Study of key structure parameters on productivity of the ring-die biomass granulator

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Abstract. The productivity of the biomass granulator is an important parameter to evaluate the quality of the equipment, where the structure of granulator is one of the important influencing factors. In this paper, the basic forming conditions of the granulator are analysed to determine the relationship between the material intake angle and the friction coefficient; Then, the height of the material pressed by the granulator and the influence of the structural parameters of the ring-die and the press roller are obtained; Finally, the empirical correlation between the productivity and the structural parameters of the ring-die biomass granulator is presented. The results show that: 1) the material intake angle $\beta$ should be less than 26°; 2) When the height of biomass material is fixed, the diameter of the roller should increase with the diameter of ring-die.

1. Introduction
Ring-die biomass granulator is the most commonly used equipment for biomass briquetting. At present, the research on the biomass granulator mainly focuses on configuration and design of ring-die and press roller. Li Yancong [1] established three kinds of mapping models between the structural parameters of ring-die and press roller, material density and particle density, and obtained the relationship between the radius of die hole and the effective length of die hole; Liu Lu [2] established the mathematical model of the prov of the ring-die granulator, and verified the model through experiments. It was found that the productivity was related to Poisson's Ratio of materials, friction coefficient between materials and ring-die, radius and length diameter ratio of mold hole, radius of ring-die and other process parameters. Zhu Haitao [3] analyzed in details of the size of the press roller and the ring-die, deduced the productivity formula of the granulator, and obtained the influence of the optimal ring-die linear speed on the particle molding degree. Xia Xianfei [4] established a production model, and found that when the material intake angle is fixed, the three-roller has more advantages in productivity than the double roller structure. Wu Yunyu [5] carried out the numerical simulation of the thermal coupling for the structural parameters and proposed the optimal design parameters of the ring-die by comparing the stress-strain distribution of the ring-die under different structural parameters. Cong Hongbin [6] established the mathematical model of the efficiency and energy consumption of the ring-die granulator, drew the curve of the efficiency and energy consumption under different equipment structure parameters and material characteristic parameters, and analyzed the influence of each parameter on the efficiency and energy consumption. N.P.Nielsen [7] found that the ratio of hole length to diameter of the ring-die can also affect the axial extrusion pressure and the friction force. For
materials with different characteristics, the ring-die with different ratio of length to diameter should be designed.

Previous studies did not consider the relationship between the intake angle and the productivity of the granulator, while in this paper, the relationship between the productivity and structural parameters of granulator are analyzed in order to provide references for design and application of the biomass equipment.

2. Basic forming conditions of granulator

Per unit time, the more material is extruded into the mold hole, the greater the output of the biomass granulator, so it is necessary to study the basic forming conditions of granulator.

As shown in Figure 1, stress analysis is carried out on the material in the triangular ABC micro-section, and the force app on it by the press roller is \( F_{N1} \), and the friction \( F_{f1} \) (friction coefficient between the material and the pressure roller is \( f_1 \)), and the pressure on it by the ring-die is \( F_{N2} \), and the friction \( F \) (friction coefficient between the material and the ring-die is \( f_2 \)). \( \beta \) is the intake Angle, \( R \) is the radius of the ring-die, and \( r \) is the radius of the press roller.

\[ \begin{align*}
\tan \beta & \leq \frac{f_1 + f_2}{1 - f_1 f_2} \\
\end{align*} \]

Where:
- \( f_1 \) is friction coefficient between material and press roller, \( (0.1 \leq f_1 \leq 0.37) \);
- \( f_2 \) is friction coefficient between material and ring-die, \( (0.1 \leq f_2 \leq 0.37) \);
- \( \beta \) is material intake angle.

From equation (1) and equation (2), as long as the intake angle meets the requirements of equation (3), the forming can be realized. Therefore, when designing the ring-die biomass granulator, selecting the appropriate material of press roller and ring-die can increase the productivity of the equipment. According to the actual situation in the production process, the friction coefficient between the material and the ring-die is 0.1, and the friction coefficient between the material and the press roller is 0.37. The calculation results show that the intake angle that meets the conditions should be less than
26 °. From the geometric relationship in Figure 1 it can be obtained that the height of the material pressed by the roller is:

\[ h = R - r \cos \beta - \sqrt{r^2 \cos^2 \beta - 2Rr + R^2} \]  

(4)

Where:
- \( h \) is height of pressing material.
- Substitute the \( \beta = 26° \) into formula (4) and get:

\[ h = R - 0.9r - \sqrt{0.8r^2 - 2Rr + R^2} \]  

(5)

According to the actual production, when \( h \) is 100mm, 110mm and 120mm respectively, and \( R \) is 150mm, 175mm, 200mm, 225mm and 250mm respectively, the relationship curves between the ring-die radius and the press roller radius is drawn, as shown in Figure 2.

![Figure 2. Schematic diagram of forming process of ring-die biomass granulator.](image)

It can be seen from Figure 2 that when the ring-die size is the same, the press roller size increases with the increase of the height of pressing material, and when the height of pressing material is fixed, the roller radius increases with the increase of the ring-die radius.

3. The establishment of productivity model

3.1. Calculation of effective forming volume

Assuming that all materials ingested by the press roller can be successfully extruded into the die hole and formed, the total volume of materials ingested into the die hole by a single press roller is:

\[ V = N\pi r^2 h \]  

(6)

Where:
- \( N \) is number of ring-die holes;
- \( r_h \) is die hole radius, mm.

Among them, the effective forming area of the ring-die is \( N\pi r^2 \), obtain:

\[ V = 2\pi RB \varepsilon h \]  

(7)

Where:
- \( B \) is effective width of ring-die, mm;
- \( \varepsilon \) is opening rate of ring-die.

3.2. Production model establishment of biomass granulator

Assuming that the time of rotation of all the rollers for one week is \( t \), the output of the biomass granulator for one hour is:
\[ Q = 3.6 \times 10^{-9} \frac{Z \rho V}{T} \]  

(8)

Where:
- \( Z \) is the number of pressing press roller;
- \( \rho \) is the initial unit weight of material, g/L;
- \( T \) is the time required for the roller to rotate for one week, S.

Let \( v \) be the linear speed of the roller rotation, then substitute formula (8) to get:

\[ Q = 1.8 \times 10^{-9} \frac{Z \rho V v}{\pi r} \]  

(9)

Where:
- \( V \) is the linear speed of roller rotation, m/s.

Substituting equation (7) into equation (9), the productivity calculation formula of the ring-die machine is as follows:

\[ Q = 3.6 \times 10^{-6} Z \rho B \pi v \]  

(10)

Substitute equation (4) into equation (10):

\[ Q = 3.6 \times 10^{-6} Z \rho B \pi v \left( R - r \cos \beta - \sqrt{r^2 \cos^2 \beta - 2rR + R^2} \right) \]  

(11)

From equation (11), it can be found that the productivity of the ring-die biomass granulator is related to the number, speed and radius of the press roller, the effective width, opening rate and radius of the ring-die, and the initial density of the materials.

4. Analysis of influencing factors of equipment productivity

Take 9JYK-2000A ring-die biomass granulator as the example to study the key structural parameters’ influence on its productivity, and the structural and material parameters are shown in Table 1.

| Name              | Parameter                  | Symbol | Unit | Value |
|-------------------|----------------------------|--------|------|-------|
| ring-die          | radius                     | \( R \) | mm   | 360   |
|                   | width                      | \( B \) | mm   | 90    |
|                   | opening rate               | \( \varepsilon \) |      | 0.3   |
| Press roller      | line speed                 | \( v \) | m/s  | 12    |
|                   | radius                     | \( r \) | mm   | 160   |
|                   | number                     | \( Z \) |      | 2     |
| Material parameters| Material initial density   | \( \rho \) | g/L     | 250   |
|                   | friction coefficient       | \( f_1 \) |      | 0.1   |
|                   | between material and press |                   |      |       |
|                   | roller                     | \( f_2 \) |      | 0.37  |
|                   | friction coefficient       |                   |      |       |
|                   | between material and ring-die|               |      |       |

Take the intake angle of the material \( \beta = 26^\circ \), the number of rollers \( Z = 2 \), the initial density of the material \( \rho = 250\) g/L, which is a fixed value. By using the control variable method, the productivity curve of the biomass granulator is drawn when the parameters such as the radius of the ring-die, the radius of the press roller, the rotation speed of the press roller, the opening rate of the ring-die, the effective width of the ring-die and so on are changed. The influence law of the technical parameters of the equipment on the productivity of the biomass granulator is presented intuitively, which provides the basis for the product series production.

4.1. Effect of ring-die radius and press roller radius on productivity

When the ring-die radius changes from 340mm to 400mm, the change of productivity of the ring-die biomass granulator is shown in Figure 3. It can be seen from the curve of the relationship between the
productivity and the ring-die radius that the productivity tends to decrease with the increase of the ring-die radius.

When the press roller radius changes from 150 mm to 170 mm, the productivity change of the ring-die biomass granulator is shown in Figure 3. It can be seen the productivity increases with the increase of press roller radius.

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{fig3.png}
\caption{Effect of ring-die and press roller radius on productivity.}
\end{figure}

4.2. Effect of speed of press roller and width of ring-die on productivity

When the linear speed of press roller changes from 75m/s to 100m/s, the productivity change of the ring-die biomass granulator is shown in Figure 4, it can be seen that the productivity increases with the press roller speed in an almost proportional way.

When the effective width of the ring-die changes from 10mm to 13mm, the productivity change of the ring-die biomass granulator is shown in figure 4, as can be seen the productivity also increases with the effective width of the ring-die.

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{fig4.png}
\caption{Influence of speed of press roller and effective width of ring-die on productivity.}
\end{figure}

5. Conclusions

In this paper, the height of the material pressed by the granulator and the influence of the geometrical parameters of the ring-die and the press roller are obtained, and the empirical correlation between the productivity and the structural parameters of the ring-die biomass granulator is presented. For the 9JYK-2000A ring-die biomass granulator which is taken as the research example, it is found that the
material intake angle $\beta$ should be less than 26°, and when the height of biomass material is fixed, the diameter of the roller should increase with the diameter of ring-die.

This research may provide a reference for the design and research of the ring-die biomass granulator.

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