Experimental Research on Mixing and Motion with Discontinuous Feed for Oil Shale Particle Groups in Rotary Kiln

Lidong Zhang¹, Xuan Zhang², Shaohua Li², Qing Wang²

¹North China Electric Power University, Beijing, 102206, China, Northeast Dianli University, Jilin, Jilin province, 132012, China
²Northeast Dianli University, Jilin, Jilin province, 132012, China

Abstract

A series of experiments were carried out to explore the characteristics and mixing of oil shale grains with diameter of 0~12mm in rotary kiln. Influence of rotational speed, filling degree and lifting flights forms on mixing efficiency were analyzed. Results showed particle group movement traces and mixing process was significantly affected by the filling degree, the rotational speed and the lifting flight forms. With the increase of filling rate, the particle size was easily to produce separate effects; however, with the decrease in speed, the mixing of particle size with rectangular lifting flight was better than that of straight lifting flight.

1. Introduction

Rotary kiln was widely used in chemical and metallurgical process, such as large-scale cement rotary kiln, ball mill, etc. Rotary kiln has many advantages such as the adjustment flexibility and wide adaptability of materials etc. Furthermore, rotary kiln as reactor can extract fossil fuels such as oil shale organic matter in order to obtain the artificial oil.

Mixing of particles is very complex, mixing degree of particles depends on the kiln structure, particle shape and size, distribution and other factors. Reference [1] studied the influence of filling degree and rotational speed on mixing effects of silica particles with the diameter of 2~3mm in cylinder rotating, results showed that with the increase of filling degree and rotational speed, the trend of particle motion flow regimes transfer from the rolling mode to cascading mode; YL Ding et al [2] studied on the mixing of 1.5mm glass particles by mathematical analysis in the cylinder without flights in the low-speed conditions; ZHAO Gai-Ju et al [3] summarized motion mode of materials in rotary dryers and drew that solid filling degree and scatter material model to optimize the flights. These studies are mostly concentrated on the dry, metallurgy and other small homogeneous grain particle motion study, for the research on motion patterns of non-uniform oil shale particles size distribution in the rotary kiln have not yet reported.
In current paper, the mixing process of oil shale with different size distribution in the rotary kiln was learned by observing the mixing effect so as to master the influence of filling degree, rotational speed and other operating parameters on particle motion patterns, furthermore, the mixing mechanism of oil shale group was studied in order to provide the experimental basis for the design and operation of the rotary kiln in thermal state.

2. Rotary structure dimensions and experimental design

Rotary kiln is the basic mixer by mixing the solid heat carrier and the oil shale or oil sands in order to extract oil by retorting. Inner diameter of experimental rotary is 125mm, axial length is 600mm, six flights were arranged interiorly, rotary kiln is installed horizontally and rotating around its central axis with the speed of 0~20 rpm, also particle diameter distribution is from 0 mm to 12 mm, the experimental parameters were showed in table 1.

Table 1 Experimental parameters

<table>
<thead>
<tr>
<th>Flights forms</th>
<th>Filling degree</th>
<th>Rotational speed(rpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>straight flights</td>
<td>1/6, 1/3, 1/2</td>
<td>17, 13.3, 10, 6.8, 3.4</td>
</tr>
<tr>
<td>rectangular flights</td>
<td>1/6, 1/3, 1/2</td>
<td>17, 13.3, 10, 6.8, 3.4</td>
</tr>
</tbody>
</table>

3. Experimental Results and Analysis

A. Analysis on factors have influence on mixing with straight flights and particle mixing mechanism

1) The influence of rotational speed and filling degree on particles mixing and motion

Figure 1 respectively show six kinds of flow regime[4] such as slipping, slumping, rolling, cascading, cataracting, and centrifuging in nonflighted rotary kiln due to difference in rotational speed.

![Fig.1 particles six movement modes in drum kiln](image)

Table 2 show the mixing and motion of oil shale in rotary kiln containing straight flights, filling degree 16.7%, 33.3%, 50%, respectively, rotational speed from 17 rpm to 3.4 rpm.

Particle mixing and motion in rotary kiln containing straight flights under different filling degree see as figure 2. As can be seen from Table 1, when the filling degree is 16.7%, the prevent corona on particles group is decline by the straight flights with the decrease of speed, resulting in particle trajectories away from cylinder center (as in figure 2-a), with the filling degree increase from 33% to 50% (as in figure 2-b, 2-c), particle group in upper layer form a slip region, while in the middle region of particle group a vortex was formed, we can observe a relatively stationary region in vortex center where particle group is relatively still, it increases with the decrease of rotational speed, the flow regime is analogous to the conversion from fall to slip in rotary kiln without flights..
Particle groups mixing also accompanied by particle group separation. Larger particles tend to appear in the upper layer or accumulate in the lower layer of particles group, which is adverse to particles mixing. The mixing mechanisms includes convection, diffusive and shear mixing. Convective mixing is that particles migration and position change, it is relevant to kiln structure and the agitation, diffusive is that redistribution of particle position because of collision between particles; shear mixing refers to the particle slip from slip surface and mixed[5]. As can be seen from Table 2, when the filling degree is 16.7%, particles were “lifted and castrated” periodically; the castrating velocity of particles and force acting on particles is different in the castrating process, therefore, segregation of particles was occurred. Convective mixing plays a dominant role at this time, the diffusive plays a subsidiary role, and no shear mixing exist. When the filling degree was increased to 50%, convective mixing still plays a dominate role, the shear mixing occurs in the slip layer and the shear layer of vortex center, the gap between large particles results in the diffusive mixing. When the filling degree is fixed, shear layer becomes smaller and smaller, shear mixing gradually weakened with the decrease of rotational speed; the diffusive mixing will be accompanied by the entire mixing process due to the irregular of particle shape.

B. Analysis on factors have influence on mixing with rectangular flights and particle mixing
mechanism

1) The influence of rotational speed and filling degree on particles mixing and motion

The experimental parameters with rectangular flights were showed in Table III.

Table III particle motion status under different filling degree and rotational speed with straight flights

<table>
<thead>
<tr>
<th>Filling degree</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>17r/min</td>
</tr>
<tr>
<td></td>
<td>13.3r/min</td>
</tr>
<tr>
<td></td>
<td>10 r/min</td>
</tr>
<tr>
<td></td>
<td>6.8 r/min</td>
</tr>
<tr>
<td></td>
<td>3.4 r/min</td>
</tr>
<tr>
<td>16.7%</td>
<td></td>
</tr>
<tr>
<td>33.3%</td>
<td></td>
</tr>
<tr>
<td>50%</td>
<td></td>
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</tbody>
</table>

Figure 3 shows the mixing and motion of oil shale in rotary kiln containing rectangular flights with different filling degree.

As can be seen from Table 2, when the filling degree is 16.7%, the prevent corona on particles group is decline by the rectangular flights with the decrease of speed from 17rpm to 3.4rpm, and the change of particle trajectories is not obvious due to the bend segment of rectangular flights have lifted part of particles, moreover, the rotational speed is far lower than critical speed[6] 305rpm (as in figure 3-a), with the filling degree increases from 33% to 50% (as in figure 3-b, 3-c), particle group in upper layer form a slip region, while in the middle region of particle group a vortex was formed, we can observe a relatively stationary region in vortex center where particle group is relatively still, the relatively still region increase with the decrease of rotational speed, which is analogous to motion regime of particle in rotary kiln containing straight flights.

Fig.3 particle motion in rotary kiln containing rectangular flights
   a-filling 16.7%; b- filling 33.3%; c- filling 50%

2) Analysis on mixing mechanism of oil shale particle groups in rotary kiln containing rectangular flights.

Particle groups mixing also accompanied by particle group separation. Larger particles tend to appear
in the upper layer or accumulate in the lower layer of particles group. As can be seen from table 3, when
the filling degree is 16.7%, the thickness of particle group is inferior to height of flights; therefore,
particles were “lifted and castrated” periodically, while residence time of particles is longer than that of
rotary kiln containing straight flights. Segregation of particles was occurred due to heterogeneous force
acting on particles in the castrating process, convective mixing plays a dominant role at this time, and no
shear mixing exist. When the filling degree was increased to 50%, convective mixing still plays a
dominate role, apart from lifting process, the relative still zone and slip layer still exist, shear mixing
occurs in the slip layer and the shear layer of vortex center. When the filling degree is fixed, shear layer
became smaller and smaller, shear mixing gradually weakened with the decrease of speed; the overall
mixing effect is decline.

4. Conclusion

- Research result suggests that mixing mechanism and motion of particles is very complex though
the structure of the rotating kiln is simple; and the separation is accompanied in the mixing process.
The flow regime and mixing effects are affected by flights forms, filling degree, rotational speed and
other factors.
- When the filling degree is less than 33%, the mixing effect with rectangular flights is better than
that of straight flights with the decrease of speed; when the filling degree is close to 50%, mixing
effect of rectangular flights and straight flights are declined with the decrease of speed.
- From the aspect of mixing mechanism, When the filling degree is less than 33%, the mixing
mechanism transformed from convective mixing into shear mixing with the decrease of speed, and
the overall mixing effect is decline, when the filling degree is up to 50%, the mixing extent of oil
shale particle with rectangular flights is superior to that of straight flights.

References

to medium rotational speeds.” Chemical Engineering Science, 2001, 56 (3) : 1769-1780.