Study on the Circulating Flow Rate of Rice Husk-Quartz Sand Mixture Particles in a Dual-Circulating Fluidized Bed

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Abstract. In order to more accurately simulate the flow characteristics of biomass particles in biomass gasification process, an experimental study was conducted on the circulating flow rate of rice husk-quartz sand mixture on a self-built dual circulating fluidized bed cold experimental system. The circulation flow rate increased with the increase of the gasification chamber wind speed ($U_a$), but the growth trend gradually slowed down. With the increase of the mass fraction of rice husk ($X_r$) in the mixed material, the circulating flow rate showed a decreasing trend under various operating conditions. The $X_r$ in the circulating material basically showed a decreasing trend, and increased with the increase of the wind speed of riser ($U_r$). The trend of increase in the lower wind speed interval was larger. After a certain wind speed value was reached, the increase trend of particles gradually became slower, and the circulating material mass fraction $X_r$ showed a decreasing trend, and the decreasing trend gradually increased; with the increase of the initial material mass ($m_{in}$), the flow rate of material circulation increased to a certain extent. The $X_r$ in the mixed material gradually increased. Under the conditions of the respective mass fraction of mixed material, the particle size of quartz sand ($d_p$) in the mixed material increased, the circulating flow rate of the particles gradually decreased, and the mass fraction of biomass in the riser decreased gradually.

Introduction

Biomass energy has a wide range of distribution and abundant storage. The product heat content of its gasification technology was 12-20 MJ/m$^3$, with a high utilization rate. It was a new technology to replace fossil energy. In order to improve the efficiency of biomass gasification reaction, researchers at home and abroad have studied different types of gasification devices[1-4], and found that the dual-circulating fluidized bed not only retains the features of enhanced heat, mass exchange and mixed flow in the fluidized bed, but also partitions different stages of the gasification reaction process, which could effectively improve the production efficiency and quality of the final product. The dual-circulating fluidized bed includes two parts, a gasification chamber (bubbling fluidized bed) and a riser (fast fluidized bed). Among them, biomass gasification reaction mainly takes place in a gasification chamber: biomass and water vapor and other gasification agents react there, and the generated gas products (CH$_4$, CO, H$_2$, etc.) are separated by a separation device and then stored in a subsequent purification device. The semi-coke formed when the biomass was not fully gasified enters the riser together with an inert heat carrier (to provide the heat required in the gasification reaction, usually quartz sand), and burns mixed with the air in this zone. The heat was absorbed by the heat carrier, and the combustion products enter the subsequent device together with the flue gas through the separation device, and the heat carrier was separated by the separation device and enters into the gasification chamber again to provide heat for the gasification reaction of the biomass [5-10].

The material circulation flow rate between two beds in a dual-circulating fluidized bed system was the key to maintaining a highly efficient gasification process, and to a certain extent the operating level in the reaction bed [11]. At present, for the research on the material circulation flow rate of the
dual-circulating fluidized bed, scholars at home and abroad often use single materials such as quartz sand for research [12-13]. It was not exactly the same as the use of biomass-inert heat carrier two-component particles in actual industrial production. There are some differences, reflecting the role of biomass-inert heat carrier mixture particles in the flow process. Therefore, the study on the particle circulating flow rate of the inert heat carrier (quartz sand) and the biomass (rice husk) mixed material under different control parameters and material composition ratio was conducted on the self-designed dual-circulating fluidized bed cold system, in order to obtain the flow characteristics of particles with large density difference.

**Experimental System and Experimental Methods**

**Experimental System**

System used in this paper was shown in Figure 1. In order to facilitate the observation of the fluidization of the particles in the experimental process, the experimental system was constructed with 6 mm thick plexiglass. The main components included a riser, a cyclone separator, a riser, a gasification chamber, a lower return pipe, and other auxiliary devices. The gasification chamber has a cylindrical shape with an inner diameter of 200 mm and a height of 2000 mm; the inner diameter of the riser was 75 mm and the height was 6000 mm; the inner diameter of the riser was 50 mm, and the lower connection was 100 mm from the distributor plate of the gasification chamber. The inner diameter of the lower connection pipe was 30 mm, and the arrangement angle was 55°. The distance between the upper inlet and the gasification chamber air distribution plate was 80 mm; the air distribution device adopts the dense hole plate type, and the opening rate was 25%, opening diameter was 6 mm, in order to prevent material from entering the air chamber, a sifter of 75 µm was laid on the sealing orifice plate. In the experimental system, the air supply of different fluidized beds was independently provided by two fans. The fan model number was 9-26No5.6. The rotor and flowmeters on the air supply pipe are used to measure and control the air flow, respectively, for adjusting the flow velocity. The inert heat carrier used in the experiment was quartz sand with a particle density of 2450 kg/m³, a bulk density of 1480 kg/m³, a sphericity of 0.57 and a particle size range of 0.150 to 0.550 mm. After the material was sieved, different proportions were used to obtain materials with different average particle sizes (0.21 mm, 0.33 mm, and 0.49 mm). Using the air-blown method [14], the particles at the two average particle diameters were measured in the experimental system to achieve a fast fluidization initiation transport rate, which was \( U_{tr, 0.21} \) as 2.84 m/s, \( U_{tr, 0.33} \) as 3.36 m/s, \( U_{tr, 0.49} \) as 4.06 m/s. The common rice husk was selected for the biomass material and its shape was spindle-shaped with a bulk density of 94 kg/m³.

![Figure 1. Cold state test apparatus of dual circulating fluidized bed.](image-url)
Experimental Methods and Working Conditions

Circulating flow rate measurement: First, add a certain amount of mixed rice husk-quartz sand particles on the side of the gasification chamber, turn on the fan to adjust the air volume value, and then start the fan on the side of the riser, adjust the control valve to the requiring conditions then close the quick shut-off valve of standpipe to collect material, after a certain period of time, opens the quick-close valve at the again to complete the material collection process. Weighed and measured the collected materials. Then, according to the material collection quality and the size of the riser and the time of material collection, the circulating flow rate of the mixed particles of the riser section was calculated by Equation 1. The selection of control parameters during the experiment was shown in Table 1.

\[ G_s = \frac{m_s}{S_r \Delta t} \quad (1) \]

In the Formula 1, \( m_s \) was the mass of the mixed material in a certain period of time, kg; \( S_r \) was the cross-sectional area of the riser, \( m^2 \); \( \Delta t \) was the time required to collect a certain mass of material, s; \( G_s \) was the particle circulation flow per unit area in the riser Rate, kg/(m\(^2\)·s). For the materials collected under each working condition, the quartz sand and the rice husk particles were sieved and then weighed separately. The mass of quartz sand and rice husk under each working condition was measured, and then the biomass was processed. Calculated the proportion of biomass and draw the relationship between biomass ratios under different conditions.

Table 1. Experimental conditions.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air velocity of gasification chamber / m·s(^{-1})</td>
<td>0.27/0.31/0.35/0.40/0.44/0.49/0.53</td>
</tr>
<tr>
<td>Air velocity of riser / m·s(^{-1})</td>
<td>4.72/5.03/5.35/5.66/5.98/6.29/6.61</td>
</tr>
<tr>
<td>Diameter of quartz sand / mm</td>
<td>0.21/0.33/0.49</td>
</tr>
<tr>
<td>Biomass ratio / %</td>
<td>0/2/4</td>
</tr>
<tr>
<td>Initial material mass/kg</td>
<td>6/7/8</td>
</tr>
</tbody>
</table>

Analysis of Experimental Results

Influence of the \( U_a \)

In the dual-circulating fluidized bed gasification chamber, biomass gasification reaction was mainly carried out, and carbon, hydrogen and the others in the biomass generated methane and other products. In this process, the efficiency of the gasification reaction and the flow of the biomass-inert heat carrier were mixed. The characteristics were closely related. Therefore, changing the velocity of the gasification chamber to measure the circulating flow rate of the mixed material, the influence of the velocity of the gasification chamber on the circulating flow rate of the mixed particles was studied. The particle circulation flow rate at each wind speed is shown in Figure 2.

From Fig.2, it could be seen that with the increase of \( U_a \), the circulating flow rate of the quartz sand or the rice husk-quartz sand mixed particles all showed a certain growth trend, but the growth trend gradually slowed down. For \( x_r=0\% \), when \( U_a \) increased from 0.27 m/s to 0.35 m/s, \( G_s \) increased from 9.15 kg/(m\(^2\)·s) to 13.57 kg/(m\(^2\)·s); when \( U_a \) was increased from 0.53 m/s to 0.62 m/s, \( G_s \) increased from 18.50 kg/(m\(^2\)·s) to 19.74 kg/(m\(^2\)·s). The reason for this phenomenon was that in this experiment system, when the \( U_a \) of the gasification chamber was 0.27 m/s, it was slightly larger than the initial critical fluidization velocity \( U_{mf} \), and the bed was in a preliminary fluidized state, which was higher than the material height at the lower connection pipe. The amount of material that could enter the return pipe was limited; with the increase of \( U_{ar} \), the height of the material above the return port was...
increased, and the amount of material that could enter the lower connection pipe in the gasification chamber was increased accordingly, so the particle circulation flow rate increased; After \( U_a \) increased to a certain extent, the bed in the gasification chamber was completely fluidized, the pressure above the lower connection pipe remains basically unchanged, and the power pressure drop of the material entering the return pipe was basically a constant value, so the increase of the circulation rate of the material particles gradually slowed down.

![Figure 2](image.png)

**Figure 2.** Effect of the gas velocity in the gasification chamber on the particle circulation rate \((m_{\text{in}}=7 \text{ kg}, U_r=6.92 \text{ m/s}, d_p=0.33 \text{ mm})\).

From Figure 2, it could also be found that with the increase of the \( X_r \) in rice husk-quartz sand mixed particles, the circulation flow rate tended to decrease under various conditions. The reason for this phenomenon was that the rice husk has a small density, a large volume, and an irregular shape. It tended to form large gaps when mixed with quartz sand. At lower \( U_a \), air flowed easily through gaps, making fluidization characteristics of the entire bed be worse and the inhibitory effect became more and more obvious with the increase of rice husk mass fraction. With the increase of \( U_a \), the bubbles formed in the bed of the gasification chamber become larger, which caused the expansion of the bed, and the mixing of the rice husk and the quartz sand was better, making the amount of material that possible to enter the lower connection pipe to participate in the increase in the amount of material circulation in the entire system increased. Therefore, the material circulation rate \( G_s \) under each \( X_r \) conditions increased with the increase of the \( U_a \).

**Impact of \( U_r \)**

The riser wind speed \((U_r)\) influenced the concentration, the flow characteristics of the two-component material in the riser, and the interaction between the particles of different components, which in turn affected the particle circulation flow rate. In this section, the experimental measurement and study of the \( G_s \) at different \( U_t \) were performed. The experimental results were shown in Figure 3. As could be seen from Figure 3, the \( G_s \) of the mixed particles increased with the increase of the \( U_t \) of the riser, and the increase trend in the smaller wind speed interval was larger. After reaching a certain \( U_t \), the increase trend of the \( G_s \) gradually became slower. For \( X_r=0\% \), \( G_s \) increased from 8.34 kg/(m\(^2\)-s) to 12.66 kg/(m\(^2\)-s) when the \( U_t \) increased from 5.03 m/s to 5.66 m/s, an increased of 4.32 kg/(m\(^2\)-s); when the \( U_t \) increases from 6.61 m/s to 6.92 m/s, the \( G_s \) only increased by 0.72 kg/(m\(^2\)-s).

The reason for this phenomenon was that the increased of the \( U_t \) decreased the concentration of the riser, especially the dense phase zone, to a certain extent, the overall pressure drop decreased. And the relative pressure drop between the riser and the gasification chamber increased. So the power provided to the material circulation increased. When \( U_t \) was relatively small, the change of the wind speed had a greater influence on the reduction of the material concentration in the dense phase zone, so that the relative pressure drop between the two beds increased more, so the circulating flow rate increased more; when \( U_t \) was higher, the effect of \( U_t \) changes on the decrease of the material
concentration in the dense phase region was weakened, the relative pressure drop change was no longer obvious, and the increase trend of the particle circulation rate $G_s$ gradually slowed down.

As could also be seen in Figure.3, with the increase of the $X_r$, the particle circulation rate $G_s$ decreased. The reason for this phenomenon was that the rice husk was bulky and had a small density. It was easy to form particle clusters when carried upward by the air flow in the riser pipe, which hinders the ascending movement of the quartz sand particles and could be discovered by the experimental process. Due to the large size of the rice husk, which was affected by the forces of all directions, there was also a certain movement in the radial direction (horizontal direction). This movement would also increase the hindrance to the movement of the ascending particles.

![Figure 3. Effect of $U_r$ on particle circulation rate ($U_a=0.44\text{m/s}, m_{int}=7\text{kg}, d_p=0.33\text{mm}$).](image)

**Influence of $m_{int}$**

The initial mixed material mass ($m_{int}$) of the dual-circulating fluidized bed system characterized the height that the bed could reach to, affected the bed particle concentration and the pressure difference between the two beds, and ultimately affected the circulating flow rate. The experimental measurement of the $G_s$ under the three initial mixture material masses was carried out, and the relationship between the initial bed material amount and the material circulation flow rate was obtained as shown in Figure.4.

From Figure.4, it could be found that with the increase of the $m_{int}$, there was a certain degree of increase in the $G_s$. The reason for this phenomenon was that the increase in $m_{int}$ causes the amount of material on the side of the gasification chamber to increase, and the amount and concentration of the material above the inlet of the lower connection pipe increase accordingly, and the pressure at the lower connection pipe inlet increased to pushed more particles into the return tube Participated in the cycle of the entire system, so the circulation flow rate increased accordingly.

![Figure 4. Effect of $m_{int}$ on $G_s$ ($U_a=0.44\text{m/s}, U_r=6.29\text{m/s}, d_p=0.49\text{mm}$).](image)
From Figure 4, it could also be found that the $G_s$ of $m_{\text{int}}$ increased from 6 kg to 7 kg was less than the $G_s$ of $m_{\text{int}}$ from 7 kg to 8 kg. The reason was that the position of the lower connection pipe on the side of the gasification chamber was located at about 150 mm above the air distribution plate. This corresponds to the initial material volume of 7.2 kg at the material height, so when $m_{\text{int}}=6$ kg and 7 kg, the particles entering the lower connection pipe in the gasification chamber was mainly carried by the collapse of bubbles, and the amount of material was relatively small. When $m_{\text{int}}=8$ kg, the amount of material that could enter the lower connection pipe on the side of the gasification chamber was greatly increased, so the $G_s$ greatly increased. In addition, it could be seen that with the increase of the $X_r$, the circulation flow rate was reduced to a certain extent, which was related to the fluidization hindrance effect of rice husk on quartz sand.

**Effect of $d_p$**

The average particle diameter $d_p$ of the inert medium quartz sand in the mixed material directly affected the fluidization characteristics of the mixed particles, and thus affected the particle circulation flow rate in the dual-circulating fluidized bed system. Figure 5 showed the relationship between the $G_s$ and the $d_p$ of under different control conditions.

From Figure 5, it could be seen that, under the corresponding $X_r$ working conditions, as the $d_p$ of the quartz sand particles in the mixed material increased, the $G_s$ gradually decreases. The reason was that when the $d_p$ of the quartz sand in the mixed particles was small, the initial fluidization velocity ($U_{\text{int}}$) corresponding to the mixture particles was small, and when the same $U_a$ was reached, more mixed particles could enter the riser through the lower connection pipe. In the riser, due to its lower terminal speed, more particles could enter the dilute phase zone of the riser and eventually enter the gasification chamber through the cyclone separator to participate in the entire cycle. When $d_p$ was increased to 0.49 mm, the silica sand particles were not easily fluidized due to the increase of the flow resistance, so that the particles entering the riser was reduced, and the solids particles concentration in the dilute phase area of the riser tube was reduced, finally making the $G_s$ dropped. In addition, the effect of the lower connection pipe on the larger particle size $d_p$ particles was significantly stronger than that of the small particle size particles, which also aggravated the decreasing trend of the circulating flow rate. As could be seen from Figure 5, as the mass fraction $X_r$ of the rice husk increased, the circulating flow rate of the mixed particles decreases. The reason for the analysis was that the $U_{\text{inf}}$ corresponding to the mixture particles increased with $X_r$ increased. Therefore, the fluidization amount of the material particles in the gasification chamber was relatively reduced, and the distribution of the rice husk in the material destroys the fluidization effect to a certain extent. So the amount of material particles that can enter the lower connection pipe under the same working condition was reduced, and finally the $G_s$ decreased. The larger the $X_r$, the more obvious the $G_s$ declined.

![Graph](https://via.placeholder.com/150)

(a) $X_r=0\%$

(b) $X_r=2\%$
Summary

Through the experimental study of the ratio of rice hull mass in the circulating flow rate and circulating flow rate of rice husk-quartz sand mixed particles under different working conditions on a self-built double-circulating fluidized bed system, the following conclusions have been obtained:

With the increased of $U_a$ in the gasification chamber, the $G_s$ has a certain growth trend; With the increased of the mass fraction of rice husk $X_r$ in the mixed particles, the $G_s$ showed a decreasing trend under various working conditions; $G_s$ increased with the increased of the $U_r$ and the increasing trend at smaller $U_r$ is larger. After reaching a certain $U_r$, the increasing trend of $G_s$ gradually becomes slower; With the increased of the $m_{int}$, the $G_s$ increased to a certain extent and the $X_r$ in the mixture particles gradually increased; as the $d_p$ of quartz sand in the mixed particles increased, the $G_s$ gradually decreased.

In this experiment, the rice husk-quartz sand mixture is taken as the research object, which is closer to the actual operating conditions. It provides a new idea for the study of the gas-solid mixed flow in the dual-circulating fluidized bed system, which has important guiding significance.

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References


