Design and Experiment of Auto Vertical Washing Equipment for Seedling Tray

Kai Li, Xiaopeng Du, Yilei Yin, and Yong Hou
Academy of Agricultural Planning and Engineering, Beijing, China
Key Laboratory of Farm Building in Structure and Construction, Ministry of Agriculture, Beijing, China
Email: will25505177@163.com, dxp397@foxmail.com, {276089613, 1729661686}@qq.com

***Abstract*—Driven by the current international standardization of seedling cultivation technology, facility seedling cultivation in China has gradually changed to industrialization. Seedling tray has become the main carrier of seedling cultivation, and the large number of tray recycling is an inevitable trend. In view of the problems that the existing seedling tray cleaning equipment needs to be soaked before washing with water, poor circulating water quality, secondary adhesion and so on, the vertical spray-washing seedling tray flushing mode, combined with the secondary filtration cycle, can achieve the cleaning effect and reduce the water consumption at the same time. Through research on equipment performance, it is determined that under the condition of 8 m^3/h, 0.58MPa water pump, the maximum nozzle pipeline pressure of 0.31MPa can be achieved by selecting nozzles with an inner diameter of 1.1mm and a spray angle of 65°, and a 3×4 array arrangement. When the conveying speed is 91mm/s, the cleaning rate reaches 95.28%. By using 80-mesh stainless steel orifice plate to filter water, when the cleaning water flow is greater than 3 m^3/h, the cleaning water level can be kept stable and the water quality is good. The design effectively improves the efficiency of seedling tray cleaning, meets the need of reuse and cleaning of seedling tray, and has reached the popularization and application.**

***Index Terms*—seedling tray, washing equipment, PIPENET simulation, design and experiment**

I. Introduction

With the vigorous demand for high-quality vegetables and flowers, the demand for high-quality seedlings is increasing sharply. On the other hand, the shortage of labor force promotes the gradual development of seedlings cultivation to industrialization. Therefore, seedling tray have become the main seedling cultivation method of large-scale factory seedling enterprises [1]-[3]. Seedling cultivation enterprises with an annual output of more than 100 million seedlings have gradually emerged in China. Based on the annual use of 72-point tray (as shown in Fig. 1) of 1.39 million tray, the annual demand of commercial seedlings in China exceeds 50 billion [4], [5]. If such a large amount of seedling tray is reused, on the one hand, the cost of seedling cultivation enterprises can be reduced, on the other hand, the recovery of polystyrene and PVC point tray can reduce a lot of pollution [6]-[8]. In order to eliminate soil borne diseases and ensure the effect of seedling cultivation, the recycled seedling tray must be cleaned and disinfected. There are more and more researches on plug seedlings [9]-[11]. Driven by the current international seedling cultivation process standardization, automatic equipment in all links came into being, and "no landing" automatic production lines have been gradually formed through logistics and transportation equipment [12]-[14]. However, the equipment for seedling tray cleaning has not attracted enough attention, and the research and development of relevant equipment in China has just started [15], [16]. Therefore, in view of the coming era of comprehensive tray seedling cultivation, the market potential of automatic seedling tray cleaning equipment is huge. Combined with the idea of circulating water saving, the development of continuous on-line cleaning equipment for seedling tray is of great significance.

Figure 1. 72-point tray.

The traditional cleaning and disinfection method of seedling tray is to manually wash and remove the substrate, dry it in the air, soak it in bactericides such as 600 times diluted carbendazim, and then wash the disinfectant with clean water and dry it naturally [17], [18]. As one of the main links, manual cleaning to remove the substrate has high labor intensity and low efficiency, and it is easy to damage the seedling tray because it is difficult to grasp the brushing strength manually. At present, physical hydraulic flushing is recognized as the most scientific, economic and environmental protection method.

Visser company of the Netherlands [19] and Syspal company of the United States [20] have successively launched on-line hydraulic flushing equipment, which mainly carries out placement cleaning for the hard transfer frame buckle. Due to the coincidence of the transportation contact surface and the cleaning surface, there are problems of incomplete cleaning and low cleaning efficiency. For the seedling tray with deep groove and

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closed four sides, the cleaning effect is general, and it is easy to accumulate water. Urbinati company of Italy [21] also improved and launched the vertical on-line cleaning machine for standard seedling tray, which is used with ultraviolet sterilization equipment. The equipment has good cleaning and sterilization effect, but the water consumption is 16.7 m^3/h. The research and development of seedling tray cleaning equipment in China is still in its infancy. Sensitar and other domestic enterprises also produce buckle type cleaning equipment, but the promotion is limited mainly to hard transfer frames. The national agricultural intelligent equipment engineering technology research center also conducted a preliminary experimental study on the influencing factors of cleaning cleanliness with reference to the vertical on-line seedling tray cleaning machine [22], [23].

After comparing the current situation and problems of seedling tray cleaning equipment at home and abroad, a vertical cleaning equipment for seedling tray is designed. In this paper, the overall structure of the equipment is designed, the working principle is clarified, the key components are simulated and analyzed, the performance of the whole machine is tested, and the key parameters of cleaning and circulating water are obtained.

II. Overall Mechanism Design

A. Hardware of the Equipment

The seedling tray cleaning equipment includes circulating filter water tank, tray pushing system, circulating water jet washing - clean water flushing pipeline. The automatic cleaning equipment for seedling tray completes the automatic cleaning on the leaning trays through high-pressure jet, washing with clean water, dewatering and drying. Fig. 2 is a structural diagram of the seedling tray cleaning equipment.

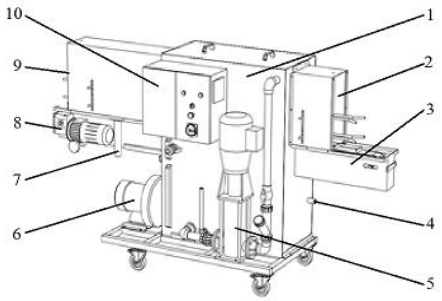


Figure 2. Structure of seedling tray cleaning equipment. 1-Circulating water tank, 2-Tray entrance, 3-Conveying mechanism, 4-Overflow port, 5-Main cleaning pump, 6-Air drying fan, 7-Air knife, 8-Conveying motor, 9-Tray exit, 10-Control box.

The circulating filter water tank is sealed internally and acts as a supporting frame for the overall equipment. The internal purification of circulating water is realized by setting a secondary filter structure. The tray pushing system is installed in the installation groove on the side wall of the water tank to make the tray pass through the tunnel formed by the circulating water jet washing - clean water flushing pipeline, so as to complete the two processes of circulating water jet washing and clean water flushing. The main technical parameters of the equipment are shown in Table I.

TABLE I. Main Technical Parameters of Washing Equipment

Evaluation Standards	Value
Dimensions(L×W×H)/mm	2746×780×1515
Main pump power/KW	2.2
Circulating water flow/ m^3/h	8
Washing water flow/ m^3/h	3
Cleaning pressure/MPa	>0.3
Circulating water tank volume/L	140
Conveying speed/ mm/s	91

B. Operating Principle

During the operation of the equipment, the worker puts the recovered trays after preliminary cleaning into the tray pushing system. The push plate in the tray push system pushes the tray into the jet washing tunnel. In the tunnel, firstly, through the circulating water jet area, the high-pressure nozzle jets circulating water on the surface of the tray to wash the residual substrate; secondly, through the clean water washing area, the 3 groups of opposed jet nozzles use external clean water to rinse the circulating water clean.

The circulating water tank is divided into upper and lower parts by the middle deflector, in which the upper part contains the cleaning pipeline and conveying system with nozzle. The water in the upper part is collected by the deflector and flows down from the spout. In addition, the lower part of the circulating water tank is divided into a primary filter chamber and a secondary filter chamber by a vertical diaphragm. The primary filter chamber is located below the spout, in which there is a horizontally placed and removable 80-mesh filter sieve for filtering large matrix particles such as seedling roots, perlite and sundries.

The circulating water after primary filtration flows into the primary filtration chamber for preliminary deposition. The water at the top is secondary filtered through the 120-mesh filter sieve on the vertical partition and overflows into the secondary filter chamber. The water pump connected to the secondary filter chamber sends the secondary filtered water to the jet cleaning pipeline through a 200-mesh Y-shaped filter, so as to realize water circulation. However, with the continuous introduction of impurities in the cleaning process, the circulating water quality will gradually become turbid.

In order to ensure the cleanliness of the seedling tray, a clean water flushing process is added to wash the seedling tray for the second time, so as to wash away the turbid circulating water. On the other hand, the clean water flushing process can also replenish the water in the circulating water tank and delay the turbidity in the water tank through the overall overflow, so as to ensure the cleaning effect of the seedling tray and the quality of circulating water.

C. Experiment Materials and Methods

The seedling tray equipment focuses on point tray with common specifications for seedling cultivation in my country. Taking into account the reusability of the tray, according to the seedling tray standard [24], [25], the experimental seedling tray is selected as 72-cavity

polystyrene with length×width×height 540×280×45mm, material thickness 0.8mm, and mass about 125g.

In the process of seedling cultivation, the substrate uses a mixture formula of conventional peat, vermiculite and perlite with a volume ratio of 3:1:1. After the seedlings are transplanted, the seedling tray is manually beaten 10 times to shake off the residual substrate in the tray as much as possible, and then the seedling tray is used as the tray to be cleaned.

The effect of seedling tray cleaning is mainly represented by the cleaning rate. The cleaning rate is expressed by the ratio of the number of holes without any solid particles remaining to the total number of holes after washing and drying.

III. Cleaning Pipeline Design

The main object of seedling tray cleaning is the substrate. The principle is to wash the substrate attached to the inner wall of the hole with high-pressure jet water. Therefore, the greater the water pressure, the greater the flow and the longer the cleaning time, the better the cleaning effect. However, due to material performance, cleaning area space and cleaning efficiency constraints, it is necessary to optimize the design of the nozzle and cleaning pipeline pump parameters.

A. Cleaning Pipeline Structure Experiment

Common stainless steel high-pressure cleaning nozzles are used for the cleaning pipeline. The nozzle diameters are 1.1mm, 1.6mm, 2.0mm, and the form is 65° sector, 110° sector, and solid cone. Set 4, 5 and 6 nozzles on each pipe for three factor and three level experiments, as shown in Table II and Fig. 3.

TABLE II. Cleaning Experiment Results

Serial Number	Nozzle form	Nozzle diameter	Number of Nozzle	cleaning rate
1	65° sector	1.1	4	94.2
2	65° sector	1.6	5	91.8
3	65° sector	2	6	89.2
4	110° sector	1.1	5	92.6
5	110° sector	1.6	6	84.4
6	110° sector	2	4	83.3
7	Cone	1.1	6	73.3
8	Cone	1.6	4	77.5
9	Cone	2	5	68.6
T1	275.2	260.1	255	
T2	260.3	253.7	253	T=754.9
T3	219.4	241.1	246.9	

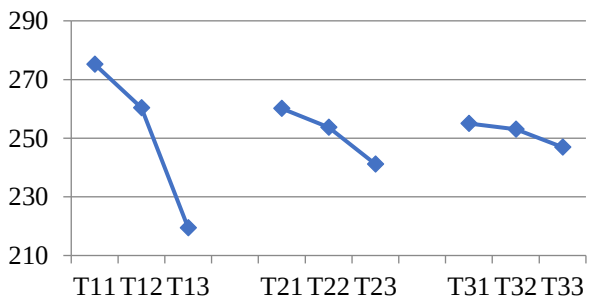


Figure 3. Three-factor influence curve.

From the above experiment results and range analysis, it can be seen that when the nozzle with a diameter of 1.1mm, a jet shape of 65° fan and a cleaning pipeline with a number of nozzles of 3×4 are selected, the cleaning degree of the seedling tray is the highest and the cleaning effect is the best. The number and form of nozzles have the most significant influence on the cleaning effect.

B. Simulation of Cleaning Pipeline Based on PIPENET

After determining the nozzle layout, it is necessary to select the water pump and design the pipeline for the cleaning pipeline. The water source from the water tank is pressurized by the multi-stage centrifugal water pump and then enters the cleaning pipeline. The cleaning pipe is composed of 3 pairs of vertically installed jet pipelines and 1 pair of flush pipeline. The jet area on the jet pipeline is 280mm wide, and 3~6 nozzles can be installed. After high-pressure jet washing, it is flushed with clean water. The cleaning pipeline structure is shown in Fig. 4.

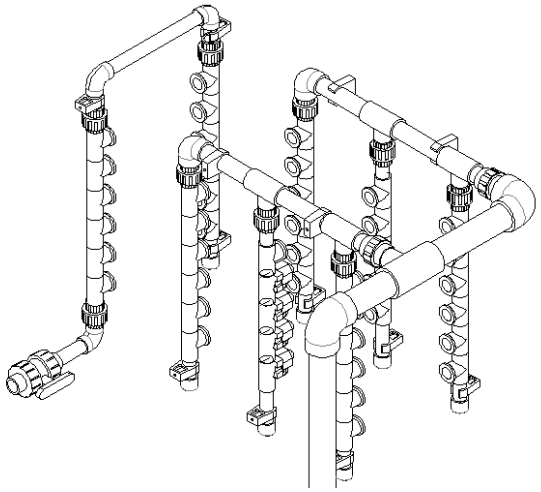
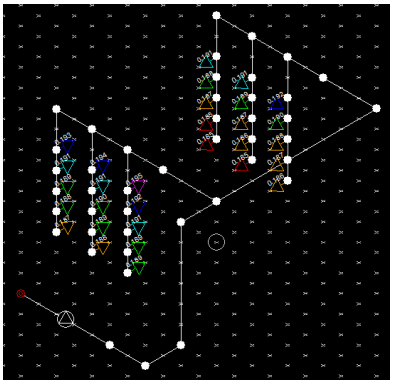


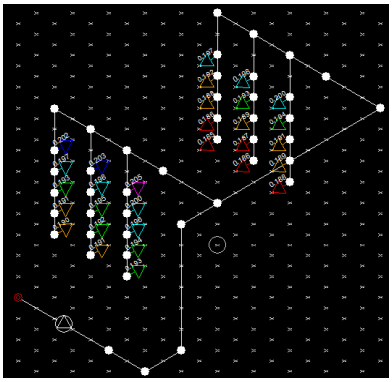
Figure 4. Pipeline structure of cleaning flushing.

In order to meet the uniformity of tray cleaning in the horizontal and vertical directions, quickly determine the pump and nozzle parameters, pipeline diameter and layout, the pipeline is modeled and simulated based on PIPENET software, as shown in Fig. 5.

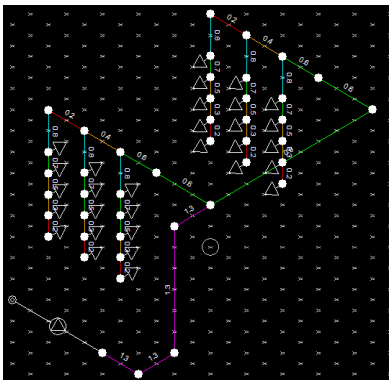
It can be seen from the simulation that the pump parameters can reach the jet conditions of nozzle pressure of 0.31MPa and more than 0.3MPa when the rated pressure is 0.58mpa and the rated flow is 8m^3/h.



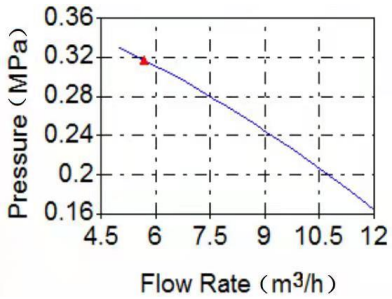
(a) Nozzle flow



(b) Nozzle pressure



(c) Pipeline flow rate



(d) Pump operating parameters

Figure 5. Simulation results based on PIPENET.

C. Conveyor System Operation Speed Experiment

In order to ensure the operating efficiency of the equipment and increase the operating speed of the conveying system, the maximum speed of the conveying operation of the equipment is verified when the cleaning rate of the tray exceeds 95%. The cleaning rate was measured under the conditions of different conveying system operating speeds, and 10 seedling trays were cleaned in each group of experiments. The experiment results are shown in Table III.

TABLE III. EXPERIMENT RESULTS OF DIFFERENT CONVEYING SPEEDS

Serial number	1	2	3	4	5	6
Convey speed mm/s	61	75	83	91	98	104
Number of impurity holes	23	30	31	34	42	57
Cleaning rate (%)	96.8	95.8	95.7	95.3	94.2	92.1

The experiment results show that when the speed of the conveying system is 91mm/s, the 10 seedling tray used in the experiment can reach a cleaning rate of 95.28%.

IV. CIRCULATING WATER SUPPLY DESIGN

A. Principle of Circulating Water Supply Balance

Fig. 6 shows the internal structure of the circulating water tank. Due to the external overflow port in the water tank, the liquid level remains below the overflow port during operation, and the liquid level is dynamically stable. The system inlet water flow is equal to the clean water flushing flow and at the same time equal to the overflow outlet drainage flow. The impurities in the circulating water come from the substrate brought in by the cleaning tray. Impurities are filtered out through the primary filter, the secondary overflow filter, and the tertiary Y-type filter. After entering the system, the substrate will float on the water surface of the primary filter tank. In order to run continuously for as long as possible, while ensuring the stability of the dynamic liquid level of the water tank, the liquid flowing out of the overflow port should be taken away as far as possible into the system to ensure the cleaning effect of the seedling tray and the quality of the circulating water. The filtration system can completely screen out seedling roots, perlite and large-particle matrix impurities. The overflow part of the circulating water tank is the circulating water in the primary filter tank.

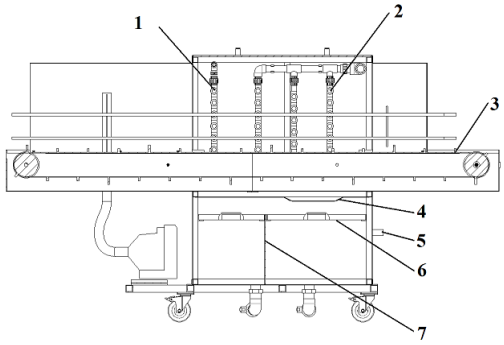


Figure 6. Internal structure of circulating water tank. 1-Flushing pipeline, 2-Jet washing pipeline, 3-Tray conveyor belt, 4-Deflector, 5-Overflow port, 6-Horizontal filter, 7-Vertical filter.

B. Circulating Water Quality Balance Analysis

Analyze the matrix components after the seedling cultivation. The residual substrates of 10 seedling trays were manually taken out. After the substrates were dried, the average residual substrate mass of the trays was 24.6g. The reclaimed substrates are dried on drying sieves of different meshes. After 1 kg of the matrix is rubbed and loosened, it is separated successively with 50-mesh, 60-mesh, 80-mesh, 120-mesh, 150-mesh, and 200-mesh sieves. The results are shown in Table IV.

TABLE IV. QUALITY OF SEPARATED SUBSTRATE WITH DIFFERENT SIEVE

Sieve /Mesh	50	60	80	120	150
Screening quality /g	529	187	146	70	31
Quality through /g	471	284	138	68	37

It can be seen that the 80-mesh filter has a filtration density of 86.2%. Therefore, the theoretical mass of the primary filter screen with 80-mesh stainless steel filter screen passing through the substrate per hour is 1.75kg. The theoretical residual matrix mass of the secondary overflow filter with 120-mesh stainless steel filter is 0.88kg. The dry density of the substrate is about 1.7g/cm^3. The stability of the turbidity of the solution in the dynamic circulating water tank can be supplied with clean water at a flow rate of 3m^3/h.

C. Flushing Pipeline Parameter Optimization Experiment

In order to ensure the subsequent disinfection effect, it is necessary to wash the seedling tray after high-pressure spraying with circulating water, so as to remove the substrates particle impurities contained in the circulating water on the seedling tray. According to the above analysis, in order to meet the dynamic stability of water quality, the cleaning flow should be more than 3m^3/h.

In order to determine the flushing effect of clean water, a cleaning experiment with flushing amount as the objective function is designed. The width of the seedling tray is 280mm, limited by space, the number of nozzles is 3, 4, 5, and 6. The nozzle form adopts a solid cone nozzle, and the nozzle diameter is 2mm and 2.2mm for two-factor full array experiment. First, measure the quality of the seedling tray. Secondly, after washing with clean water, let it stand for 10 minutes, and measure the quality of the seedling tray again to detect the quality of the substrate removed by washing. The experiment results are shown in Table V.

TABLE V. EXPERIMENT RESULTS OF FLUSHING WITH CLEAN WATER

Serial number	Number of nozzles	Nozzle of diameter	Quality of removal
1	3	2mm	37g
2	4	2mm	38g
3	5	2mm	43g
4	6	2mm	51g
5	3	2.4mm	26g
6	4	2.4mm	43g
7	5	2.4mm	28g
8	6	2.4mm	25g

According to the experimental results, the clean water flushing pipeline has determined to set 6 nozzles to increase the water spray per unit area, which can achieve a better flushing effect. However, as the nozzle diameter increases, the impact pressure decreases, and the agglomerated substrate in the seedling tray cannot be washed away, resulting in less removal quality.

V. CONCLUSION

1) Through research on equipment performance, it is determined that under the condition of 8m^3/h, 0.58MPa water pump, the maximum nozzle pipeline pressure of 0.31MPa can be achieved by selecting nozzles with an inner diameter of 1.1mm and a spray angle of 65°, and a 3×4 array arrangement. When the conveying speed is 91mm/s, the cleaning rate reaches 95.28%.

2) When the flushing water flow is greater than 3 m^3/h, the 80-mesh first-level horizontal filter and 120-mesh second-level overflow filter cooperate to filter the water, which can keep the cleaning water level stable and good water quality.

3) This design effectively improves the efficiency of the seedling tray cleaning link, and meets the need for repeated use and cleaning of the seedling tray.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Kai Li conducted the research; Yilei Yin and Yong Hou built a prototype of the device; Kai Li and Xiaopeng Du wrote the paper; all authors had approved the final version.

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Kai Li was born in Taiyuan, Shanxi Province, China in May 1986. He received the B.S. degree in agricultural mechanization and automation from Northeast Agricultural University, Harbin, China in 2010 and the Ph.D. degree in agricultural mechanization engineering from South China Agricultural University, Guangzhou, China in 2015.
He worked as a senior engineer at Academy of Agricultural Planning and Engineering, MARA for 6 years. His research interests include horticultural automatic operation equipment, agricultural robot, greenhouse environment control. Dr. Li is a member of the Chinese society of agricultural engineering.