Research on High Pressure Fine Mist Cultivation Equipment

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Abstract. Most of the existing aerosol cultivation equipments are bulky, simple-structured and poor in functional stability. Based on this, the author developed a set of automatic control high-pressure fine mist cultivation device, designed the PLC automatic control circuit, and simulated and tested the temperature and humidity change curves. The test results verify the simulation model and the overall device runs well, among which the spray atomization process, and the temperature field, humidity field and velocity field under three atomization modes are simulated. Three atomization schemes are analyzed, and in the end the optimal one is selected. In comparison, the side-by-side spray is completely covered; the atomization is more sufficient. The results show that the time when the humidity reaches 90% in the same position is different under different initial humidity conditions. The atomization humidity maintenance time in different environments is approximately the same, and can be maintained for 4 to 5 hours. It can be seen from the comparison of the results that the greater the humidity, the shorter the heat exchange time and the faster the heat exchange.

Keywords: Aerosol cultivation; High pressure fine mist; Structural design; Control design; Atomization simulation; Experimental study

1. Introduction
Population, resources and environment are the major issues of international concern today. As the most widely distributed substance on our planet, water resources occupy an essential position among natural resources. The most important water resource is fresh water. However, with current technology, it is impossible to extract seawater in a cost-effective manner, so fresh water resources are very valuable [1-4].

Due to the uneven distribution and timing of precipitation, China is a country with water shortage. More than 80 percent of water resources gathered in the southeast of China, while only 35 percent of the land is arable there. In contrast, northern China occupies less than 20 percent of national water resources but possesses 65 percent of the arable land [5-7]. In addition, the traditional cultivation mode has some shortcomings: too much pesticides but less efficiency. A huge amount of pesticide residue enters the soil through water and becomes part of the food chain. Therefore, the problems of crop water use, pesticide use and land use efficiency must be solved.

With the development of science and technology, the emergence of new cultivation techniques has changed the farming mode of traditional agriculture. Soilless cultivation leads to high yield and good quality products, which can avoid the drawbacks of soil continuous cropping and greatly expand the agricultural production space.

Aerosol cultivation originated in Italy, mainly used to grow vegetables. In 1988, Peterson designed a set of intermittent aerosol device. This device can spray at a frequency of 10 minutes, a single
injection of 7s, a nozzle flow of 1.3mL/s, and operates stable for 32 weeks. In 2004, Utah State University used a rectangular device with a width of 60 cm and a length of 450 cm to arrange four rows of nozzles, with ten in each row and nozzles spaced at 20 cm apart. Using a periodic spray, the experimental device finds the best method for nodulation and nitrogen fixation in actinomycetes, which accurately controlling the gas phase distribution around the roots and nodules of the plant [8]. In 2012, the University of California conducted a study on aerosol cultivation of lettuce. The results showed that in the aerosol cultivation of lettuce, applying more concentrated nutrient solution at night can reduce the accumulation of mineral elements in the leaves without reducing leaf yield [9]. Comparing the advantages and disadvantages of different cultivation methods in modern agricultural production, Xu Weizhong proposed environmental control of plant roots to achieve the goal of high yield and high quality. It provides an idea for the establishment of the aerosol cultivation system, and can help realize the stable control of the plant root environment through the coordination with the computer. Although no specific cultivation device and control device have been designed, a theoretical basis for the establishment of plant factories in the future has been made.

In summary, the system design of aerosol cultivation devices at home and abroad is not thorough enough. It is still in the exploration stage to provide an appropriate environment for plant roots. Although there are many theories and patents on aerosol cultivation devices in China, there are few all-sided experimental devices designed. Most of the designed devices are intermittently atomized by electronic timers, which obviously do not satisfy the growth need of plants. Based on this, this paper develops a set of aerosol cultivation equipment, which can achieve sufficient atomization, good diffusing effect, automatic temperature and humidity adjustment. At the same time, it can meet the temperature and humidity requirements of different plant roots, and has the advantages of high yield, high quality and no pollution.

2. Overall Design of Cultivation Equipment

2.1. Nutrient Solution Supply System

The high-pressure fine mist cultivation equipment system can be generally divided into two parts: peripheral test equipment and test bench. The peripheral testing equipment mainly includes a nutrient solution supply system, a data acquisition system and a control system. The high-pressure fine mist cultivation device test bench mainly includes a cultivation system and a nutrient solution recovery pipeline, and its main components includes base, cultivation tube, nozzles, temperature and humidity sensor, and recovery pipe, etc. The nutrient solution supply system is powered by a high-pressure pumping station with a rated working pressure of 16MPa and a rated speed of 1500 r/min. The nozzle adopts Danfoss' fine water mist nozzle, and the atomization flow rate is 2.5L/min at 6MPa. The sensor uses a temperature and humidity sensor and a PT100 temperature sensor.

The atomization cultivation scheme is shown in figure 1. There are three preliminary atomization schemes. As shown in figure 1(a), a single nozzle is placed on the left side O of the cultivation tube, which is one-sided atomization. As shown in figure 1(b), a single nozzle is placed on the left side O and the right side O’ of the cultivation tube respectively, which is double-sided atomization. As shown in figure 1(c), five nozzles are placed at positions G, H, I, J, and K below the axis of the cultivation tube, which are intermediate side-by-side atomization, and figure 1(d) is a three-dimensional model thereof. Subsequent simulation and experimental studies will be carried out on the three atomization schemes.
2.2. Automatic Control System

As shown in figure 2, the automatic control system adopts S7-200 smart programmable logic controller. The temperature and humidity sensor SHT20 can output 0-10V voltage signal or 4-20mA current signal. The PT100 can output the signal into corresponding voltage or current signal by connecting with the temperature transmitter module. After receiving voltage or current signals, the S7-200 smart determines whether the temperature and humidity of the cultivation tube are appropriate or the temperature of the liquid storage tank needs to be heated. Thus, the S7-200 smart can be used to control each actuator, adjust the temperature and humidity of the cultivation tube, and provide an appropriate temperature and humidity for the cultivation environment.

Figure 3 is a PLC control flow chart. After the system starts working, the program is initialized first, and then the appropriate temperature and humidity are set according to different plants at different periods, so that the plant roots are in an appropriate temperature and humidity range. Then, the temperature and humidity of the cultivation tube and the temperature of the liquid storage tank will be detected. It needs to be certified that whether the cultivation tube’s and the liquid storage tank’s figures are within the set range. If the temperature in the liquid storage tank is within the set range, the spray atomization will be carried out directly. If not, the heating device will be automatically turned on until the measured temperature reaches the set one. After the heating is stopped, the spray atomization will be turned on. When the temperature and humidity in the cultivation tube reach the set range, the spray atomization will end.

Figure 1. Atomization scheme of cultivation tube.

Figure 2. Temperature and Humidity Control System.
3. The Atomization Simulation

3.1. Results of One-Sided and Double-Sided Atomization
In the existing CFD simulation software, the initial and secondary atomization of spray atomization cannot be simulated at the same time. The discrete phase model simulates the results of secondary atomization, which can satisfy the research need on the temperature and humidity changes in the cultivation tube. Therefore, the Discrete Phase Model (DPM) in CFD software was used to simulate the unsteady coupling of the continuous and the discrete phase for the atomization characteristics of the nozzle with the injection pressure $P=6\text{MPa}$. The simulation results of one-sided and double-sided atomization are shown in figures 4 and 5. As can be seen from the figures, the atomization blind spots exist in both one-sided and double-sided atomization.
Five nozzles are arranged in intermediate side-by-side atomization, and their positions are G (0, 157, -25), H (0, 457, -25), I (0, 757, -25), J (0, 1057, -25), K (0, 1357, -25). The ambient temperature is 295K with air humidity of 43%. The atomization medium was water, the temperature was 291 K, and the particle spray cone angle was 60°. The mass flow rate of each injection source was 0.04175 kg/s. In the Y-axis direction, each nozzle is separated by 300, and under such conditions, an unsteady state simulation is carried out. The flow field characteristics of the atomization process, temperature field and humidity field of the side-by-side spray will be analyzed below.

Figure 6 shows the process of liquid atomization. Obviously, it can be found that at 400ms, the atomized particles gradually spread to the periphery and reached the lower wall. At 800ms, the diffusion phenomenon became more obvious.

Figure 7 shows the temperature diagram of intermediate side-by-side atomization. At 0.1s, the temperature at the center axis of the nozzle is the lowest and it is 291K. The temperatures on both sides of the central axis are symmetrically distributed along the axis and diffuse from a circular shape to an elliptical one. As the atomization advances, the temperature inside the cultivation tube has been significantly reduced. At the two sides of the area of the nozzle along the central axis, the blue low temperature area has spread and its distribution is relatively uniform. The cooling effect is relatively obvious, and the temperature drop near the pipe wall is also obvious.
In the post-processing software, the temperature distributions of four locations (0, 150, 25) (0, 200, 25) (0, 250, 25) (0, 300, 25) were selected for analysis. As shown in figure 8, the point of coordinates (0, 150, 25) is closest to the axis of the nozzle. It can be seen that the temperature here is reduced to 291K in 20s. The points at positions (0, 200, 25) (0, 250, 25) (0, 300, 25) are equally spaced from the nozzle, and the gradient of cooling is also gradually reduced. At 240 s, the Y-axis coordinates 150, 200, 250 are almost close to the spray temperature. Only the point 300’s (on Y-axis) temperature is about 291.5K.

Figure 7. X=0 section, temperature profile at different times.

Figure 8. Temperature distribution curve at different positions in the X=0 plane.
As can be seen from figure 9, the relative humidity of the air above the nozzle is the largest. After leaving the nozzle, the liquid immediately atomizes into droplets and spreads around. Obviously, the moisture content of the central axis is higher, and the relative humidity is above 90%. However, the relative humidity of air away from the axis of nozzle changes little and slowly.

![Humidity Profile](image)

(a) 0-150s Humidity Profile  
(b) 150-240s Humidity Profile

**Figure 9.** X=0 section, humidity profile at different times.

Figure 10 is a humidity distribution curve, and it can be seen that as the atomization time increases, the humidity at each point also gradually increases. However, the humidity change rate at different locations is not the same. After 240s of atomization, the humidity at the point (0,300,25), which is far from the nozzle, also reaches 90%, while the humidity at other places is close to 100%.

![Humidity Distribution Curve](image)

**Figure 10.** Humidity distribution curve at different positions in the X=0 plane.

### 4. Conclusion

Combined with the characteristics of aerosol cultivation, this paper developed a set of high-pressure fine mist cultivation equipment. A high-pressure nozzle with small flow and sufficient atomization was selected. It is not easy to block under high pressure and has a long service life. Meanwhile, an automatic control system was designed, which can set different temperature and humidity according to different plants and different growth periods. The main research contents and conclusions are as follows:

1. The research introduces aerosol cultivation devices at home and abroad and the unique advantages of aerosol cultivation. A set of intelligent high-pressure fine mist cultivation equipment was designed. From the aspects of the design of nutrient solution supply system and software design and algorithm, the general design idea of high pressure fine mist cultivation equipment was introduced.
(2) Secondly, the geometric model, mesh model, physical calculation model and CFD model of atomization are established. The numerical simulation of spray atomization involves two-phase flow and coupling between discrete and continuous phases. Unsteady-state tracking calculations were performed on discrete phase particles by unsteady calculation. In addition, the parameters of the nozzle, the fluid motion mode and the air humidity were calculated.

(3) The spray atomization process and the temperature field, humidity field and velocity field under three atomization modes are studied through the unsteady coupling calculation of discrete phase and continuous phase. The simulation results show that the atomization area of the one-side spray and the double-side spray is not large enough; the atomization is not enough, and the middle part of the cultivation tube has different degrees of non-atomization area. In comparison, the side-by-side spray’s atomization area is completely covered, and its atomization is more sufficient.

(4) A test bench for a high-pressure fine mist cultivation device was built and an experimental research was conducted. When the initial temperature is close, it can be found that the greater the humidity is, the shorter the heat exchange time and the faster the heat transfer is.

Acknowledgements
The authors would like to thank the anonymous reviewers for their insightful comments and suggestions that have helped to improve the presentation of this article. This research was partly funded by the Key Research and Development Plan of Shandong Province of China (2017GGX30106); the Natural Science Foundation of Shandong Province of China (ZR2018ME023); the Science and Technology on Underwater Vehicle Technology Research Fund (SXJQR2017KFJJ04); the National Natural Science Foundation of China (51475197, 51275495, 51708528); and the National College Student Innovation and Entrepreneurship Training Program.

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