Experimental Study and Fuzzy Prediction of Surface Bulk Negative Pressure Collection

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Abstract. The surface loose sand with particle size less than 10mm was used as the experimental bulk material, and the negative pressure collection experiment of surface bulk material was carried out by using the rectangular nozzle. The influence of collection parameters such as the system air volume, nozzle movement speed, and suction nozzle height above the ground on the sand collection thickness was studied. The research shows that the collection thickness of bulk material increases with the increase of system air volume and is proportional to the second power of system air volume. The collection thickness decreases with the increase of the moving velocity of the nozzle and is proportional to the -0.5 power of the moving velocity of the nozzle. The collection thickness decreases sharply with the increase of the height above the ground of the suction nozzle, and is basically 0 when the height above the ground is greater than 20mm. The mathematical model of the relationship between sand collection thickness and collection parameters is established by using fuzzy reasoning method. The accurate prediction of sand collection thickness under given collection parameters is realized by rule inference. Experimental results show that the prediction error is less than 10%.

1. Introduction

The negative pressure conveyance is the use of fan or vacuum pump as the power source to transport the material, which has obvious advantages, such as cleanliness and highly efficiency. It is widely used to transport, separate the chemical materials and remove, recycle the ground loose materials in chemical industry. At present, the research on negative pressure collection system at home and abroad mainly focuses on the improvement of suction nozzle structure, flow field distribution [1-3], simulation and optimization of gas path system [4, 5], and the motion characteristics of the two-phase flow [6]. However, there are few studies on the effect and evaluation of negative pressure collection in bulk materials.

In improving the collection efficiency and saving energy, it is of great significance to accurately control the collection depth of surface bulk materials by negative pressure collection machinery. In the process of negative pressure collection of surface sandy soil, the parameters that affect the collection thickness of sandy soil mainly include system air volume, moving speed of suction nozzle and height above the ground. Due to the diversity of bulk material gradation in most cases and the complex mechanical properties among the particles, the relationship between the bulk material collection...
thickness and the collection parameters of the system cannot be established by theoretical deduction, but can only be obtained by experiments. Therefore, on the negative pressure collection platform, loose sand with particle size less than 10mm was used as the experimental bulk to carry out the negative pressure collection experiment of surface sand with equal thickness. The mathematical model of the relationship between sand collection thickness and collection parameters is established by fuzzy reasoning method. And establishing a fuzzy rule base for predicting the collection thickness based on the experimental results. The accurate prediction of sand collection thickness under given collection parameters is realized by rule inference.

2. Experiment

2.1. Experimental Equipment and Materials
The negative pressure collection experiment platform is shown in Fig. 1, which is composed of suction nozzle, bin, cloth bag dust remover, roots vacuum pump and frequency converter. After the operation of roots vacuum pump, the whole collection system forms negative pressure, which enables the external air to carry the sand material into the suction nozzle and move along the pipeline to the bin. In the bin, most of the materials are separated from the gas-solid two-phase flow, and the unseparated fine powder particles are purified in the bag-type dust remover with the airflow. The purified air is directly discharged into the atmosphere through the muffler. The frequency converter configured on the experimental platform can precisely control the speed of the vacuum pump driving motor and thus accurately control the air volume of the suction nozzle. The air volume of the experimental platform is $0 \sim 50\text{m}^3/\text{min}$. The maximum vacuum is 50kPa. The suction nozzle adopts rectangular section structure, and the section size is length × width = 500mm×100mm.

![Figure 1. Experiment platform for negative pressure collection and experimental bulk materials.](image)

The experimental material is the sand and soil mixture with particle size less than 10mm, and the bulk density is $1.81\times10^3\text{kg}/\text{m}^3$. The sand material is naturally laid in the trough in a loose state and the laid specification is length×width×thickness = 5000mm×800mm×50mm.

2.2. Experimental Methods
When the sand is naturally laid in the bin (before collection), the heap density is basically the same as that after natural settlement in the bin (after collection). Therefore, the sand collected in a single experiment is weighed and the collection length and width are measured to calculate the average collection thickness of the sand. At the same time, the average moving speed of the suction nozzle relative to the surface sand soil can be obtained by timing the moving process and measuring the length of the sand pit formed after a collection. The fan speed adjusts the system air volume, which is controlled by frequency converter.
3. Experimental Results and Discussion

3.1. Effect of System Air Volume on Collection Thickness

In order to study the effect of system air volume on sand collection thickness, the negative pressure collection experiment of sand was carried out by fixing the height of suction nozzle above the ground and changing the air volume of system and the moving speed of suction nozzle. During the experiment, the suction nozzle was fixed at a height of 5mm from the ground, the air volume of the system was controlled at 20, 30, 40 and 50m$^3$/min, the moving speed of suction nozzle was controlled at 2, 3, 4 and 5m/min, respectively. The relationship curve between sand collection thickness and system air volume was obtained through experiments, as shown in Fig. 2.

![Figure 2. Relationship between collected thickness and system air volume.](image)

As can be seen from the experimental results, the minimum value of sand collection thickness is 3.1mm, and the maximum value is 24.7mm, which increases with the increase of system air volume. When the system air volume is 20m$^3$/min, no matter how small the moving speed of suction nozzle is, the sand soil collection thickness is less than 4mm. It can be seen that when the air volume of the system is too small, the system cannot effectively collect the surface sand.

![Figure 3. Relationship between collection thickness and system air volume in the logarithmic coordinates.](image)

Fig. 3 shows the relationship between the collection thickness and the experimental data of system air volume in the logarithmic coordinate system. Line $y_1$, $y_2$, $y_3$, $y_4$ represent the fitting curve of the relationship between the sand collection thickness and the system air volume, when the suction nozzle movement speed is 2, 3, 4 and 5m/min. It can be seen that the four fitted lines are basically parallel, and their slopes are 2.01, 2.02, 1.87 and 1.83 respectively. It follows that the collection of thickness is proportional to the square of the system air volume, when only considering system air volume.
3.2. Effect of Suction Nozzle Moving Speed on Collection Thickness

According to the experimental results of the relationship between the collection thickness of sand and the air flow of the system, the system air flow is taken as a constant, the moving speed of the suction nozzle as a variable, and the objective function is still the collection thickness, the relationship between the collection thickness and the moving speed of the suction nozzle can be obtained. The broken line diagram of the experimental data points is shown in Fig. 4. As can be seen from the figure, the collection thickness decreases with the increase of the nozzle movement speed.

![Figure 4. Relationship between collection thickness and nozzle movement speed.](image)

Fig. 5 shows the relationship between the collection thickness and the nozzle movement speed in the logarithmic coordinate system. Line $y_1, y_2, y_3$ and $y_4$ represent the fitting curve of the relationship between the sand collection thickness and the nozzle movement speed, when the system air volume is 50, 40, 30 and 20 m$^3$/min. It can be seen that line $y_1, y_2, y_3$ are basically parallel, and their slopes are -0.43, -0.47 and -0.54 respectively. It is worth noting that the experiment found that when the system air volume was 20 m$^3$/min, only the topsoil and a small amount of tiny gravel in the surface were sucked into the system. At this time, the system does not have the ability to collect the surface sand with same thickness. Therefore, the experimental data obtained under system air volume 20 m$^3$/min is not representative, which is also reflected by the excessive deviation between the slope of line $y_4$ and the other three fitting lines. Thus, the collection thickness is proportional to the -0.5 times of the nozzle movement speed, when only considering the effect of nozzle movement speed on collection thickness.

![Figure 5. Relationship between collection thickness and nozzle movement speed in the logarithmic coordinates.](image)

3.3. Effect of Suction Nozzle Height above the Ground on Collection Thickness

In order to study the effect of suction nozzle height above the ground on sand collection thickness, the negative pressure collection experiment of sand was carried out by fixing the air volume of the system,
changing the movement speed and the height above the ground of suction nozzle. During the experiment, the air volume of the system was controlled at 50m$^3$/min, the moving speed of the suction nozzle was controlled at 2, 3, 4 and 5m/min, and the height of the suction nozzle above the ground was controlled at 5, 10, 15 and 20mm, respectively. The relationship curve between sand collection thickness and height of suction nozzle above the ground was obtained through experiments, as shown in Fig. 6.

**Figure 6.** Relationship between collection thickness and suction nozzle height above the ground.

As can be seen from Fig. 6, the minimum sand collection thickness is 0mm, and the maximum sand collection thickness is 24.7mm, which decreases sharply with the increase of suction nozzle height above the ground. When the height above the ground is more than 10mm, the collection thickness decreases rapidly. When the height above the ground increases to 20mm and the movement speed is 2m/min, the sand collection thickness is only 1.3mm. At higher moving speeds, the system is no longer able to collect surface sand. It can be seen that when the suction nozzle is too high from the surface, the wind speed around the suction nozzle decreases sharply, and the wind speed on the sand soil surface is lower than the suspension speed, so the system cannot effectively collect the sand soil.

4. Prediction and Experiment of Bulk Material Collection Thickness

4.1. Distribution of Fuzzy Functions of Collected Parameters

The first step to apply fuzzy logic modeling is to determine the variation range of variables, then divide the variation range of each variable into a set of fuzzy subsets, set the corresponding name, and determine the corresponding membership function. The fuzzy subset of input variables is determined into different numbers artificially. The membership function is determined by assignment. In the paper, each collection parameter is triangular distribution, which is used to determine the membership function. According to the experimental results, when the system air volume $Q$ is 20m$^3$/min or suction nozzle height above the ground is 20mm, the system is no longer capable of collecting surface sand. Therefore, when predicting the sand collection thickness, the variation ranges of $Q$, $v$ and $d$ are taken as 30–50m$^3$/min, 5–15mm, 2–4m/min. The three parameters are divided into {small, medium and large} three fuzzy subsets respectively, which are respectively expressed as $Q = \{Q_1, Q_2, Q_3\}$, $v = \{v_1, v_2, v_3\}$, $d = \{d_1, d_2, d_3\}$. The structure framework of the generated fuzzy model is shown in Fig. 7.
4.2. Prediction and Verification

Table 1 shows the comparison and error between the experimental value $h$ and the predicted value $h_0$ of the sand collection thickness under the given collection parameters. It can be seen the error between the experimental values and the predicted values in the four groups is less than 10%.

| Experimental serial number | System air volume $Q$ m$^3$/min | Suction nozzle movement speed $v$ m/min | Height above the ground $d$ mm | Experimental value $h$ mm | Predictive value $h_0$ mm | relative error % |
|----------------------------|---------------------------------|---------------------------------------|-------------------------------|--------------------------|--------------------------|------------------|
| 1                          | 50                              | 3.5                                   | 10                            | 6.7                      | 6.1                      | 9.0              |
| 2                          | 45                              | 3                                     | 10                            | 7.7                      | 7.2                      | 6.5              |
| 3                          | 35                              | 2                                     | 5                             | 15.9                     | 15.3                     | 3.8              |
| 4                          | 40                              | 2.5                                   | 5                             | 16.0                     | 16.9                     | 5.6              |

5. Conclusion

(1) The experiment researched the effect of negative pressure collection parameters on the surface sand collection thickness. The results show that the collection thickness of sand increases with the increase of system air volume and is proportional to the second power of system air volume. The collection thickness decreases with the increase of the moving speed of the suction nozzle and is proportional to the -0.5 times of the nozzle movement speed. The collection thickness decreases with the increase of the suction nozzle height above the ground, and is basically zero when the height above the ground is greater than 20mm.

(2) With fuzzy inference method, establishing a fuzzy rule base to predict the sand collection thickness by the experimental results. The rule inferences can accurate prediction of sand collection thickness under the condition of given negative pressure collection parameters. The experimental results show that the prediction error is less than 10%.

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