Study on Mixing Property of Circulation/Shear Coupling Mechanism-Double Impeller Configuration

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Abstract

One of the approaches to achieve high-efficient size mixing is to set up a double impeller configuration using the axial flow impeller and the radial flow impeller as the functional elements. This paper studies power consumption property, mixing time property ($\theta_m$), shearing performance and the property parameters of the axial impeller (AFI). In the paper, the result shows that: the power consumption rule of the double impeller mechanism of different impeller combinations follows the acting rule under the single impeller stirring mechanism. $\theta_m$ of “RFI+AFI” double impeller configuration is shortened along the increase of distance between the impellers; $\theta_m$ reflects different secondary flow circulation influence modes under the condition of different distances between the impellers along the change rule corresponding to the impeller’s discharge performance change. Under the “RFI+AFI” double impeller configuration, the distance change of impellers within the smaller range has small influence on $\theta_m$; under the large impeller distance, $\theta_m$ has remarkable increase; the impeller’s discharge performance is enhanced; and the corresponding $\theta_m$ is shortened. “RFI+AFI” has relatively strong shearing effect under the smaller impeller distance; along the enlargement of distance between the impellers, its shearing performance is reduced. “RFI+AFI” suffers corresponding shearing qty in the groove under the condition of different impeller distances. The discharge performance of the radial flow impeller is a main factor influencing the shearing performance of the double impeller configuration. Through studying the mixing performance corresponding to the combination of impellers with different discharge performances, it lays foundation for designing a novel and high-efficient size mixing device.

Keywords: Size Mixing, Axial Flow Impeller, Radial Flow Impeller, Shear, Mixing Time

1. Introduction

In a form of current dressing form along the ore property: fineness, impurity and difficulty, the separation gravity of granule and particulate is enlarged increasingly. If the mineral is granulized, it is easy to generate self-aggregation among granules and coordinated aggregation among the granule and other particles [1-4]. Based on the characteristics of fineness, impurity and difficulty, how to treat by high-efficient size mixing, which is the premise of achieving effective picking in poor, miscellaneous and difficult dressing [5,6]; its difficult point mainly lies on: on one hand, the granular mineral exposes the fresh surface; on the other hand, the ore pulp and medicament is fully dispersed to achieve effective contact [7]. The current study shows that one high-efficient stirring device achieves the field flow with high shearing while having forceful circulation capability [7,8]. Based on it, one of effective approaches to achieve high-efficient size mixing is to set up the double impeller configuration using the axial flow impeller and radial flow impeller as functional elements [9]. In this paper, in the process of setting up the acting mechanism combined by the axial flow impeller and the radial flow impeller, the study on the acting rule of impellers with different characteristics in combined configuration lays foundation for designing a novel and high-efficient size mixing device.

2. Model design of circulation and shear coupling formation mechanism

Based on the characteristics of secondary flow circulation, the combination of axial flow impeller and radial flow impeller has two models [9]: “Radial Flow Impeller (RFI)+Axial Flow Impeller (AFI)”
and RFI+AFI. As it is the double impeller acting system, the distance L between two impellers must generate certain influence on the acting effect of the whole flow field. Therefore, three impeller distance conditions are set in the studying process, that is zero distance (L=0), middle distance (L=2H/9, H is the liquid height in the stirring groove, which is the same with the Diameter D of the stirring groove), and large distance (L=4H/9).

### 2.1. Impeller model

The discharge performance of impeller is an important parameter to characterize the impeller performance and characterize the circulation/sharing property under the action of impellers with different types. Therefore, the impeller selects Impulse impellers with different levels of discharge performance (II), 4-pitched-blade opening-type turbine (4PBT, the angle θ of the pitched blade is 45°), 4-pitched-blade opening-type turbine (6PBT, θ is 45°), 2-pitched-blade paddle-type impeller (2PBI, θ is 45°) and 4-direct-blade opening-type turbine (4DBT, θ is 90°), 6-direct-blade opening-type turbine (6DBT, θ is 90°) are used as the representatives of axial flow impeller and radial flow impeller respectively for studying the characteristics of double impellers with different models. The power consumption property and the discharge performance of each impeller are as below:

\[
P_{I}^{2PBI} < P_{II}^{4DBT} < P_{IV}^{4PBT} < P_{V}^{6PBT} < P_{V}^{4DBT}
\]

\[
K_{qd}^{II} > K_{qd}^{4PBT} > K_{qd}^{4DBT} > K_{qd}^{2PBI}
\]

\[
K_{qd}^{6DBT} > K_{qd}^{4DBT}
\]

Wherein, \( P \) - power dissipation under the same operating condition; \( K_{qd} \) - discharge capacitance value; its physical significance is the discharge flow rate under the unit consumption [10].

If the axial flow impeller is down flow, it shall mark “D” at the end of word; correspondingly, if it is up-flow, it shall mark “U” at the end of word. The double impeller configuration mainly studied is listed as Table 1.

<table>
<thead>
<tr>
<th>Double impeller combination form</th>
<th>Double impeller model</th>
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</thead>
<tbody>
<tr>
<td>RFI+AFI</td>
<td>4DBT+2PBID</td>
</tr>
<tr>
<td>AFI+RFI</td>
<td>2PB+4DBT</td>
</tr>
<tr>
<td></td>
<td>4DBT+4PBTD</td>
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<td>6DBT+6PBTD</td>
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<td>4PBTU+6DBT</td>
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</table>

### 2.2. Configuration of accessories

The baffle plate is a key accessory for achieving the shearing effect effectively [11]. Therefore, the baffle plate becomes a necessary auxiliary unit in designing double impeller model.

### 3. Mixing characteristic research under the action of "RFI+AFI"

#### 3.1. “RFI+AFI” power consumption and mixing time(θm) characteristic

Figure 1 shows the PV-N-θm relationship diagram of each RFI+AFI stirring mechanism under the conditions of different rotational speed N. Under the condition of different impeller distances, PV
increases along the increase of N; the higher N is, the more obvious the increase trend is. Under the condition of each stirring mechanism, PV corresponding to $L=2H/9$ is equal to that corresponding to $L=4H/9$. It shows that under the smaller impeller distance, the PV is larger; along the increase of $L$, PV decreases gradually; when $L$ increases to a certain degree, the change of the impeller's position generate no large influence on PV. Therefore, it can reflect the coupling of secondary flow circulation of two impellers in the process of enlarging the impeller distance: with the coupling in a flow field, the resistance suffered by the impeller decreases in the driving process, thereby reducing the corresponding power consumption.

In terms of mixing time, $\theta_m$ shortens rapidly along the increase of N; but its shortening trend becomes smooth gradually, that is $\theta_m$ has no obvious decrease after N rises to a certain level. Under the condition of different impeller distance, the overall feature of each stirring mechanism is that $\theta_m$ shortens along the increase of L.

Furthermore, analyze the acting effect corresponding to different types of impellers:

1) Compared with figure 1①~④, under the same condition of radial flow impeller configuration and operating condition, PV rule follows the acting rule under the axial flow single-impeller stirring mechanism, that is:

\[
P_{\text{4DBT+2PBID}} < P_{\text{4DBT+4PBTD}} < P_{\text{4DBT+6PBTD}}
\]  

However, corresponds to different rules under the different impeller distance conditions; it shows that secondary flow circulation has different mutual influence modes under the effect of two types of impellers.

① When $L$ is 0, the $\theta_m$ rule is:

\[
\theta_{m4DBT+2PBID} > \theta_{m4DBT+4PBTD} > \theta_{m4DBT+6PBTD} > \theta_{m4DBT+IID}
\]  

At that time, the double impeller configuration can be considered as a single impeller with special configuration; along the increase of discharge performance of axial flow impeller, the required $\theta_m$ shortens under the same operating condition.

② When $L$ is $2H/9$, the $\theta_m$ rule is:

\[
\theta_{m4DBT+2PBID} > \theta_{m4DBT+IID} > \theta_{m4DBT+4PBTD} > \theta_{m4DBT+6PBTD}
\]

The discharge performance of the axial flow impeller is strengthened within a certain range, which can realize the shortening of $\theta_m$; when the discharge performance of the axial flow impeller exceeds a certain strength range, $\theta_m$ increases. Combined with the analytical conclusion of PV, there is a certain coupling degree in the flow field between two impellers; the discharge capability of the axial flow impeller is enhanced, which can effectively achieve co-strengthening with the flow field of the radial flow impeller; therefore, the mixing time is obviously shortened compared with $L=0$. But after the discharge performance of the axial flow impeller exceeds a certain range, it can generate negative function, that is the over-strong discharge performance of the axial flow impeller will damage the balance state of the flow field coupled with the radial flow impeller.

③ When $L$ is $4H/9$, the $\theta_m$ rule is:

\[
\theta_{m4DBT+6PBTD} > \theta_{m4DBT+4PBTD} > \theta_{m4DBT+IID} > \theta_{m4DBT+2PBID}
\]

The acting scope of the impeller expands further along the enlargement of $L$; compared with $L=2H/9$, its corresponding $\theta_m$ is decreased further. But the descending rule of $\theta_m$ reflects that there
is certain restriction of secondary flow circulation of the axial flow impeller and the radial flow impeller in the mutual coupling process: the stronger the discharge performance of the axial flow impeller, the more the corresponding $\theta_m$ is; when the discharge performance of the axial flow impeller strengthens to a certain degree, the restriction balance is broken; and $\theta_m$ has the descending trend.

2) Compared with figures 1③ and ⑤, under the same condition of axial flow impeller model and operating condition, if strengthening the discharge performance of the radial flow impeller, PV increases; and the corresponding $\theta_m$ is shortened effectively.

**Figure 1.** The relationship of PV, N and $\theta_m$ of “RFI+AFI” double-impeller configuration ①4DBT+2PB1D; ②4DBT+I1D; ③4DBT+4PBTD; ④4DBT+6PBTD; ⑤6DBT+4PBTD
3.2. “RFI+AFI” shearing characteristic

$C_S$ is used to weigh the shearing qty suffered by the flow in the groove:

$$C_S = \left( \frac{1}{N} \right) \sqrt{P_v / \mu}$$  \hspace{1cm} (8)

In the formula, $\mu$ is the power viscosity of flow Pa•s; $C_S$ physical significance is the shearing qty suffered by the flow when the stirring impeller rotates for one revolution [11].

The figure 2①~⑤ shows the shearing property curves under the action of various RFI+AFI double impeller configuration. The shearing property of various stirring mechanism increases along the increase of $N$; but its increasing trend slows down gradually. Under the condition of smaller impeller distance ($L=0$), the shearing property is relatively strong in the flow field; along the enlargement of the impeller distance, the shearing performance decreases; and its variation extent is smaller: the shearing qty suffered by the fluid inside the groove under the conditions of $L=2H/9$ and $L=4H/9$ is the same. Under the condition of radial flow impeller mode and the same operating condition, analyze it compared with figures ①~④. The discharge performance of the axial flow impeller increases; the shearing performance is improved but the increase extent of $C_S$ is limited. It shows that the axial flow impeller is not the main factor influencing the shearing performance of the double impeller configuration.

Compared with figures ③ and ⑤, under the condition of axial flow impeller mode and the same operating condition, the enhancement of discharge performance of the radial flow impeller has obvious influence on improving the shearing performance. Compared with figure 2④ further, under the same condition of double impeller configuration (4DBT+4PBTD), the promotion extent on $C_S$ by enhancing the discharge performance of the radial flow impeller is more obvious than the discharge performance...
of axial flow impeller. Therefore, the discharge performance of the radial flow impeller becomes a main factor influencing the shearing performance of the double impeller configuration.

4. Mixing characteristic research under the action of "AFI+RFI"

4.1. AFI+RFI power consumption and mixing time property

Figures 3①~⑤ shows the corresponding relation of the power dissipation and the mixing time of various AFI+RFI stirring mechanisms under the condition of different rotational speeds. As it is improper to operate at a high rotational speed under the condition of L=4H/9, it mainly observes the acting effects under two different distance conditions of L=0 and L=2H/9 after N=500rpm. Under the condition of different impeller distances, PV increases rapidly along the increase of N; in the process of changing from L=0 to L=4H/9, the corresponding PV has small change extent, which shows L has small influence on PV.

Figure 3. The relationship of PV, N and θm of “AFI+RFI” double-impeller configuration
① 2PBIU+4DBT; ② IIU+4DBT; ③ 4PBTU+4DBT; ④ 6PBTU+4DBT; ⑤ 4PBTU+6DBT

θm keeps the corresponding decrease relation along the increase of PV. The corresponding θm when L=0 and L=2H/9 has small difference that: it only has slight difference at a low rotational speed (N<500rpm); and it is the same at a high rotational speed, which shows that L has small influence on θm when L changes in a small scope. Although it only measures θm at a low rotational speed when L=4H/9; and the θm corresponding to small impeller distance has large remarkable result.

Further, analyze the corresponding acting effects in an angle of different impeller models:

1) When comparing and analyzing figures 3①~④, under the condition of radial flow impeller mode and the same operating condition, PV still follows the acting rule corresponding to the axial flow single impeller, that is:
The change rule of \( \theta_m \) caused by the difference of discharge performance of axial flow impeller shows consistency under the condition of various impeller distances:

\[
P_{V_2PBHU+4DBT} < P_{V_4IU+4DBT} < P_{V_4PBTU+4DBT} < P_{V_6PBTU+4DBT}
\]

(9)

Along the enhancement of discharge performance of axial flow impeller, the corresponding \( \theta_m \) shortens.

2) Compared with figures 3③ and ⑤, under the condition of axial flow impeller mode and the same operating condition, the discharge performance of the radial flow impeller is enhanced; the corresponding PV increases and \( \theta_m \) shortens.

With regard to the same impeller combined model, PV of AFI+RFI has remarkable increase than that of RFI+AFI; and this increasing trend enlarges along the increase of L. The analytical reasons are as below: different from the downward discharge qty of the axial flow impeller of RFI+AFI, the discharge flow of the axial flow impeller in AFI+RFI is upward; in the process of flow field, the axial flow impeller also overcomes the gravity of fluid while giving certain kinetic energy to the discharge flow. When L is smaller, the axial suction effect of the radial flow impeller can give assistance; but along the increase of L, the auxiliary effect of the radial flow impeller is reduced; the driving requirement of the axial flow impeller increases, thereby causing the enlargement of power consumption in the impeller driving process. Within the small impeller distance scope, \( \theta_m \) corresponding to AFI+RFI and RFI+AFI is small obviously; under the condition of large impeller distance, \( \theta_m \) corresponding to AFI+RFI is larger than that of RFI+AFI obviously.

4.2. AFI+RFI shearing property

The figure 4①~⑤ shows the shearing property curve corresponding to each stirring mechanism under AFI+RFI double impeller configuration. It can be seen that the shearing qty suffered by the fluid inside the groove is equal under different impeller distance conditions.
The enhancement of discharge performance of axial flow impeller has small promotion extent on its corresponding shearing performance; and the enhancement of discharge performance of radial flow impeller has obvious promotion effect on its shearing performance. Therefore, the radial flow impeller gives prominence to the shearing effect; and thus it has large influence on the shearing performance of the flow field.

Compared with RFI+AFI, CS value corresponding to AFI+RFI is larger obviously, and thus the shearing performance of its flow field is higher.

5. Conclusion

The dressing on different ores has both common and different stirring requirements on the corresponding size mixing units. The convective circulation inside the stirring groove is a flowing state necessary for each size mixing process; but the dressing has different requirements on turbulent diffusion (shearing effect). The key to R&D of high-efficient size mixing equipment lies in how to achieve full contact between mineral particles and medicaments in a short time and thus achieve better size mixing effect. Therefore, in the acting effect of the double impeller configuration, θm and CS shall be used as the evaluation keys. Through combined configuration on the impellers with different performances, analyze the rules influencing its mixing performance to obtain the conclusions as below:

1) The power consumption action rule of double impeller mechanism combined by different impellers follows its action rule under the single impeller stirring mechanism; therefore, it can show that the power consumption property of the double impeller is determined by the power consumption property of each single impeller in nature.

2) Under the condition of different impeller distances, θm overall property of each stirring mechanism in RFI+AFI is that: along the increase of L, θm shortens. Under the condition of different impeller distances, θm corresponding to the change of discharge performance of the impeller has
different change rules, which shows different mutual influence modes of secondary flow circulation under the effect of two models of impellers.

3) Under the condition of different impeller distances, $\theta_m$ overall property of each stirring mechanism in AFI+RFI is that: L has small influence on $\theta_m$ within a smaller scope. Under the condition of large impeller distance, $\theta_m$ increases obviously; the discharge performance of the impeller enhances; and the corresponding $\theta_m$ shortens.

4) Under the condition of smaller impeller distance, the shearing effect in the flow field is strong relatively; along the enlargement of the impeller distance, the shearing performance decreases in a small change scope. In AFI+RFI, the shearing qty suffered by the fluid inside the groove is equal under the condition of different impeller distances. The discharge performance of the radial flow impeller is a main factor influencing the shearing performance of double impeller configuration.

5) Under the same condition, compared with RFI+AFI, the power consumption of AFI+RFI increases remarkably; and the shearing performance of its corresponding flow field enhances. Within a small impeller distance scope, $\theta_m$ of AFI+RFI is smaller than that of RFI+AFI obviously; under the condition of large impeller distance, $\theta_m$ of AFI+RFI is larger than that of RFI+AFI obviously.

Under a new status, it requires more comprehensive performance for size mixing; therefore, one of the developing requirements is to combine characteristics and couple them to a novel size mixing mechanism with regard to different stirring mechanisms. The double impeller configuration shapes a stirring action mechanism characterized by double sections initially while merging the strong circulation and strong shearing action successfully, that is a double-section mode of combining high-efficient powerful circulating mixing and high shearing and stirring, which provides the practical basis for developing a novel, high-efficient and modified size mixing device.

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7. References

