VIRTUAL SIMULATION AND ANALYSIS OF THE ABSORBING PROPERTIES OF SUCTION NOZZLE OF AIR-SUCTION PEANUT DIBBLER

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The absorbing seed performance of the suction hole was researched by the method of the computational fluid dynamics. Using the Fluent analysis software, it was built on the finite element model of the suction hole, then it was analyzed the absorbing effect of the suction nozzle shape, and a reasonable shape of the suction hole was determined. Through the numerical simulation orthogonal test of the airflow field of the suction hole, the influence on the vacuum pressure, nozzle diameter and nozzle length of the suction hole to the effect of adsorbed peanut seeds was analyzed. The simulation test results show that the parameters affecting the absorbing performance are vacuum pressure > nozzle diameter > nozzle length; when the outlet of the suction hole has a tapered shape, the absorbing effect to peanut seeds was the best; the bigger vacuum pressure and nozzle diameter of the suction hole, the better absorbing seed performance is; the influence of nozzle length to absorbing seed performance is related to the nozzle diameter of the suction hole. The results provide basis and reference for the optimum design of the seed-metering device structure parameters of the air-suction peanut dibbler.

Key words： Air-suction Seeder, Peanut, Suction hole, Air Field, Simulation Testing

1. Introduction

Air suction seeding device has many advantages: the device has no strict requirements to the seed size, produces no seed damage, is a simple solution for single grain precise seeding, has good versatility, and is suitable for high speed seeding. Therefore it has been widely used in precision seeding operation [1]. At present, the research on the structure and performance of seed metering device of air suction seeder is focused on the corn, wheat, rape and vegetable seeds, and there is no systematic theoretical study on Peanut air suction and precision seeding [2-9]. The seed-metering plate of the air suction seeding device is the key

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component to using of the precise absorbing seeds. The effect of absorbing peanut seed was determined by the structure and parameters of the suction hole on seed-metering plate. The traditional theory and physical test methods are difficult to analyze the absorbability of the suction hole, which are consuming time and laborious, and the data error is not intuitive. Relevant literature can be seen [10-21]: with the rapid development of computer technology, the software of the simulation analysis was used for numerical calculation and image display by established seed in the kinematics, dynamics equation in the process of absorbing seeds, the process of absorbing seeds was quantitatively described by the established equation, therefore the method was widely used in the field of agricultural technology. Based on the development of air suction seed-metering plate as the research object, using FLUENT software to analyze the influence of the shape, aperture, guide and hole spacing on the suction performance of the suction hole. It provides theoretical basis and method for rational selection and optimization of structural parameters in the design of the air-sucking peanut precision dibbler.

2. The Size of Peanut Seed

The structure and shape parameters of the suction hole are related to the shape and size of the peanut seed. When the seed is adsorbed, its upright posture is more conducive to accurate adsorption. Therefore, the shape and size of suction hole are mainly limited by the width and thickness of seeds. The thickness of the peanut seed is measured in the thickness of the two cotyledons, and the width of the ovum is the width of the seed, as shown in Fig. 1. In this paper, the species of Chinese peanut producing areas, such as Haihua, Luhua 11, Baisha (big) and Silihong were used as experiments. The peanut seeds were selected at random selection of different varieties, and 50 granules were selected for each variety. The width and thickness of the seeds were measured.

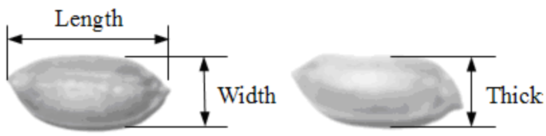


Fig. 1 Geometric size of peanut seeds

The test result shows that the width and thickness of peanut seeds normally distributed. Haihua mainly concentrated in 7.98 ~ 11.92 mm, 7.50 ~ 9.60 mm, Luhua 11 mainly concentrated in the 8.56 ~ 11.76 mm, 7.76 ~ 9.52 mm, Baihua (big) mainly concentrated in the 8.70 ~ 10.98 mm, 7.56 ~ 9.56 mm, Silihong mainly concentrated in the 6.94 ~ 9.04 mm, 6.90 ~ 8.68 mm.

3. Established of the Simulation Model of Suction Hole Airflow Field

3.1 The Initializes the Conditions of the Simulation Model

The assumption condition of the simulation model of the airflow field is presented [21-23]: (1) the fluid is been assumed to be the ideal gas, that is constant, continuous and incompressible; (2) The airflow speed of the inlet of suction seed hole is uniform and the vacuum pressure of the outlet of the gas chamber is constant; (3) No slip boundary conditions are applied on all walls in the gas chamber. The condition of simulation test is: temperature is normal temperature (20℃) and adiabatic, the fluid is air (density is 1.205 kg/m^3, viscosity is 1.83×10^{-5} Pa.s), and Reference atmosphere pressure is 1.01×10^{5} Pa.

3.2 The Fluid Computing Model

The calculating of the physical model of suction seed hole is established with the gambit. First, the corresponding grid division and setting boundary type are carried out, then the physical model is imported the fluent solver to simulate analysis. The modeling process of airflow field of suction hole is shown in Fig. 2.

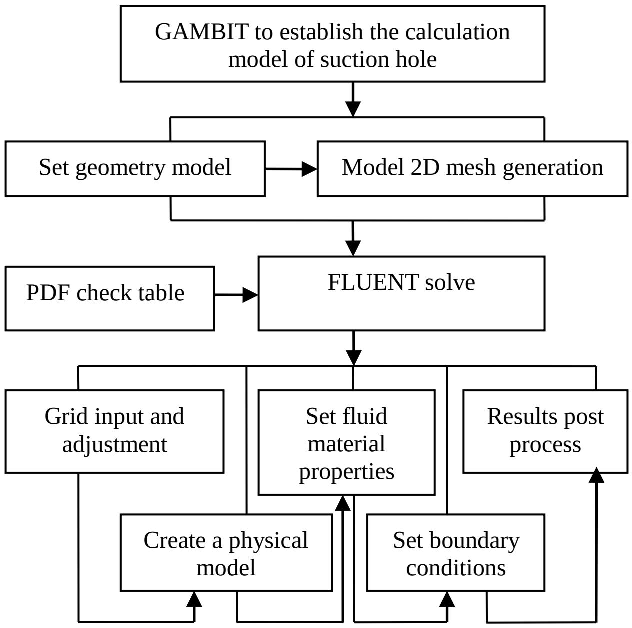


Fig.2 The flow chart of simulation analysis modeling of airflow field of suction hole

In the simulation model, the airflow inlet of suction seed hole is defined as the input, the airflow outlet of suction seed hole is the output, and the rest parts are defined as the wall surface. The input and output are defined as the opening boundary. According to actual work needs, the initial value of input pressure is determined as 5.65 kPa, and the initial value of output pressure is determined as 0 kPa. The standard K - epsilon turbulence model is selected, and the property of the fluid is defined as air. As shown in Figure 3, when the nozzle diameter is 5.0 mm, the airflow distribution situation of the suction seed hole is simulated.

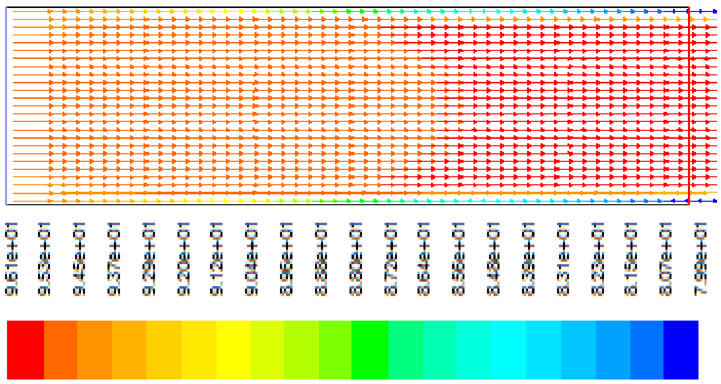
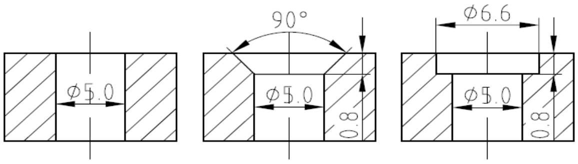


Fig. 3 The simulation analysis result of airflow field of suction hole

4. Simulation Test and Result Analysis

4.1 Effects of the Shape of the Suction Hole

The shapes of suction seed hole are usually used: straight hole, inlet is sink hole, inlet is taper hole, outlet is taper hole, and outlet is sink hole. The structure sizes of suction hole are determined according to shape and size of peanut seed, as shown in Figure 4. The simulation results are shown in Figure 5. The simulation result has shown that: the average airflow speed and maximum speed of straight hole is 110.34 m/s. When the inlet of suction hole is sink hole, the average airflow speed is 72.61m/s, and maximum airflow speed is 94.61m/s. When the inlet of suction hole is taper hole, the average airflow speed is 91.24m/s, the maximum airflow speed is 128.79m/s. When the outlet of suction hole is sink hole, the average airflow speed is 126.12 m/s, and maximum airflow speed is 128.35 m/s. When the outlet of suction hole is taper hole, the average airflow speed is 182.67 m/s, the maximum airflow speed is 184.83m/s. When the outlet of suction hole is taper hole, the airflow speed of the inlet of suction hole is the highest and suction seed ability is the strongest.



(a) Straight hole (b) Taper hole (c) Sink hole

Fig.4 Different type of suction hole

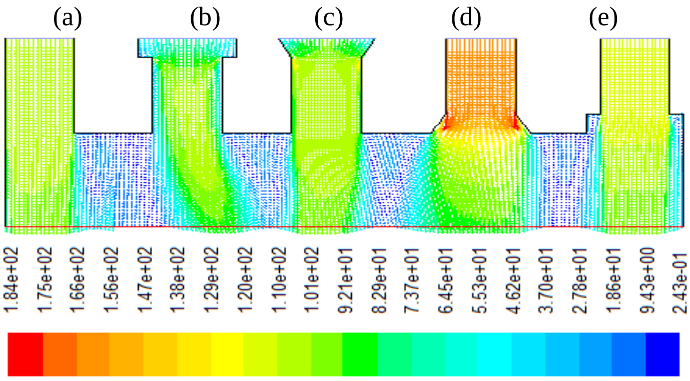


Fig.5 Speed field of different types nozzle

4.2 Influence of the Structure Parameters of the Suction Hole

4.2.1 Test Design

The nozzle diameter A, vacuum pressure B and nozzle length C is selected as the test factors, and the average airflow speed of suction hole is as the test index. The values of nozzle diameter, vacuum pressure and nozzle length are determined according to the relevant experiential parameters of peanut precision planter and the size range of peanut seeds. In the experiment, the simulation model parameters are changed according to different levels of factors, and the corresponding numerical simulation is performed. Chosen the $L_{27}(3^3)$to arrange test [24,25]. The test factors levels are shown in table 1. The design scheme and simulation results are shown in table 2.

Table 1.

Factors and levels

Level	Factors		
	Nozzle diameter/(mm)	Vacuum pressure/(kPa)	Nozzle length/(mm)
1	4.0	5	5
2	5.0	7	10
3	6.0	9	15

Table 2.

Test scheme and numerical simulation results

NO.	Test factors			Airflow speed of nozzle $(m.s^{-1})$	NO.	Test factors			Airflow speed of nozzle $(m.s^{-1})$
	A	*B*	*C*			*A*	*B*	*C*	
1	1	1	1	90.62	15	2	2	3	100.44
2	1	1	2	90.48	16	2	3	1	122.61
3	1	1	3	90.15	17	2	3	2	116.27
4	1	2	1	107.05	18	2	3	3	112.72
5	1	2	2	106.93	19	3	1	1	93.37
6	1	2	3	106.64	20	3	1	2	92.64
7	1	3	1	122.11	21	3	1	3	90.42
8	1	3	2	121.98	22	3	2	1	110.37
9	1	3	3	121.43	23	3	2	2	109.79
10	2	1	1	91.24	24	3	2	3	106.42
11	2	1	2	86.27	25	3	3	1	125.48
12	2	1	3	84.45	26	3	3	2	125.13
13	2	2	1	108.13	27	3	3	3	120.92
14	2	2	2	104.84					

4.2.2 Results Analysis

The simulation test results was be processed by the statistical analysis software SPSS. The statistical results of the test data are shown in table 3. The results of variance analysis are shown in Table 4. The distributions of airflow fields of suction holes in different conditions are shown in Figures 6, 7 and 8.

Table 3.

The result of range analysis

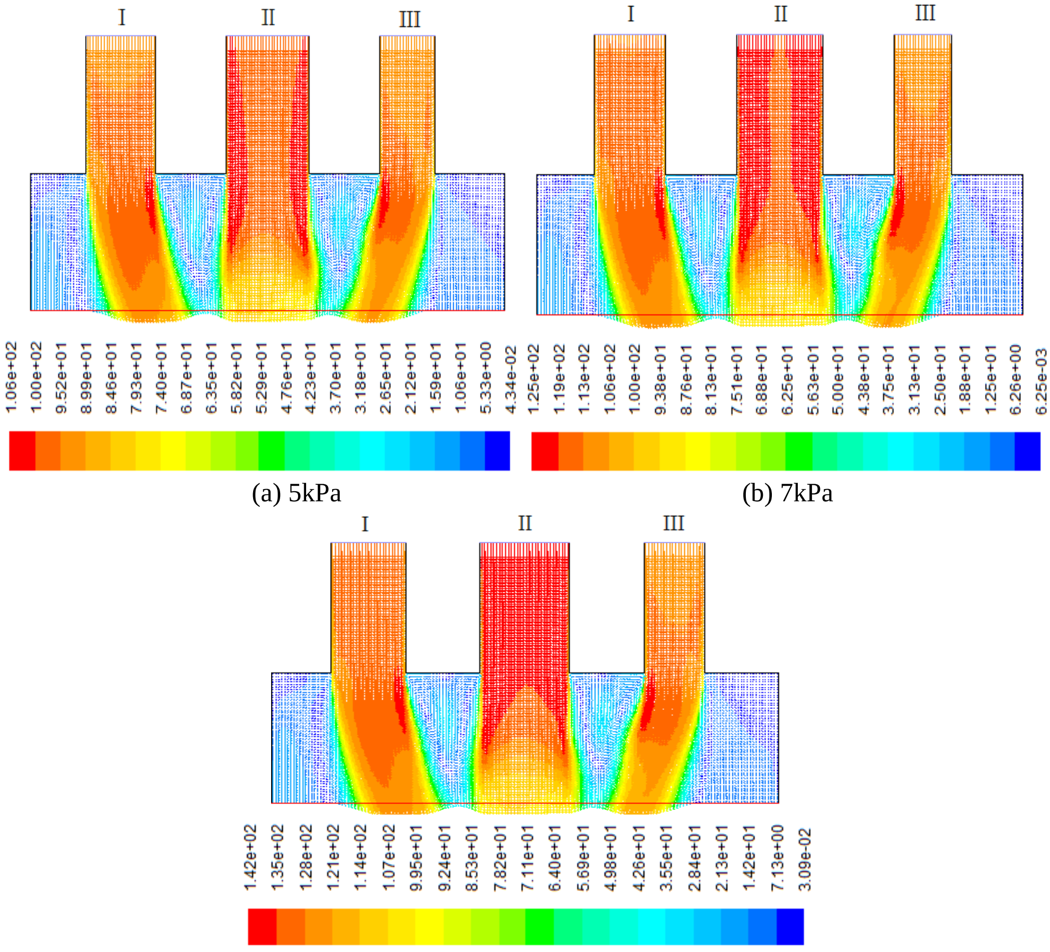
Index	Nozzle diameter	Vacuum pressure	Nozzle length
Mean Square	13.30	13.30	13.30
Mean1	106.38	89.96	107.89
Mean2	102.99	106.73	106.04
Mean3	108.28	120.96	103.73
Range	5.29	31.00	4.16

Table 4.

The result of variance analysis

Source	Sum of Squares	Mean Square	F	Sig.
A	128.978	64.489	21.713	.000
B	4334.547	2167.273	729.716	.000
C	77.977	38.989	13.127	.000
Error	59.400	2.970		
Total	307316.058			

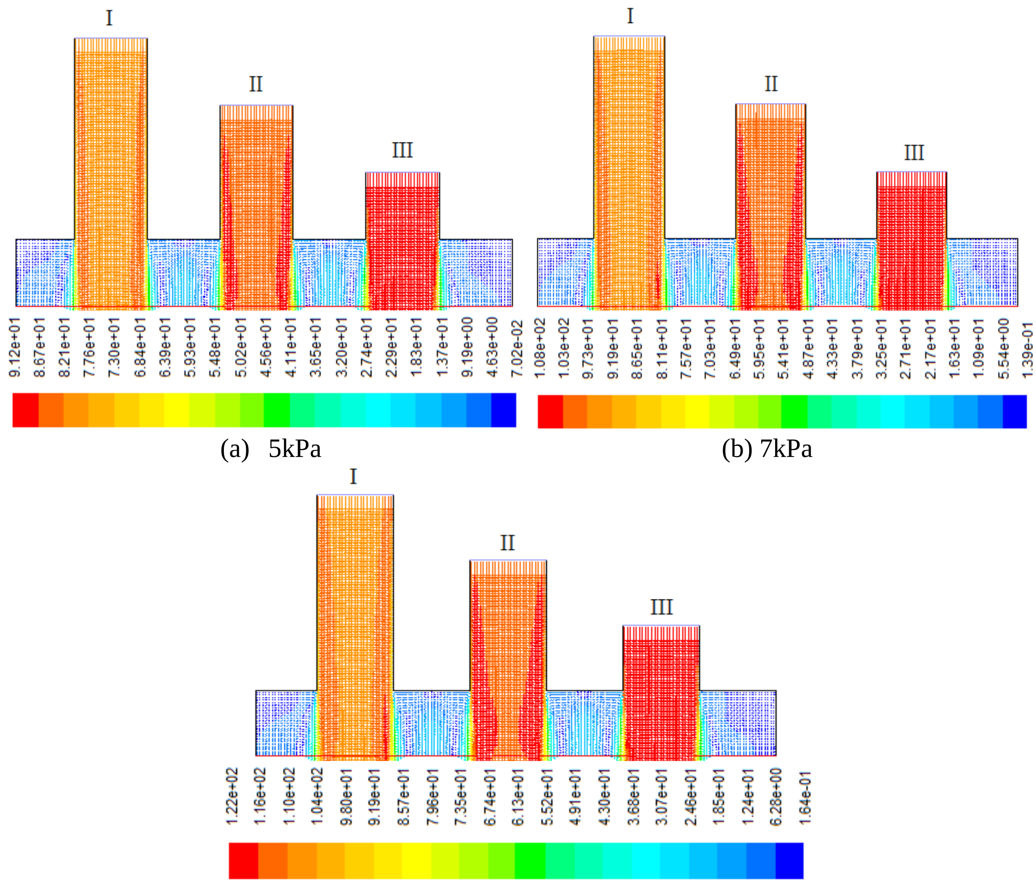
a. R-squared = 0.987(adjusted R-squared = 0.983)



(a) 5kPa (b) 7kPa

(c) 9kPa

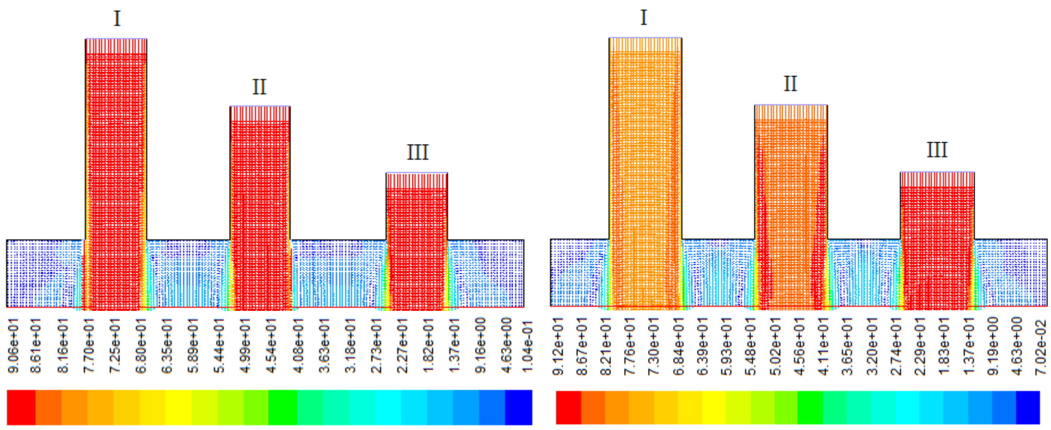
Fig.6 Effect of nozzle diameter to speed field under different vacuum pressure
(The nozzle length is 5mm)
I: nozzle diameter 5.0mm; II: nozzle diameter 6.0mm; III: Nozzle diameter 4.0mm



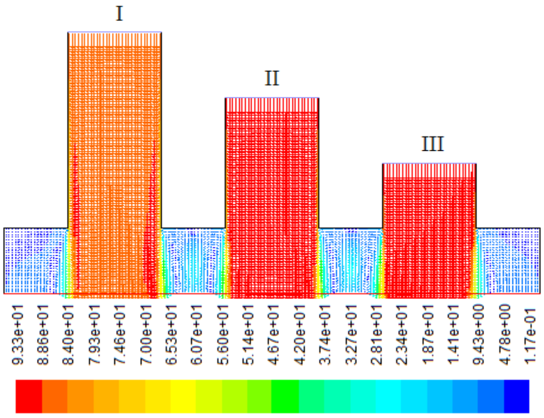
(a) 5kPa (b) 7kPa

(c) 9kPa

Fig.7 Effect of nozzle length to speed field under different vacuum pressure
(The nozzle diameter is 5mm)
I: nozzle length 15mm; II: nozzle length 10mm; III: Nozzle length 5mm



(a) 4.0mm (b) 5.0mm



(c) 6.0mm

Fig.8 Effect of nozzle length to speed field under different nozzle diameter
(The vacuum pressure is 5kPa)
I: nozzle length 15mm; II: nozzle length 10mm; III: Nozzle length 5mm

Test results can be seen: the sequence of the factors affecting to the adsorbed seed performance are vacuum pressure > nozzle diameter > nozzle length, and vacuum pressure, nozzle diameter and nozzle length have remarkable influence to adsorbed seed performance of the suction hole. Under the same conditions, with the increase of vacuum pressure, the airflow speed of suction hole is increased, the adsorbed seed performance of the suction hole is improved, and the airflow speed and flow rate are increased. Under the same nozzle radius, the higher the airflow speed at the center of the suction hole is, the stronger the adsorbed seed ability, so the bigger the nozzle diameter is, the better the adsorbed seed performance is. When the nozzle length is less than 5.0mm, the nozzle length has almost no influence to airflow speed of the outlet, only can be stabilized to airflow. When the nozzle length is greater than 5.0mm, the airflow speed of the outlet is reduced with the increase of nozzle length.

As shown in fig.6, 7, 8, the simulation results show that: When the nozzle length is same, the adsorbed seed performance is increased with the increase of nozzle diameter, and the uniformity and stability of the airflow speed in the suction holes will be better with the increase of vacuum pressure. When the nozzle diameter is same, the airflow speed in the suction holes is uniform increased with the increase of vacuum pressure, and the influence of the vacuum pressure to airflow speed is increased with the increase of the nozzle length. At the same vacuum pressure, the influence of nozzle length to airflow speed of the outlet is difference with the change of nozzle diameter. When the nozzle diameter is less than 4.0mm, the nozzle length can be only adjusted and stabilized to airflow. When the nozzle diameter is greater than 4.0mm, the airflow speed is reduced with the increase of nozzle length.

5. Performance test

5.2 Test Method

Through the bench test for the air-suction peanut seed-metering device designed was carried out to test the seed-adsorbing performance under different conditions. Choose vacuum pressure, nozzle diameter as experiment factors, in accordance with the national standard GB/T6973-2005 single seeding-machine testing method of statistical experiments index, select reseed index, void index as the test indexes. The test selected four red peanut varieties, peanut seeds before used should be graded, cleaned, seeds chose should be clean without debris, uniform particles, no damage, no dry seeds, weak seed etc..

5.2 Test Results and Analysis

5.2.1 Effects of vacuum pressure

Choose the size of the 5.0mm metering disc, in the speed of 55r/min conditions do the performance test on the test bench, Test results can be seen: The size of the vacuum pressure determines the seed-adsorbing force, which can directly affect the ability of the peanut kernel to be adsorbed to the seed-adsorbing hole and the number，state of grains. Vacuum pressure is too large or too small adsorbing effect and job performance will be seriously affected. When the vacuum pressure is too small, due to the lack of seed-adsorbing force, the leakage phenomenon is easy to be caused. When the vacuum pressure is too large, easily get more seeds adsorbed on holes, so seed disc reseeds. As seen from Fig.9, with the decline of the vacuum pressure, the qualified index and the reseed index showed a downward trend, and the leakage index showed an upward trend.

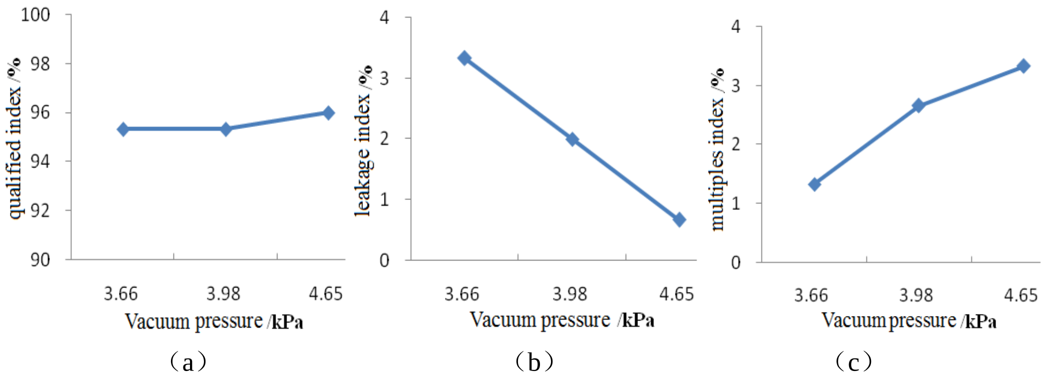


Fig.9 Effect of vacuum pressure to seeding performance

5.2.2 Effects of nozzle diameter

In the test, the nozzle diameters were selected 4.5mm, 5.0mm and 5.5mm, the vacuum pressure was 4.65kPa, and rotating speed 55r/min. The test results are shown in Fig.10. The test results show that with the increase of the nozzle diameters, the area of the suction increases, and the area of the suction increases further results in the force increases, seed-adsorbing performance is improved, the qualified index and reseed index were increased, no seed index decreased, when the nozzle diameters is greater than 5.0mm, with nozzle diameters continue to increase, the performance begins to decline, qualified index falls, reseed index increases.

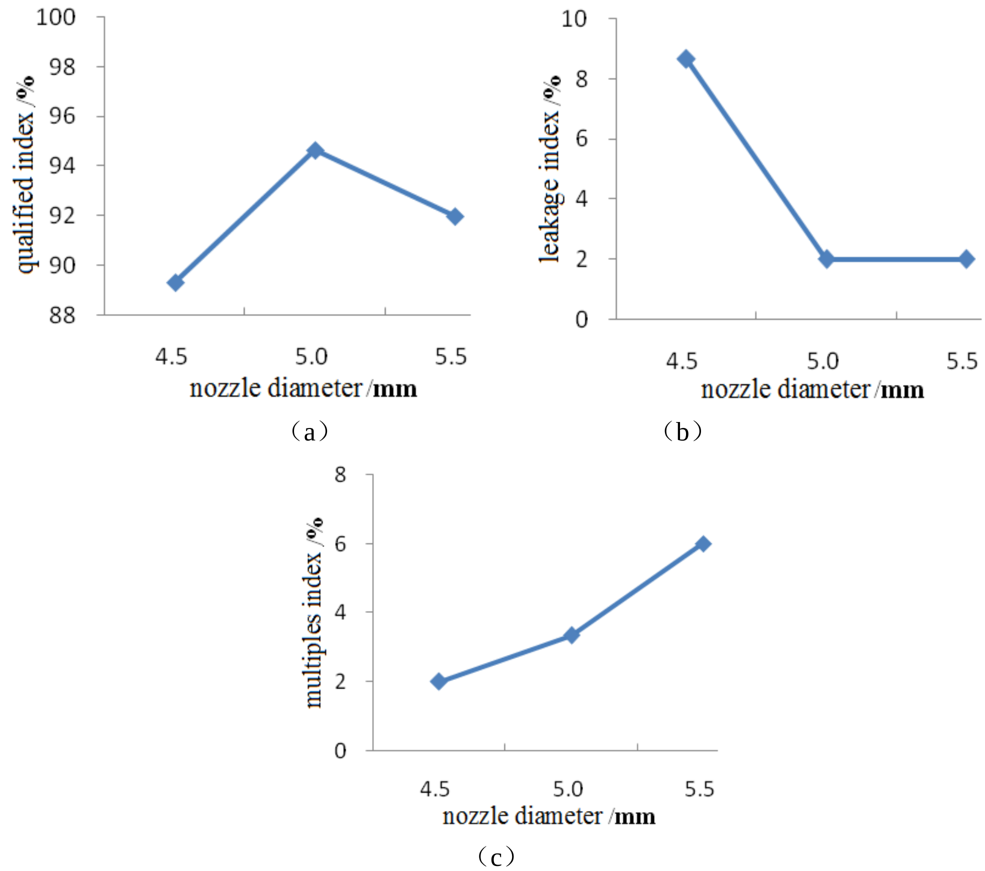


Fig.10 Effect of the nozzle diameter to seeding performance

6. Conclusion

When the outlet is tapered hole, the adsorbed seed performance is better than the other shapes of suction hole. The sequence of the factors affecting to the adsorbed seed performance are vacuum pressure > nozzle diameter > nozzle length. The bigger the vacuum pressure of the suction hole is, the bigger the airflow speed of the suction hole is, and the better the adsorbed seed performance is. When the nozzle diameters are same, the airflow speed is increased with the increase of vacuum pressure of suction hole, and the influence of the vacuum pressure to airflow speed is increased with the increase of the nozzle length. The bigger the nozzle diameter is, the greater the adsorbed seed radius is, and the stronger the adsorbed seed ability is, the better the adsorbed seed effect. At the same nozzle length, the adsorbed seed ability gradually is increased with the increase of nozzle diameter, but the nozzle diameters are greater than 5.0mm, with nozzle diameters continue to increase, the performance begins to decline. At the same vacuum pressure, when the nozzle diameter is less than 4.0mm, the nozzle length has almost no influence to airflow speed of the outlet. The stability of the airflow is improved with the increase of the nozzle length. When the nozzle diameter is greater than 4.0mm, the airflow speed of the outlet is reduced with the increase of nozzle length. The influence of nozzle length to airflow speed of the outlet is improved with the increase of the vacuum pressure. The reliability of the simulation results is verified by the bench test. The working situations of the suction holes can be accurately simulated under different conditions. This method provides the corresponding design theory and technical methods for the optimization design and the reasonable parameter selection of the suction hole.

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