a trade-off between the head loss and separation efficiency. In agriculture, the flow of the filter in the irrigation system depends on the irrigation control area and the irrigation mode, which is relatively constant, but for the same reason we can adjust the overall size of the filter to achieve a higher separation efficiency with an appropriate increase in the head loss.

< # Fig. 7 approximately here # >

To further improve the separation efficiency and adjust the overall size of the filter, taking the design flow rate of 50 m^3/h as an example, the SI-CI filter was scaled. The separation efficiency is shown in Fig. 8a, and the zoom height is found to be 756 mm (XZ filter) with the best effect. Compared with the original 945 mm filter, the separation efficiency was increased by 21.99%-65.10%. At the same time, compared with the CK filter the separation efficiency of the XZ filter for sediment particles above 30 μm increased by 86.58%-973.71% (Fig. 8b) and its head loss increased by 27.27%-55.56%, where the smaller the particle size, the more significant the lifting effect. The increased of head loss will increase the energy consumption of irrigation system. This method is suitable for areas with high concentration of sand but sufficient energy. In the future, we can deepen the research to propose a suitable application range of centrifugal filters with different improvements.

The suitable sediment concentration of the filter is also the main limiting factor for its promotion and application (You et al., 2004). Due to the large area and high cost of the sedimentation tank, centrifugal filter is generally suitable for high-concentration Turbidity water above 8 g/L. Sand and gravel (Solé-Torres et al., 2019), screen (Duran-Ros et al., 2009; Juanico et al., 1995), and other conventional filters are often used in Turbidity water with a concentration below 5 g/L. However, for Turbidity water with a concentration of 5-8 g/L, effective filtration facilities are rare (Puig-Bargués et al., 2005; Capra and Scicolone., 2004). For the new filter suitable concentration pair, such as 8c, the separation efficiency of the new filter XZ at a sediment concentration of 7 g/L is better than that of the CK filter at a sediment concentration of 3 g/L. Therefore, the centrifugal filter can, up to a certain extent, fill the lack of effective filtration facilities for Turbidity water with a concentration of 5-8 g/L.

< # Fig. 8 approximately here # >

5 Conclusion

(1) Compared with the conventional centrifugal filter (CK), the average separation efficiency and head loss of the optimized semi-closed water inlet (SI) filter increased by 47.36%-257.55% and 18.73%-28.16%, respectively. The average separation efficiency of the optimized volute inlet (CI) filter increased by 22.83%-123.19% while reducing the head loss by 39.06%-45.98%.

(2) The separation efficiency of different centrifugal filters increased significantly with an increasing particle size; however, the head loss did not show significant changes with variations in the particle size. In addition, a significant ($P < 0.05$) quadratic correlation was found between the head loss and separation efficiency for particle sizes of 40-100 μm.

(3) Under the flow condition of a 1 g/L sediment concentration and a 50 m^3/h flow rate, the casing inlet (CI) can synergistically improve the fine particle separation efficiency and the reduction of the head loss, and the semi-closed (SI) inlet can increase the separation efficiency of particle diameters above 30 μm by 14.29%-60.56% on this basis, further reducing the volume of the filter and increasing the separation efficiency by 21.99%-65.10%.

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Compliance with ethical standards

Conflict of interest: On behalf of all authors, the corresponding author states that there is no conflict of interest.

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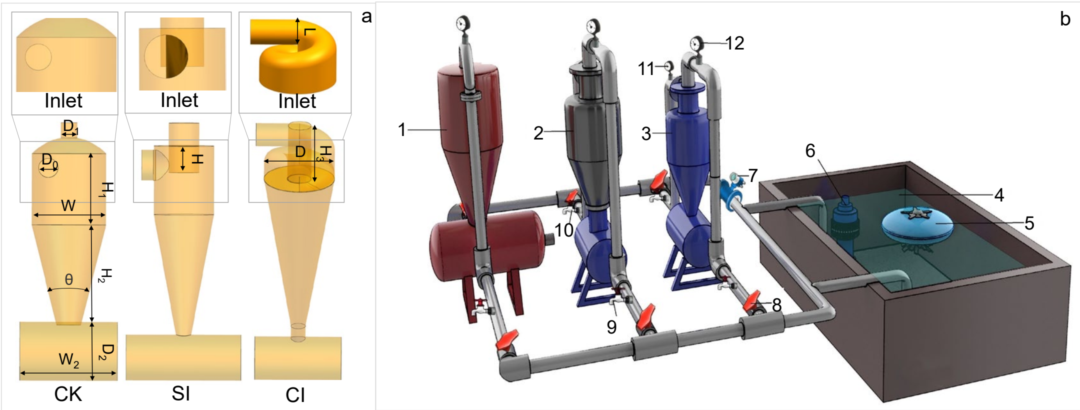


Fig. 1 (a) Three kinds of centrifugal filter structure; (b) Centrifugal filter test platform layout diagram, among them, 1~3: tested centrifugal filter SI, CI, CK; 4: reservoir; 5: floating type stirrer; 6: submersible pump; 7: electromagnetic flowmeter; 8: diversion butterfly valve; 9: overflow sampling port; 10: inflow sampling port; 11: inflow pressure gauge; 12: overflow pressure gauge. D: outer diameter of volute; D_0: inlet diameter; D_1: diameter of overflow pipe; D_2: diameter of sand tank ;L: volute pitch; H: depth of overflow pipe; H_3: volute height; θ: cone angle;

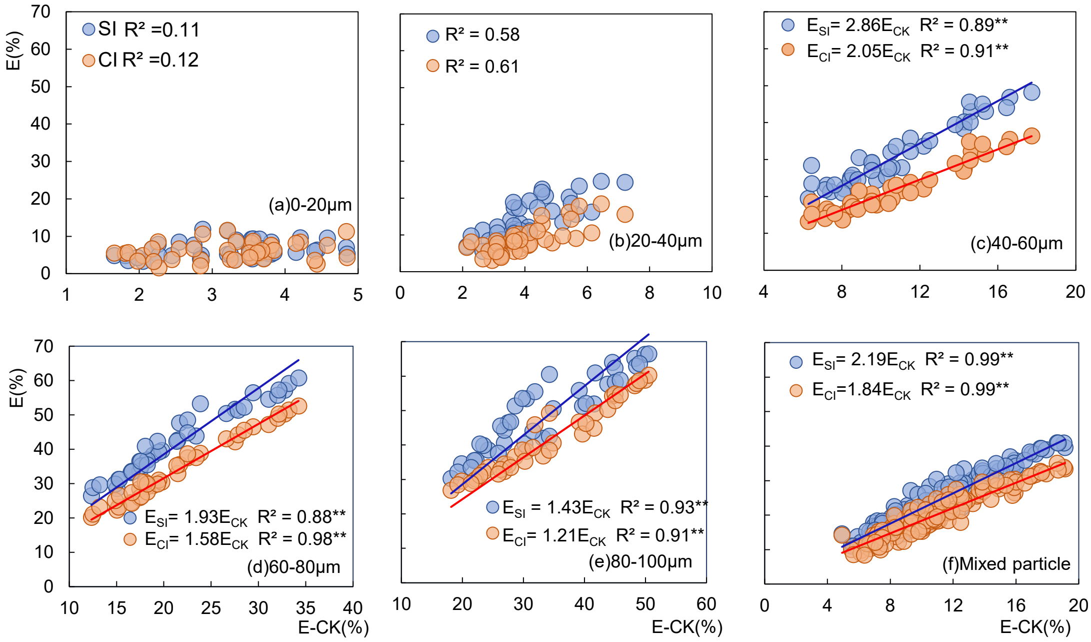


Fig. 2 Comparison of sediment separation efficiency under the sediment gradation conditions of a typical Yellow River irrigation area, (a)-(e) are the separation efficiency of a single particle size gradation, (f) are the separation efficiency of a mixed particle size gradation, where ** indicates *P*<0.01

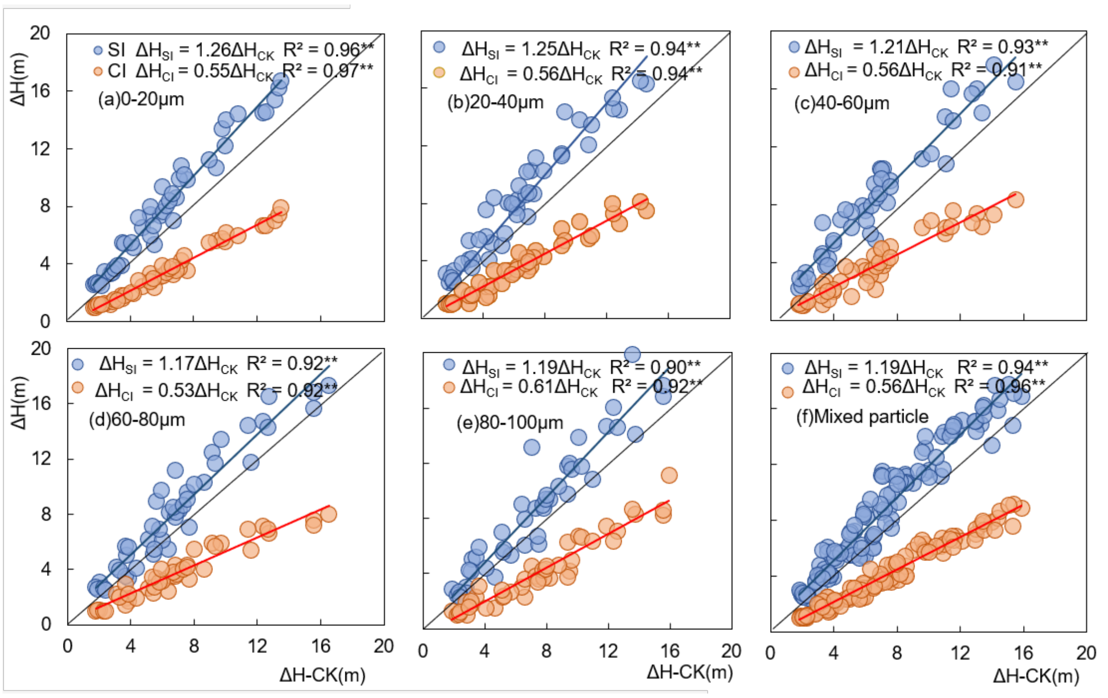
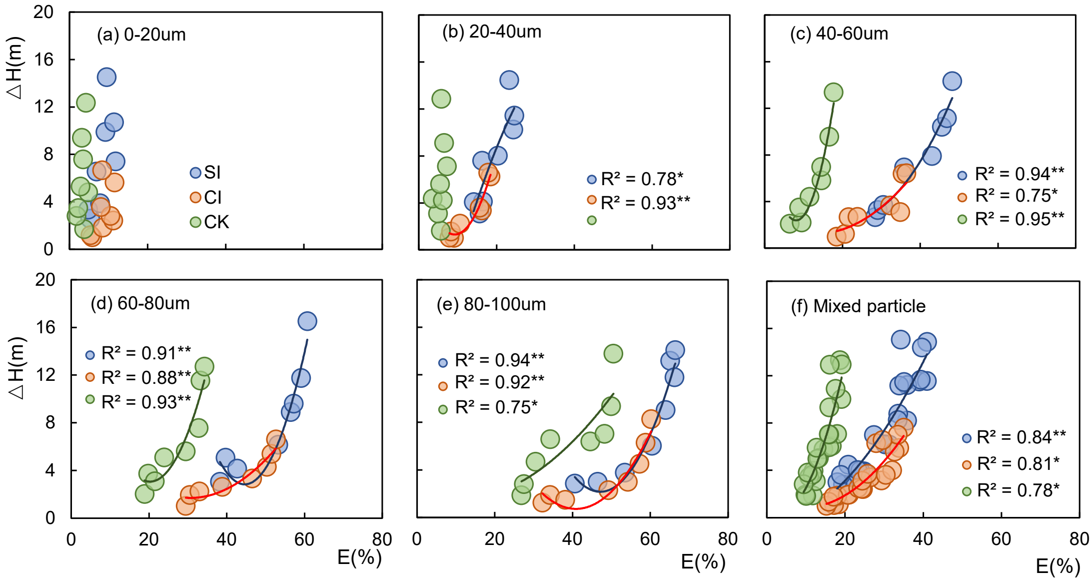
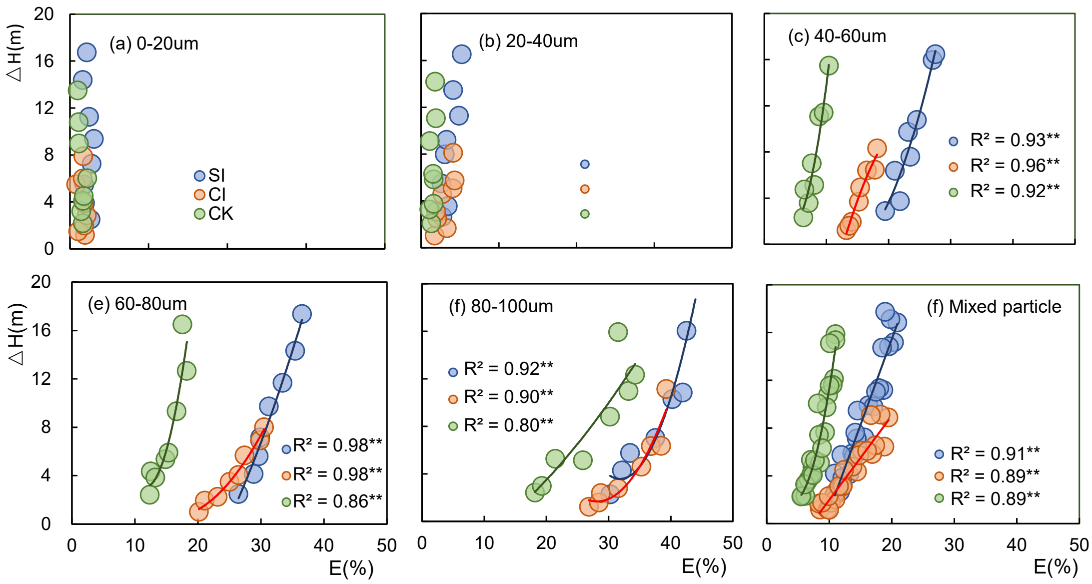


Fig. 3 Head loss comparison, (a)-(e) is the head loss of a single particle size gradation, (f) is the head loss of a mixed particle size gradation, where ** means *P*<0.01



(1)1g/L



（2） 5g/L

Fig. 4 Correlation between head loss and separation efficiency, (a)-(e) is the correlation between the head loss of a single particle size gradation and the separation efficiency, (f) is the correlation between the head loss of the mixed particle size gradation and the separation efficiency, where * means P<0.05, and ** means P<0.01.

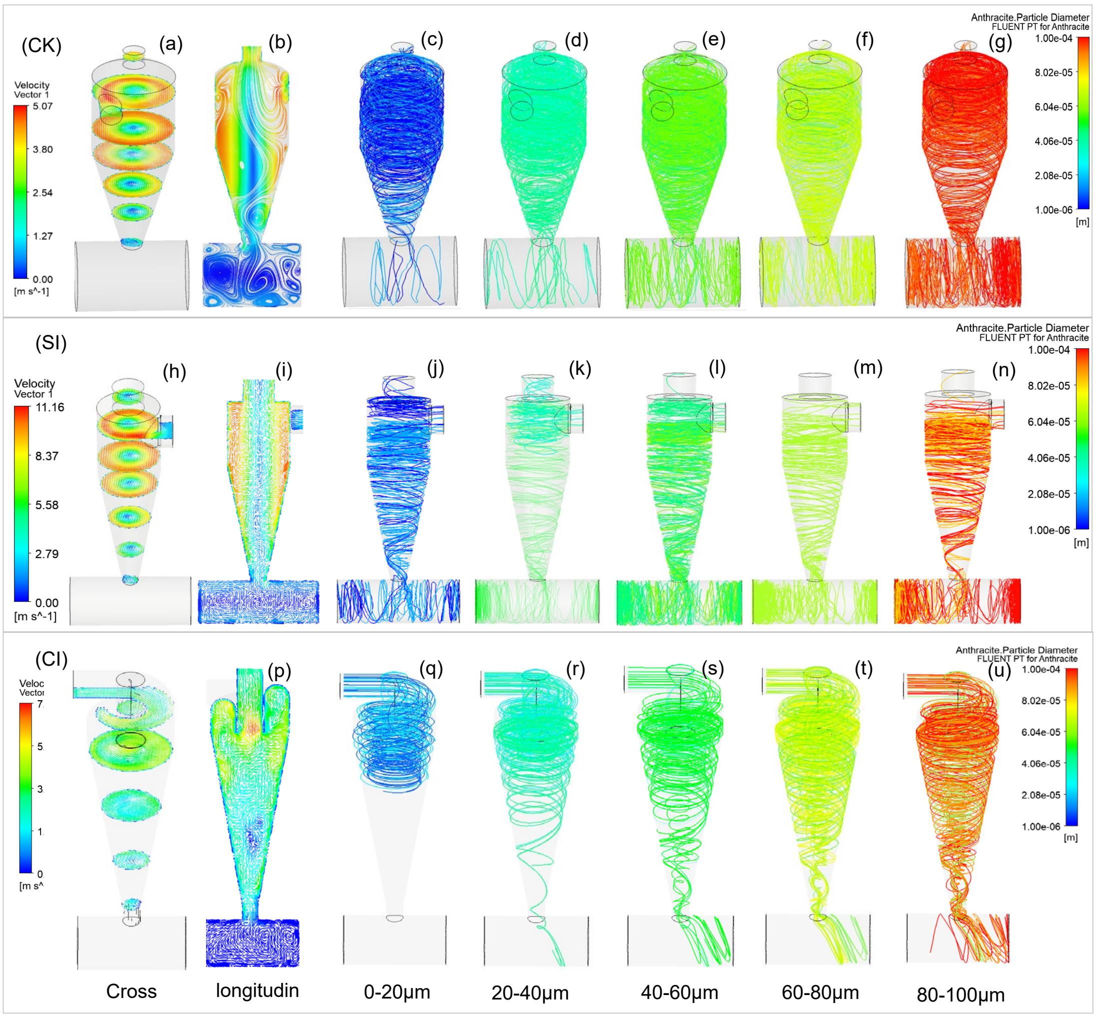


Fig. 5 Internal flow analysis, (a), (b), (h), (i), (o), (p) are the cross-section and vertical cross-section of the flow field of the three filters of CK, SI, and CI Field; Figures (c)-(g), (j)-(n), (q)-(u) are the movement of sediment particles of different sizes in the filters of CK, SI, and CI filters trajectory.

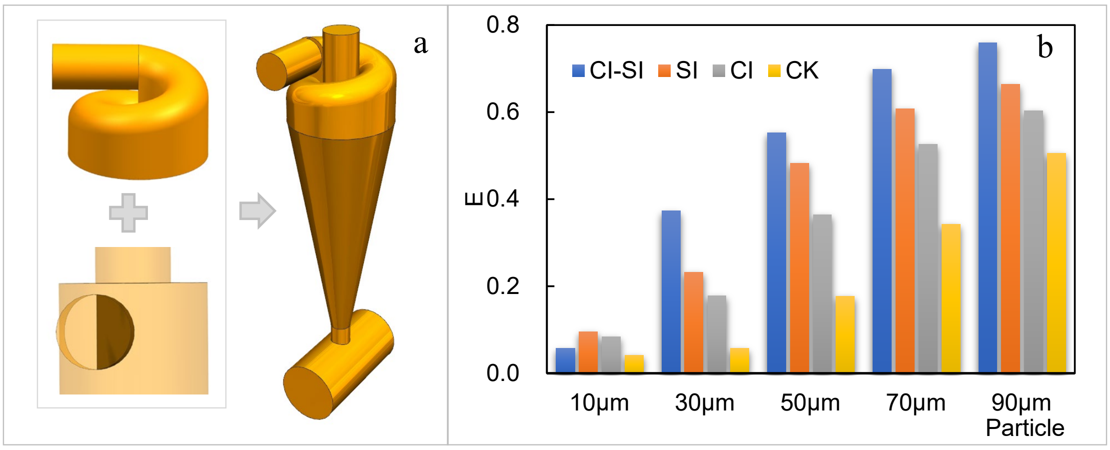


Fig. 6 (a) Optimization design ideas of centrifugal filter structure; (b) Performance comparison of the new centrifugal filter CI-SI and CK, SI, CI three centrifugal filters at a concentration of 1g/L.

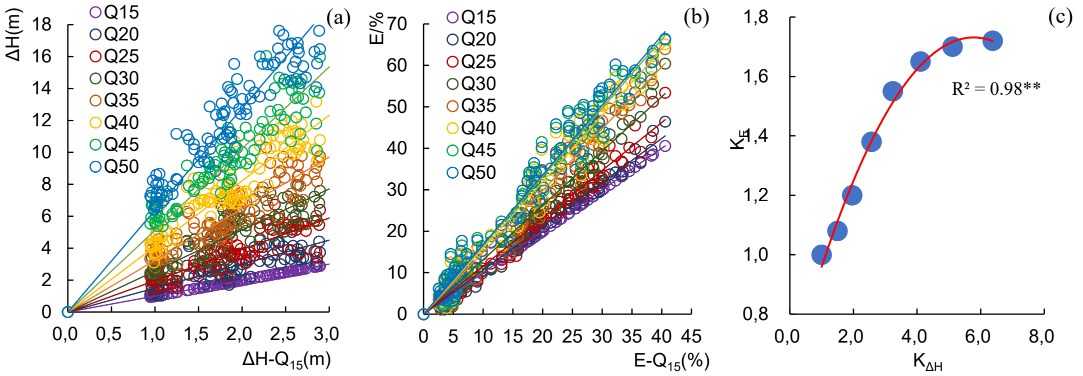


Fig. 7 Correlation between head loss and separation efficiency under different flow conditions, QX : flow rate of X m^3/h; K_E is the slope of the fitted curve of separation efficiency in Fig.7 (b); $K_{\Delta H}$ is the slope of the fitted curve of Head loss in Fig.7 (a).

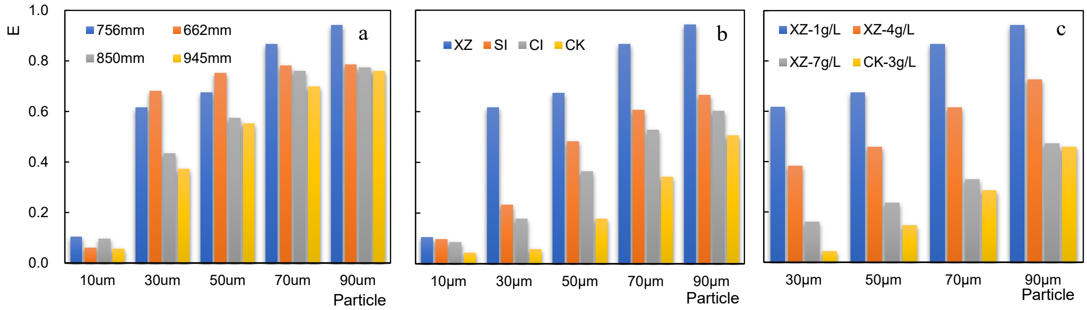


Fig. 8 (a) Separation efficiency of centrifugal filters of different sizes at a concentration of 1g/L; (b) performance comparison of a newly made centrifugal filter (XZ)and three centrifugal filters of CK, SI, and CI at a concentration of 1g/L; and (c) Separation efficiency at different concentrations.

Table 1 Structural parameters of the centrifugal filters

<table>
<tr><td rowspan="2">Casing inlet filter (CI)</td><td>Outer diameter of volute D (mm)</td><td>Volute pitch L (mm)</td><td>Volute height H_3 (mm)</td><td>Inlet diameter D_0 (mm)</td><td>Diameter of overflow pipe D_1 (mm)</td><td>Depth of overflow pipe H (mm)</td><td>Vertebral height H_2 (mm)</td><td>Cone angle θ/°</td><td>Diameter of sand tank D_2 (mm)</td><td>Sand collecting tank length W_2 (mm)</td></tr>
<tr><td>244</td><td>88</td><td>172</td><td>80</td><td>80</td><td>172</td><td>530</td><td>30</td><td>180</td><td>300</td></tr>
<tr><td rowspan="2">Semi-closed inlet filter (SI)</td><td>Inlet diameter D_0 (mm)</td><td>Diameter of overflow pipe D_1 (mm)</td><td>Depth of overflow pipe H (mm)</td><td>Depth of cylindrical section H_1 (mm)</td><td>Width of cylindrical section W (mm)</td><td>Vertebral height H_2 (mm)</td><td>Cone angle θ/°</td><td>Diameter of sand tank D_2 (mm)</td><td>Sand collecting tank length W_2 (mm)</td><td></td></tr>
<tr><td>80</td><td>80</td><td>70</td><td>300</td><td>280</td><td>420</td><td>25</td><td>260</td><td>400</td><td></td></tr>
<tr><td rowspan="2">Conventional inlet cone filter (CK)</td><td>Inlet diameter D_0 (mm)</td><td>Diameter of overflow pipe D_1 (mm)</td><td>Depth of overflow pipe H (mm)</td><td>Depth of cylindrical section H_1 (mm)</td><td>Width of cylindrical section W (mm)</td><td>Vertebral height H_2 (mm)</td><td>Cone angle θ/°</td><td>Diameter of sand tank D_2 (mm)</td><td>Sand collecting tank length W_2 (mm)</td><td></td></tr>
<tr><td>80</td><td>80</td><td>0</td><td>180</td><td>250</td><td>320</td><td>30</td><td>120</td><td>300</td><td></td></tr>
</table>

Table 2 Simulated mixed particle size and sediment gradation in typical irrigation areas

	0-20μm	20-40μm	40-60μm	60-80μm	80-100μm
Ningxia	20	25	25	20	10
Neimeng	25	25	25	15	10
Shanxi	30	25	25	15	5

Note: Simulated mixed particle size and sediment gradation under five concentration conditions (1, 2, 3, 4, 5 g/L)