Review of Filter and Its Performance Testing in Agricultural Efficient Water-saving Drip Irrigation System

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Abstract. Developing efficient water-saving irrigation technology is one of the important ways to solve the problem of water shortage in China. Rational allocation of drip irrigation filtration system is an important way to slow down the blockage of each component of drip irrigation system (such as emitters, solenoid valve, etc.). 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. Based on this, this paper comprehensively expounded the structure, performance characteristics, working principle and research progress of different types of filter, and the trends of filter research and product development were put forward in order to provide theoretical support for the wider application of drip irrigation technology and the construction of new countryside.

1. Introduction

The shortage of water resources has always been one of the main obstacles to the economic, social and cultural development of China. In 2014, General Secretary Xi Jinping pointed out that the old "water problem" needs to be solved, and the new "water problem" is even more urgent because of the continuous development of China's economy and society. The "new problem" mentioned includes the major problem of water shortages. Agricultural water use has always accounted for more than 60% of the total amount of water used in China including industrial water and urban domestic water, ranking first among all industries in China. The agricultural water shortage is serious, and the water use efficiency is low, which seriously threatens peasants' income and affects rural economic growth. The prospects in agricultural water conservation are very broad. In agricultural production, the efficiency of irrigation water use in farmland is much lower than that in developed countries (China 0.53-0.54 and developed countries have reached 0.70-0.80) [1]. According to the “Views on the implementation of the strictest water resources management system” (Guofa [2012] No.3), it is clear that by 2020, the efficiency of irrigation water use in the whole country needs to be higher than 0.55, so it is very urgent to improve the efficiency of agricultural irrigation water use in our country. Drip irrigation is a water-saving form of irrigation using a drip irrigation pipe or a drip irrigation belt of a plastic material about 16 mm in diameter to deliver the irrigation water directly to the crop root area to achieve local irrigation
According to the current situation of agricultural irrigation related development at home and abroad, drip irrigation technology is one of the most effective and water-saving irrigation technologies, and it is the precondition and powerful guarantee for the improvement of quality and efficiency of modern agriculture and the transformation and upgrading of new rural construction [4-6].

The Chinese government has always placed the use of water-saving irrigation technology at the height of "revolutionary measures ", especially in recent years, the Party Central Committee and the State Council have put on a higher level of the application and popularization of water-saving irrigation technology in drip irrigation. And a series of principles and policies have been put forward to support it: from 2006 to 2019, the first document of the Party Central Committee pointed out the need to apply water-saving irrigation technology in many places, the State Council's “Outline of the National Agricultural Water Saving Program (2012-2020)” and General Secretary Xi Jinping put forward the 16-word strategy of "water-saving priority ", the strategy of "revitalizing the countryside "put forward in the report of the 19th National Congress of the Communist Party of China, the “National Water Saving Action Plan” jointly promulgated by the two ministries and commissions, etc.. These policies illustrate that the development of water-saving irrigation in our country is ushered in unprecedented development opportunities [7]. The area of micro-irrigation, dominated by drip irrigation technology, has a nearly 10-fold increase in the last decade by 2016, which makes our country being the most widely used the drip irrigation technique in the world.

Filter is an essential water purification treatment equipment in drip irrigation system. Reasonable allocation of drip irrigation filtration system, can effectively reduce the impurities into the drip irrigation system, and then slow down blockage in the drip irrigation system pipe network and field components (such as emitters, solenoid valves, etc.). Based on the principle and function of the filter, the filter can generally be divided into four types: centrifugation, sand, screen and lamination. At present, many manufacturers at home and abroad, such as NETAFIM (Israel), ARKAL (Israel), AZUD (Spain), Toro (USA), China Dayu Water Saving Group Co., Ltd., China Xinjiang Tianye (Group) Co., Ltd., China's Gansu Yasheng Yamette Water Saving Co., Ltd., have all produced a large number of advanced high-quality products.

In recent years, 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 structure, performance characteristics, working principle, research progress of the test and representative products of the filter. Therefore, this paper comprehensively expounded the structure, performance characteristics, working principle and research progress of different types of filters, and some representative products are summarized, and the trends of filter research and product development were put forward in order to provide theoretical support for the wider application of drip irrigation technology and the construction of new countryside.

2. Performance characteristics and structure of filter

2.1. Centrifugal filter

Centrifugal filters are generally used for primary filtering of drip irrigation systems. Centrifugal filter is mainly used to separate and remove heavy particles of raw water, such as coarse granular sand, and it can be used for sediment filtration in well water and river water. When the sediment content or stone content of irrigation water source is relatively high, it is suitable to choose this filter. There are two common structural forms, conical and cylindrical. The concrete structure composition is shown in Figure 1, mainly including filter upper and lower shell, fixed lock and lock pin, sealing ring, groove connector, sand collecting tank plug, flushing pipe and sand tank.
1. upper shell, 2. filter lower shell, 3. fixed lock, 4.lock pin, 5.sealing ring, 6. groove connector, 7.sand collecting tank plug, 8. flushing pipe, 9. Sand tank

Figure 1 The structure composition of centrifugal filter

2.2 Sand filter
Sand filter, like centrifugal filter, is often used as primary filter equipment. Sand filter is equipment for all-round filtration of irrigation water sources by means of uniformly distributed quartz sand with the same particle size or specific gradation. It has strong intercept ability. Among all filters, sand filter is the best way to filter many types of impurities (inorganic or organic) in water. Sand filter is the most common and effective filter for removing impurities in water, especially organic ones. And it does not affect the continuous supply of water. As long as there is more than 10 mg/L of organic matter in the water source, sand filter should be selected regardless of the content of inorganic matter [8-9]. Its specific structure is shown in Figure 2, mainly including inlet, cloth water tray, filter cap, outlet, overhaul port, quartz sand medium and inlet of filling sand, etc.

1.inlet, 2.cloth water tray, 3.filter cap, 4.outlet, 5.overhaul port, 6.quartz sand medium, 7. inlet of filling sand

Figure2 The structure composition of sand filter

2.3 Screen filter
Screen filter is often used for secondary filtration. Its filter medium is nylon screen or stainless-steel screen. It has become the most widely used filter in micro-irrigation system at home and abroad because of its low cost and high filter ability. There are many kinds of screen filters. screen filters can be divided into vertical filter and horizontal filter according to the installation mode, plastic filter and metal filter according to the manufacturing materials, manual cleaning filter and automatic cleaning filter according to the cleaning mode. It is generally required that the selected screen diameter is 1/7/1/10 of the minimum size of the flow path of emitter. Screen filter is generally composed of screen, casing, pipe, etc. The representative structure is shown in Figure 3
2.4 Lamination filter

The lamination filter has high filtering effect of impurity. The water flow containing impurities is fully filtered by superimposed layers. The lamination material is mostly the high-quality engineering plastic. Its thickness is generally a few millimeters and has the characteristic color according to the product filter precision. There are small grooves on both sides of the lamination, and the size of the groove determines the filtering precision of the lamination filter. Many pieces of the same lamination are stacked together and mounted on a uniquely designed inner brace to form a filter. And then this filter is usually installed in a strong performance of engineering plastic filter tube to form a complete lamination filter. The lamination filter is mainly composed of lamination, filter core column, piston and so on, and the representative structure is shown in Fig. 4.

3. Filtering and Backwashing Process and Principle

3.1 Centrifugal filter

After the water is pressurized by the water pump, it flow into the inner of the centrifugal filter tank through the connecting pipe along the cutting line direction, and a large centrifugal force is generated by the rotary motion in the tank. The sand and other relatively heavy solids move to the inner wall of the tank under the action of centrifugal force, and move downward along the inner wall to the bottom sand collecting tank. And the relatively clear water moves upward along the center of the tank to the outlet, then enters the next stage filter equipment, completing the water sand separation. Sand collecting tanks located at the bottom of the centrifugal filter tank should be regularly inspected and remove the sand.

3.2 Sand filter

When the sand filter works normally, the water can be filtered by flowing through the inlet, passing water distribution plate, and evenly reaching the medium layer. After this, most of the impurities in the water can enter the quartz sand filter layer with the flow, and is intercepted on its surface. The remaining
relatively small impurities move to the inside of the filter layer and are intercepted, realizing the deep filtration of the water. The water filtered through the quartz sand filter layer, flows through the filter cap at the bottom of the tank, and then enters the next filter equipment through the outlet and the system pipe.

When the impurities intercepted by the filter layer reach a certain level, the filter layer needs to be backwashed. The backwash process is divided into two forms: automatic and manual. The automatic backwash filter can realize the automatic control of the filter material backwash process. The filter is equipped with a control device which can sense the internal pressure difference of the filter at any time. When the pressure difference caused by the filter layer intercepting impurities reaches the preset value, the pressure difference control device sends the signal immediately, which makes the valve of controlling the filtering process automatically close, and the valve of controlling the backwash process and the impurity discharge channel automatically open. At this time, the relatively clean water filtered through other sand filters passes through the outlet of the backwash unit, and the filter layer of the backwash unit is rinsed until the dirt attached to the inner and surface of the filter layer is washed clean. After washing, the water carrying the intercepted impurities is discharged from the sewage outlet through the sewage pipe to complete a sewage discharge process. After the backwash is finished, the backwashed filter returns to the filtration state and continues to filter the raw water together with the remaining filter units. In addition, there are some filter products backwash using timing control. When the filter process reaches the pre-set length of time, the system automatically goes into the backwash stage, the specific backwash process are consistent with the pressure difference control conditions.

For the non-automatic backwash filter, the filter state of one or more of the same filter tanks is converted to the backwash state by means of the opening and closing of the valves. The water flow filtered in the filter tank of the same filter group is reversed to flush the filter material, and this water carrying the impurities inside the filter material of the backwash tank is discharged out of the tank through the backwash outlet. When the water flow of the backwash is in a clean state, the backwash is finished. And then backwash valve should be closed to restore the tank body of the backwash filter to the filter state. The above operation should be repeat until the all backwash tanks are washed clean. When the filter material needs to be washed by manual backwash, the operation of the filter needs to be stopped, the overhaul port needs to be opened, and all the quartz sand filter material from the tank needs to be manually removed and cleaned with clean water, and then fill it back to the tank again by the mouth of filling sand.

3.3 Screen filter
Filtering process is that the water flows through the inlet into the screen filter, and the impurity particles larger than the pore size of the screen are intercepted on the side of the filter screen, and the clean water is discharged by the outlet. In the filtering process of automatic backwash filter, the deposition of impurity particles on the filter surface gradually increases, which leads to the increase of the pressure difference inside the filter body. When the pressure difference reaches the value set before operation, the filter control device will automatically open the automatic backwash process and clean all the impurity intercepted on the inner surface of the filter screen. The backwash process lasts about tens of seconds. Manual backwashing process is that after the screen filter operates for a period of time, the filter screen should be removed from the filter shell, and the surface impurities of the filter screen is manually removed by the brush until the screen is clean.

3.4 Lamination filter
The filtration process of the lamination filter is as follows: the water flow enters the inner shell from the inlet of the bottom side of the shell, and the laminations are compressed by the elastic force of the spring and the pressure of the water flow, forming the spaces to intercept the impurities between grooves on the contact surface of the adjacent laminations. The filtered water flow out from the outlet. The backwash process is divided into two categories: automatic and manual. For automatic backwash lamination filter, the pressure difference reaches the preset value as the impurities trapped inside the
lamination increase, or when the operation period of the filter reaches the preset value, the control device automatically switches the system from the filter state to the backwash state through the information transmission. The piston inside the filter overcomes the spring’s elastic force to move towards the top of the shell, making the pressed lamination loose. At the same time, the backwashed water flows along the radial direction of the laminations at a higher speed, and the trapped impurities on the surface of the lamination are thrown away with the high-speed flow. When the laminations are washed clean, the direction of the flow is changed, and the laminations are again pressed at the water flow pressure and spring elastic, resulting in the filters being in filtering situation again. For the manual backwash, the filter laminations should be removed from the shell, and the impurities intercepted on the surface of the lamination should be manually removed by the brush and washed with water. After that, the laminations should be reassembled to the filter.

4. Research Progress of Filter Performance Testing

4.1 Centrifugal filter
In recent years, some scholars have studied the performance and filtering ability of centrifugal filters, and achieved significant results. Chai Haidong [10] summed up the common types, structure, advantages and disadvantages of filters and their applicable conditions in drip irrigation project at present. He also pointed out that the advantages of centrifugal filters are strong storage capacity, easy maintenance, and their disadvantages are difficult to filter impurities that the density is close to or less than water density, and the internal high-speed turbulence will cause large head loss. Cui Rui et al.[11] compared the performance of cylindrical hydro cyclone with that of conical centrifugal filter. They found that the flow rate and head loss of the two are exponential, and the head loss and sediment removal ability of the former are better than that of the later due to its simple structure and the local optimized structure. Zhou Jiayu et al.[12] simulated the centrifugal filters with different bottom angles of the central cone by FLUENT 15.0. They found that the separation effect of the water sand of the filter is significantly improved when the bottom angle of the upper cone section is reduced properly, and the wear of the upper cone section is effectively alleviated, and the optimum angle of the bottom angle of the upper cone section of the central cone is between 40°and 50°. Mailapalli DR et al.,[13] studied the variation law of solid particulate matter content, head loss and so on in the continuous operation of the system under muddy water conditions; Jayen Pveerapen et al.,[14] studied the influence of the design parameters of the central cone bottom angle and the diameter of the cylindrical segment of the centrifugal filter on its application effect, and put forward the improved design method of the existed filter.

4.2 Sand filter
The two main indexes used by many experts and scholars to judge the performance of sand filters are $d_e$ (effective particle size) and $UC_s$ (uniform coefficient). The $d_e$ refers to the aperture of the screen allowing a volume of 10% of the total filter material passing through, being usually expressed as $d_{10}$. The $UC_s$ refers to the ratio between the aperture size of the screen allowing a volume of 60% of the all filter media passing through and $d_{10}$. $d_{10}/d_{60}$[15]. The $d_{10}$ and $d_{60}$ can be obtained by particle gradation curves. The concrete method is as following: the mass or weight of the filter material in different particle size stages are obtained by sieving all the filter material through different pore size sieves. The particle gradation curve is drawn by means of the logarithmic coordinate system. The horizontal coordinate is the particle diameter of the filter material, and the vertical coordinate is the percentage of the accumulated weight of the filter material with the diameter less than (or greater than) a certain particle, and then the $d_{10}$ and $d_{60}$ of the tested filter material can be obtained by the curve, and then $d_e$ and $UC_s$ can be calculated. The larger the $d_e$ of the filter material, the lower the filtering ability, and vice versa. Therefore the particle gradation of filter materials can be selected according to the actual conditions of the project. The higher the $UC_s$ of the filter media, the better the uniformity, and vice versa [16]. Pizarro Cabello [17] Suggested that the $UC_s$ for filter media is between 1.4-1.6; Dong Wenchu [18]
suggested that the $UC_s$ should be 1.5; Burt and Styles [16] recommended that products with lower $UC_s$ should be considered when the filter media was selected.

Many experts and scholars have explored the hydraulic performance and filtering effects of sand filters. Zhang Wenzheng et al.[19] studied the filtering effect of sand filter, screen filter and lamination filter under micro-irrigation condition, and found that the filtering effect of sand filter is better than that of screen and lamination filter when filtering the Yellow River. Zhao Pengfei et al.[20] explored the effect of glass ball on micro-irrigation filter and found that the filtering of glass ball on impurities in water is divided into two stages, and the principle of impurity removal varied from stage to stage. Yang shuxin et al. [21] introduced the application and operation of sand filter, and analyzed the technical problems of the vertical and horizontal sand filter in design and production. He found that horizontal sand filters are more suitable in water-saving irrigation systems using channel water. Arbat G et al.[22] studied the influence of the various components inside the quartz sand filter on the head loss. They found that in the total head loss of the filter, the head loss caused by the quartz sand filter layer occupy for 84.6%, the inlet and outlet part is 4.4%, and the water distribution plate and nozzle is 11%. They also found that the total head loss irregularly increases with the decrease of nozzle area. Brouckaert BM [23] studied the occurrence characteristic of backwash of sand filter. He considered that the space height above the filter layer inside the tank should reach at least 25% of the thickness of filter layer in order to ensure that it will not affect the expansion of quartz sand filter layer during backwashing; Benham B and Ross B [24] studied the effect of filtration flow rate in the sand filter on its filtration effect. They suggested that the filtration flow rate should be less than 0.017 m/s.

4.3 Screen filter

Qin Tianyun et al.[25] studied the water head loss and filtration capacity of screen filters with different mesh and lamination filter under the muddy water with different flow rate and different mass concentration, they found that the hydraulic performance of the screen filter is better than that of the lamination filter type, but the filtration effect is versa. Shi Kai et al.[26] explored the decontamination effect of the screen filter, and they suggested that the discharge rate is set at 180 m$^3$/h and the discharge time is 50s, which can make the discharge cleanliness up to 98% in order to ensure that the filter achieves high decontamination effect under the condition of low discharge water consumption. Li Man et al.[27] studied the decontamination effect of the screen filters with different mesh for drip irrigation system, they found that the occurred period of peak value of the decontamination curve is about 10s, and it is stable in the period of 20-30s, and the decontamination effect of the filter is remarkable. Lei Jianhua et al.[28] expounded the working principle, structural characteristics and innovation of the self-developed hydraulic-driven self-cleaning screen filter, and studied the hydraulic performance of the four different types of filters. They found that the hydraulic-driven self-cleaning screen filter has better passing ability of water flow and cleaning effect, and is lighter in whole, smaller area and longer in life. Luo Xiuping [29] studied the influence of the flow velocity of the self-cleaning screen filter on the internal water flow movement characteristics of the impurity discharge system, and found that the self-cleaning effect and head loss of the filter will increase and the filter period will be shortened when the decontamination flow rate of the filter increases; Aleph river abrimiti [30-31] studied the characteristics of the internal flow motion of the torpedo screen filter system under the condition of different sizes, and they found that the change of the size of the filter has little effect on the internal flow field, and the influence on the pressure and speed is more similar, and the filters with different structure size have the most suitable working flow range. Based on this, the optimum impurity discharge time is 40-50s by the physical testing and theoretical analysis. Yu Liming et al.[32] simulated the influence of different flow rates on the movement and distribution of sediment particles in Y-type screen filter by using computational fluid dynamics-discrete element method, and implemented the test to support their results. Liang Jurong et al.[33] determined the correlation between the local head loss, flow rate, operation time and impurity content of screen filter based on the in-depth analysis of the filtering mechanism. Capra A et al.[33] implemented performance tests of different types of filters, and considered that the filtering ability of the screen filter is relatively poor to that of other types of filters.
4.4 Lamination filter

Yang Peiling et al. studied the hydraulic performance and filtration capacity of five common lamination filters under different sediment concentration and filtration flow conditions, and established a comprehensive evaluation method for the filtration performance of the lamination filter[35]. They applied the fractal theory to the flow path design of the lamination, and developed a new type of lamination filter. They also analyzed the head loss, the intercepted sediment volume, the particle size of the intercepted sediment and the uniformity of the sediment in the flow path [36]. Cui Rui et al.[37] studied that the head loss of the lamination plate was affected by the change of different flow rate under two different flow path conditions. They found that the head loss and flow rate of the two kinds of laminations are specifically related, and the loss in the laminations with composite path is smaller than that of the traditional ones. Li Nan et al.[38] studied the hydraulic performance and filtering capacity of the lamination filter, and found that the water head loss irregularly increases with the increase of the quantity of filling sand, and when the quantity of filling sand accumulates to a certain level, the water head loss sharply increases, and quickly reaches or exceeds the preset backwash pressure difference. Li Hao et al.[39] used CFD simulation software to simulate the 3D flow inside the lamination filter under the condition of clear water. They found that the flow motion characteristics can be obtained by the porous media model, and the hydraulic performance of the filter can be accurately estimated. H Yurdem et al. [40] studied the correlation between the parameters of the structural design of the lamination filter and its hydraulic performance and filtering capacity by means of dimensional analysis, and proposed the prediction model of the filter head loss under different parameters. Anonymous [41] introduced a new lamination filter for the 20th anniversary of the birth of the Bagless Plus filter series, and studied the effects of different lamination surfaces and morphologies on the filter capacity.

5. Conclusion

Based on the analysis of the current research trends and advantages and disadvantages of filters, the following research and product development directions are proposed:

(1) Increase the research on the reasonable configuration and optimal operation mode of filter equipment in drip irrigation system under complex water quality conditions;

(2) Study the clogging mechanism of the core structure of the filter based on the essence of reducing its hydraulic performance and filtering capacity;

(3) Optimize the structure of the filter, such as changing the structure of the lamination filter channel, changing the filter layer structure of the sand filter, and then improving the performance of the filter.

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