OPTIMIZATION AND EXPERIMENT OF COUPLED HOT-WIND ROASTING-TEA MACHINE BASED ON CFD-DEM

基于 CFD-DEM 耦合的热风茶叶炒制机优化与试验

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ABSTRACT

A drum-type hot-wind roasting-tea machine was designed to improve the quality of the roasted tea. The basic structure and working principle of the machine were studied theoretically and experimentally. The CFD-DEM coupled method and the Box-Behnken experimental design method were introduced to analyze the influence of the shape of the anti-skid bars and working rotating speed on the roasting-tea quality. The optimum combination of the working parameters with the height of the anti-skid bar is 30 cm, the figure of the anti-skid bar is 6, the rotating speed of the roller is 15 r/min, the broken-tea ratio is 2.15%, and the tea’s sensory appraisal index is 89.32. The comprehensive performance index was better.

MATERIALS AND METHODS

The structure and working principle of the roasting tea machine

The structure of the roasting tea machine

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The drum-type hot-wind roasting tea machine is made up of the outer shell of roller, the roller, the control cabinet of hot-wind, the regulator, the rack, the control cabinet, the anti-skid bar, the rear roasting board, the front roasting board and so on, as shown Fig. 1 and Fig. 2.

The working principle of the roasting tea machine

The outer shell of roller stands on the rack with the two sides of the spindles. During the work, turning on the volume damper of hot-wind, the hot wind passes through the square-diameter reducing pipe and then emits into the outer shell of the roller, the hot wind heats the inner wall of the roller, the extractor fan makes the hot wind uniform distribution more on the tea leaves. The drive motor makes the roller rotate, the anti-skid bar carries the tea leaves to run around, which makes the tea leaves be heated more homogeneously. The roasting board pushes the tea leaves automatically, which makes the tea leaves shapes more compact. The temperature and humidity sensor in the roasting machine, which guarantees the made-up tea fulfill the demand of the moisture content. The motor drives the screw elevator movement, then pulls the in-put and out-put materials mouth ups and downs, the made-up tea comes out automatically. During the roasting process, there has an imbalance of temperature and press between the hot-wind and the tea leaves, their interaction causes the heat transfer and the mass transfer, which makes the tea’s temperature rise and at the same time the tea’s inner moisture down, and then leads to the roasting made-up tea.

The rotating speed of the roller

When the tea leaves move to the highest point in the roller, this research makes a force analysis of the tea leaves, as the Fig. 3. When the tea leaves stay on the highest point K, the research ignores the effect from the anti-skid bar, the own weight of the tea leaves equals the centrifugal force \( F_R \), as:

\[
G = mg = F_R = m\omega^2 R = m\left(\frac{n_{lim}}{30}\right)^2 R
\]

Where:
- \( m \) is the whole quality of the tea leaves, [kg];
- \( n_{lim} \) is the ultimate speed of the roller, [r/min];
- \( R \) is the radius of the roller, [m];
- \( g \) is the acceleration of gravity;
- \( \omega \) is the angular speed, [rad/s].

This paper calculates the ultimate speed of the roller, \( n_{lim} = 42.28 \) r/min.

![Fig. 3 - Stress analysis of tea grain at K point](image3.png)

![Fig. 4 - Schematic diagram of movement characteristics](image4.png)
This research makes an experiment on the angle of the teas’ material-distributed curtain and the tea’s movement when the roller’s speed is 10-40 r/min. The results show that when the deviation angle of the tea leaves in the drum is 10°-45°, the water content of the tea leaves is reduced, and the appearance of the tea leaves is kept well. Combining the actual experiment and the analysis of the tea’s movement characteristics in the roller, when the ultimate rotating speed of the roller is 30%-45%, there is a perfect result.

**The shape of the anti-skid bar**

Fig. 5 shows three common shapes of the anti-skid bars. The tossing and casting experiments were performed to select the suitable shape of the anti-skid bar. The experiment results show if the anti-skid bar is the right-angle shape and the obtuse-angle shape, in the rotation of the roller, the anti-skid bar holds a bigger quantity of the tea leaves, a bigger rising height of the tea leaves, which makes the tossing and casting speed of the tea leaves bigger, leads to a higher broken-tea ratio. If the anti-skid bar is the triangular shape, in the rotation of the roller, the tea leaves rise a optimum height and form a better effect of the material-distributed curtain, which is very beneficial to the tea roasting process.

**The quantity of the anti-skid bars**

Fig. 6 shows the motion state of tea at an instant. The paper assumes the tea particle stays its position angle $\alpha_k$, the casting speed $V$. there gets the relationship between the particle position angle and time $t$:

$$t = \frac{\pi(\alpha - \alpha_{k1})}{180\alpha_k} = \frac{2R_0 \cos \alpha_{k1}}{g} + \frac{\sqrt{(R_0 \cos \alpha_{k1})^2 - (R_0)^2 + Rg \sin \alpha_{k1}}}{g}$$  \hfill (2)

Where:

$\alpha_k$ is the position angle of K anti-skid bar in a moment;  
$\alpha$ is the position angle after time $t$.

In order to explain the motion characteristics of the tea particle in the rotation with the roller, this paper puts forward the concept—the density of the tea material distributed curtain in the roller, which means when the tea leaves rotate with the roller, the quantity of the detaine tea particles per unit volume in the roller.

**Fig. 6 - Movement trajectory of tea granules**

**Fig. 7 - The change law of position Angle with time**

Fig. 7 shows the change of the position angle of the anti-skid bar follows the time change. If supposes that the anti-skid bar K has the position angle $\alpha$, the amount of the tea leaves is held $P_\alpha$, if the position angle is $\alpha_{k1}$, the amount of the tea leaves is $P_{\alpha k1}$, then the anti-skid bar K casts the amount of the tea particles: $P_{\alpha k1} - P_\alpha$, from the above analysis, the density of the tea material distributed curtain has its computational formula:

$$\rho = \frac{\sum_{k=1}^{n} (P_{\alpha k1} - P_\alpha)}{SL}$$  \hfill (3)

where:

$\rho$ is the density of the tea;  
$S$ is the cross sectional area of the tea distributed curtain in the roller;
L is the width of the tea distributed curtain in the roller;
k is the momentary processing quantity of the anti-skid bars in the rotation of the roller.

From the above analysis of the tea leaves casting test, there is a changing rule between the quantity of the anti-skid bar in the roller and the density of the tea material distributed curtain, the results are shown in Table 1.

<table>
<thead>
<tr>
<th>The quantity of the anti-skid bars</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>The momentary processing quantity of the anti-skid bars in the rotation of the roller</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>The density of the tea material distributed curtain kg/m³</td>
<td>20.00</td>
<td>13.33</td>
<td>10.67</td>
<td>10.14</td>
<td>6.67</td>
</tr>
</tbody>
</table>

The results show that: with the addition of the quantity of the anti-skid bar, the quantity of the anti-skid bars joins in operation in a moment gradually, the density of the tea material distributed curtain decreases gradually. Considering the influence of the size and shape of tea particles and the uniformity of tea leaves in the process of movement, from the above experiment and reference to the Agricultural Machinery Design Manual, The best solution is determined as follows: 6 triangular anti-skid ribs are evenly arranged on the inner wall of the drum with an interval of 60°.

**Simulation analysis**

This paper combines Fluent16.0 and EDEM2.7 to make a simulation computation, Fluent software is used to find out the solution of the gas phase, the solid phase finds its solution with the software EDEM, and the Euler-Euler coupling method is introduced for simulation analysis.

SolidWorks is used to model three kinds of drums with different anti-skid rib shapes. The meshing module under ANASYS16.0 software is used to divide the inner flow channel mesh of the simplified drum, as shown in Fig. 8. To improve the computation speed and enhance the computation accuracy, on the actual shapes of the tea leaves, this research simplifies 4 models in Fig. 9 to make a simulation computation.

**RESULTS**

**The movement effect of the tea particles from the shape of the anti-skid bar**

Under the same rotating speed (n=15 r/min) and same moment (t=2s), this paper makes three simulations of the different shapes (right-angle, obtuse-angle, triangle) of the anti-skid bar, as shown in Fig. 10.

From the simulation results, this paper finds that the tea leaves can set up the material distributed curtain with rotation of the roller in right-angle and obtuse-angle situations for contacting the hot wind sufficiently, as shown in Fig. 10 a) and b). But under these two situations, the anti-skid bars hold more tea leaves, which makes the tea leaves inhomogeneous distribution, the tea leaves can’t get good extrusion shapes, the appearance of the tea leaves is not good. With the rotation of the roller, the tea particles are taken up so high on the flat XOZ, which makes the angle of the material distributed curtain is too bigger and makes the
broken-tea ratio higher, leading to the lower quality of the tea roasting process. In Fig. 10 c) represents the triangle anti-skid bar, comparing with Fig. 10 a) and b), in the roasting process, there is a good extrusion among the tea particles, which is better to make the tea leaves have a good appearance, because the tea leaves are taken up lower in the roller, which decreases the broken-tea ratio heavily, and has the optimum effect in the tea roasting process. 

**The effect of shape of the anti-skid bar to the tea particles speed**

Fig. 11 shows that the 3 different shapes of the anti-skid bars have their different effects on the changing rules of the tea movement speed in the roller. Fig. 11 a) is the right-angle shape, the changing speed of the tea particles belongs to the scope of 0.86-1.10 m/s, the fluctuant speed of the tea particles is very high, which makes the position of the tea particles rise higher or lower; In the actual roasting operation, it is very easy to make the tea’s appearance molding is not good, and decrease the tea roasting quality. Fig. 11 b) is the obtuse-angle shape, the average speed of the tea particles changes in the scope of 0.73-1.22 m/s, it fluctuates the most and has a harmful effect on the tea roasting process. Fig. 11c) is triangle shape, the changing scope of the tea particles average speed belongs to 0.85-1.09 m/s, comparing with Fig. 11a) and b), the fluctuant scope of the tea particles speed is the mini one, and there is not the higher peak value or the lower peak value of the speed, which makes the tea particles have a homogeneous speed in the roller, and makes the tea leaves have a perfect appearance molding, and makes the tea leaves have the best roasting quality in the roasting process.

![image](image-url)

**Fig. 11 - Effects of three kinds of anti-skid bars one the grain velocity of tea leaves**

**The effect of the dispersion degree of the tea particles from the roller’s rotating speed**

This paper uses the separation ratio \( q \) proposed by Akash Gupta (2017) to describe the degree of dispersion of tea particles, \( q \) is a smaller number, which shows the tea particles is more sparse, the dispersion effect is better, the tea leaves roasting homogeneity is better, if \( q \) is a bigger one, there will have a bad result. This research uses EDEM software to record and resolve the contact number of tea leaves at different times. Through the operation of the statistics data, this paper gets the different segregation ratio curves with 3 different rotating speed of the roller, as shown in Fig. 12.

As can be seen from Fig. 12, the tea leaves segregation ratio rises continuously with 3 different working situations in the beginning stage, and the main reason is that the contact among the tea particles plays the key role in first stage. With the rotation of the roller, in the moment before the tea leaves are cast, the segregation ratios under these 3 different working situations all get their peak values. When the tea leaves are cast, the segregation ratio holds its low ebb. If the rotating speed of the roller is 10 r/min, the tea leaves segregation ratio is max, if the speed is 20 r/min, the segregation ratio is mini. If the rotating speed is very lower, the area of the material distributed curtain is small, which makes a bad effect on the roasting process. If the rotating speed is too high, which makes the tea leaves crushed, which decreases the tea roasting quality. From the above analysis, when the rotating speed of the roller is 15 r/min, the tea leaves segregation ratio is the perfect one, which gets the best tea roasting quality.

![image](image-url)

**Fig. 12 - Variation curve of the separation ratio of tea particles**

**The effect of the rotating speed to the internal flow field in the roller**

In the ANSYS Fluent processing module, the flow field distribution cloud map under different working situations \((n=10 \text{ r/min}, n=15 \text{ r/min}, n=20 \text{ r/min})\) is obtained, as shown in Fig. 13.
As can be seen from Fig. 13, if the rotating speed of the roller is 10 r/min, the temperature change of the solid phase happens mainly in the near inner wall-surface of the barrel, which makes an insufficient contact with the hot wind of the continuous phase, gets a smaller regional area of the temperature change, the changing speed lower, if \( t=3.5 \) s, the changing regional area of the solid phase temperature is less 25% of the whole roller sectional area, the tea roasting effect is clear lower. In Fig. 13 c), if the rotating speed of the roller is 20 r/min, comparing with Fig. 13 a), this paper finds the temperature changing area of the solid phase increases to a bigger one, which has sufficient contact with the hot wind of the continuous phase, enhances the roasting effect on a certain extent. From the temperature change from \( t=1 \) s to \( t=3.5 \) s, this research finds out, because of the high rotating speed of the roller, the casting speed of the tea particles is high, if \( t=3.5 \) s, the changing regional area of the solid phase temperature is about 70% of the whole roller sectional area, which makes the tea particles of the solid phase crush each other and decreases the tea roasting quality. In Fig. 13 b), this research finds, if the rotating speed of the roller is 15 r/min, the temperature change is sufficient, the near inner wall-surface temperature tends towards the balance with the rotation of the roller gradually, the temperature changing area is about 50% of the whole roller sectional area, the temperature changing area is a best one.

On the above analysis, if the form of the anti-skid bar is the triangle shape, the rotating speed of the roller keeps 15 r/min, the tea roasting quality is the best one.

**Fig. 13 - Cloud diagram of flow field distribution in three working conditions at the same time**

**The prototyping experiment**

**The experiment condition**

The prototyping test was carried out to verify the rationality of the working performance and the parameter design of the drum-type roasting tea machine, as shown in Fig. 14.

**Fig. 14 - Experimental prototype of hot-wind roasting-tea machine**
This test chooses 3 degree fresh tea leaves as the row materials, before the tea roasting, the moisture content of the fresh leaves is 15%-20%, the average unit weight is 100.2 kg/m³. The experiment instruments and equipment include the drum-type, hot-wind roasting-tea machine, many kinds of teapots with the precision of 1 kg per one, a TCS electronic scale with the precision of 10g-100g, a second chronograph with the resolution precision of 0.01s, a determinating instrument of the crushing tea dust, and a experiment tool bag.

The experiment method and result

This paper uses Box-Behnken as a test method, broken-tea ratio and the tea out-looking sense as the assessment index. The paper sets out a series of experiments on the height of the anti-skid bar (the level-value X₁, the coded value x₁), the number of the anti-skid bar (the level-value X₂, the coded value x₂), the rotating speed (the level-value X₃, the coded value x₃), the level-value and the coded value of the experiment elements as shown in Table 2. The experimental scheme and the result are shown in Table 3.

Table 2

<table>
<thead>
<tr>
<th>Coded value</th>
<th>The height of the anti-skid bar</th>
<th>The number of the anti-skid bar</th>
<th>The rotating speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1</td>
<td>20</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>0</td>
<td>30</td>
<td>6</td>
<td>15</td>
</tr>
<tr>
<td>1</td>
<td>40</td>
<td>8</td>
<td>20</td>
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</tbody>
</table>

Table 3

<table>
<thead>
<tr>
<th>No.</th>
<th>The height of the anti-skid bar x₁</th>
<th>The number of the anti-skid bar x₂</th>
<th>The rotating speed x₃</th>
<th>The broken-tea ratio Y₁</th>
<th>The tea out-looking sense Y₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>-1</td>
<td>2.3</td>
<td>85</td>
</tr>
<tr>
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<td>0</td>
<td>0</td>
<td>2</td>
<td>90</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>90</td>
</tr>
<tr>
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<td>1</td>
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<td>83</td>
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</tr>
<tr>
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<td>0</td>
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</tr>
<tr>
<td>7</td>
<td>-1</td>
<td>0</td>
<td>1</td>
<td>2.4</td>
<td>84</td>
</tr>
<tr>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
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</tr>
<tr>
<td>9</td>
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<td>1</td>
<td>2.7</td>
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<td>2.4</td>
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<tr>
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<td>0</td>
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<td>0</td>
<td>2</td>
<td>90</td>
</tr>
</tbody>
</table>

The regression model

This research imports the experimental data in Design-Expert 10.0 to make a regression fit, which sets up the regression model of the broken-tea ratio and the assessment index of the out-looking sense from different elements, as shown in Eq.(4). After getting rid of the non-distinctive regression items, the regression model of the broken-tea ratio and the sense assessment index shows Eq.(5):

\[
\begin{align*}
Y_1 &= 2.02 + 0.13 x_1 + 0.13 x_2 + 0.13 x_3 + 0.075 x_1 x_2 + 0.025 x_1 x_3 + 0.025 x_2 x_3 + 0.23 x_1^2 + 0.18 x_2^2 + 0.18 x_3^2 \\
Y_2 &= 90.40 - 0.75 x_1 - 0.50 x_2 - 1.00 x_3 + 0.000 x_1 x_2 + 0.000 x_1 x_3 - 2.95 x_2^2 - 2.45 x_3^2 - 3.45 x_1^2
\end{align*}
\]
Increased rotating speed of the roller, this tendency decreases at the beginning and then decreases at the end. If the anti-skid bar keeps same, the broken-tea ratio has a changing tendency with the increased height of the anti-skid bar, this tendency decreases at the beginning and then increases at the end. In Fig 15 b), if the rotating speed of the roller keeps samely, the broken-tea ratio has a changing tendency with the increased quantity of the anti-skid bars, this tendency decreases at the beginning and then increases at the end, if the quantity of the anti-skid bar keeps same, the broken-tea ratio has a changing tendency with the increased rotating speed of the roller, this tendency decreases at the beginning and then increases at the end. In Fig 15 c), if the rotating speed of the roller keeps samely, the broken-tea ratio has a changing tendency with the increased height of the anti-skid bar, this tendency decreases at the beginning and then increases at the end. If the height of the anti-skid bar keeps samely, the broken-tea ratio has a changing tendency with the increased rotating speed of the roller, this tendency decreases at the beginning and then increases at the end. In Fig 15 d), this thesis finds, if the anti-skid bar keeps same, the sense assessment index has a changing tendency with the increased height of the anti-skid bar, this tendency increases at the beginning and then decreases at the end. If the height of the anti-skid bar keeps same, the broken-tea ratio has a changing tendency with the increased height of the anti-skid bar, this tendency increases at the beginning and then decreases at the end. In Fig 15 e), this thesis finds, if the rotating speed of the roller keeps samely, the sense assessment index has a changing tendency with the increased quantity of the anti-skid bars, this tendency increases at the beginning and then decreases at the end. If the height of the anti-skid bar keeps samely, the broken-tea ratio has a changing tendency with the increased rotating speed of the roller, this tendency increases at the beginning and then decreases at the end. In Fig 15 f), this thesis finds, if the rotating speed of the roller keeps samely, the sense assessment index has a changing tendency with the increased height of the anti-skid bar, this tendency increases at the beginning and then decreases at the end. If the height of the anti-skid bar keeps samely, the sense assessment index has a changing tendency with the increased rotating speed of the roller, this tendency increases at the beginning and then decreases at the end.

Analysis of the effect of experimental factors

In the regression equation, choosing one element respectively that it's level of factor is o on random, studying the rest two elements and seeking out their effect to the broken-tea ratio and the sense assessment index, this thesis uses the software Design-Expert 10.0 to make an analysis and gets the response hook face affected by the interaction factors, that shown in Fig. 15.

In Fig. 15 a), this thesis finds that if the anti-skid bar keeps the same quantity, the broken-tea ratio has a changing tendency with the increased height of the anti-skid bar, this tendency decreases at the beginning and then increases at the end. If the anti-skid bar keeps same height, the broken-tea ratio has a changing tendency with the increased quantity of the anti-skid bars, this tendency decreases at the beginning and then increases at the end. In Fig. 15 b), if the rotating speed of the roller keeps samely, the broken-tea ratio has a changing tendency with the increased quantity of the anti-skid bars, this tendency decreases at the beginning and then increases at the end, if the quantity of the anti-skid bar keeps same, the broken-tea ratio has a changing tendency with the increased rotating speed of the roller, this tendency decreases at the beginning and then increases at the end. In Fig 15 c), if the rotating speed of the roller keeps samely, the broken-tea ratio has a changing tendency with the increased height of the anti-skid bar, this tendency decreases at the beginning and then increases at the end. If the height of the anti-skid bar keeps samely, the broken-tea ratio has a changing tendency with the increased rotating speed of the roller, this tendency decreases at the beginning and then increases at the end. In Fig 15 d), if the rotating speed of the roller keeps samely, the broken-tea ratio has a changing tendency with the increased height of the anti-skid bar, this tendency decreases at the beginning and then increases at the end. In Fig 15 e), if the rotating speed of the roller keeps samely, the broken-tea ratio has a changing tendency with the increased height of the anti-skid bar, this tendency decreases at the beginning and then increases at the end. In Fig 15 f), this thesis finds, if the rotating speed of the roller keeps samely, the broken-tea ratio has a changing tendency with the increased height of the anti-skid bar, this tendency decreases at the beginning and then decreases at the end. If the height of the anti-skid bar keeps samely, the broken-tea ratio has a changing tendency with the increased rotating speed of the roller, this tendency increases at the beginning and then decreases at the end.

\[
\begin{align*}
Y_1 &= 2.02 + 0.13x_1 + 0.13x_2 + 0.13x_3 + 0.075x_1x_2 + 0.23x_1^2 + 0.18x_2^2 + 0.18x_3^2 \\
Y_2 &= 90.40 - 0.75x_1 - 0.50x_2 - 1.00x_3^3 - 2.95x_1^2 - 2.45x_2^2 - 3.45x_3^2
\end{align*}
\]

Fig. 15 - Response surfaces of interactive factors influence on test indexes
The optimization model and the experimental verification

Based on the working performance demand and the actual working condition of the drum-style hot-wind roasting tea machine, this work plans to succeed in the lower broken-tea ration, the higher sense assessment index. According to the different elements have different effects, this thesis needs to optimize all results. This thesis regards the broken-tea ratio and the sense assessment index as an objective function, makes the optimization design to 3 experimental elements, including the rotating speed of the roller, the height of the anti-skid bar and the number of the anti-skid bar. The optimization constraint conditions can be conducted as follows:

\[
\begin{aligned}
\min Y_1 &= f_1(X_1, X_2, X_3) \\
\max Y_2 &= f_2(X_1, X_2, X_3) \\
X_1 &\in (20, 40) \\
X_2 &\in (4,8) \\
X_3 &\in (10,20)
\end{aligned}
\]  

(6)

The influence laws of three experimental factors affecting the broken tea rate and sensory evaluation indexes are comprehensively considered to get the best parameter combination, uses the software Design-Expert 10.0 to make an optimization solution. This research gets the optimum working parameter combination, the height of the anti-skid bar is 31.91mm, the quantity of the anti-skid bar is 6.4, the rotating speed of the roller is 16.52 r/min, the broken-tea ratio is 2.15%, the sense assessment index is 89.32.

In order to use the optimum parameter combination in the actual production, this thesis makes the round number of them, the height of the anti-skid bar is 30 mm, the quantity of the anti-skid bar is 6, the rotating speed of the roller is 15 r/min, makes 3 repetitive tests to get average value, the broken-tea ratio is 2.02 %, the sense assessment index is 90.02, which means the experimental results keeps an accord with the theoretical results substantially, which means the regression model is good. The actual roasting effect shows in Fig. 16, which fulfills the tea quality demand.

![Fig. 16 - Tea leaves after roasting](image)

CONCLUSIONS

(1) According to the present tea processing equipment, there are still many problems, such as low productivity, high broken-tea ratio and so on, to improve the quality of the processed tea, this thesis designs a drum-type hot-wind roasting-tea machine. This paper states the elementary working construction and the operation principle, and makes a theoretical analysis of the design parameter, confirms the key parameters, such as the rotating speed of the roller, the form of the anti-skid bar, the number of the anti-skid bar.

(2) The coupling method CFD-DEM was used to analyze the effect from the form of the anti-skid bar in the inner wall of the machine and the rotating speed to the tea roasting quality. The simulation results show, the form of the anti-skid bar is triangle, the rotating speed of the roller is 15 r/min, the tea leaves get an optimum movement rule, an optimum separation ratio and an optimum flow field change.

(3) The Box-Behnken was introduced to design the experimental methods, regards the height of the anti-skid bar, the quantity of the anti-skid bar, the rotating speed of the roller as the experimental elements, regards the broken-tea ratio and the sense assessment index as the test index, making the series experiments on the operation parameter of the roasting tea machine, finding out that the optimum working parameter combinations are the height of the anti-skid bar is 30 mm, the quantity of the anti-skid bar is 6, the rotating speed is 15 r/min, the broken-tea ratio is 2.15%, the sense assessment index is 89.32.

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