

Experimental Research on Blast Furnace Slag Fluidized Bed Waste Heat Recovery Device

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Abstract

Based on domestic and foreign research in the field of blast furnace slag waste heat recovery, this paper proposes a technical solution based on fluidized bed waste heat recovery. This solution can not only efficiently recover the waste heat of blast furnace slag, but also ensure the glass content of cold slag, and at the same time avoid the massive consumption of water resources, water pollution and air pollution. In this thesis, a fluidized bed waste heat recovery device is developed according to the theory of fluidized bed technology, which uses airflow to cool blast furnace slag particles to solve key problems. A high-precision fluidized bed waste heat recovery equipment test bench was built, and further experimental studies were carried out.

Keywords

Granulated blast furnace slag; Waste heat recovery; Fluidized bed.

1. Introduction

In 2020, the world's total annual steel output will be 1.878 billion tons, and China's annual output will be 1.064.8 billion tons, accounting for 56.8%. [1] The iron and steel industry is a pillar industry for China's national economic development, and it is also China's energy-intensive industry. In 2019, China's energy consumption was 4.87488 million tons of standard coal, and the energy consumption of ferrous metal smelting and rolling processing industry accounted for 13.4%. [2] In addition, the steel industry also has a very serious impact on the environment. According to statistics, the carbon emissions of the steel industry in recent years accounted for 10% to 20% of China's total carbon emissions.

At present, under the policy requirements of energy saving and emission reduction, recycling the waste heat generated in the steel production process is one of the effective means. Therefore, for the iron and steel industry, researchers around the world are actively developing various waste heat recovery technologies. Among them, mechanical centrifugal granulation is a good way to recover the waste heat of blast furnace slag. [3-5]

However, due to the size and structure of the centrifugal granulation equipment, the slag particles in the granulation bin are not enough to completely replace the heat. The temperature of the blast furnace slag after leaving the bin is between 900°C and 1000°C, which still has high residual heat. Energy, therefore, requires a secondary waste heat recovery equipment to recover the heat contained in the granulated blast furnace slag.

The fluidized bed equipment [6-7] not only has higher waste heat recovery efficiency, but also has a lower degree of blockage in the heat exchange process of blast furnace slag compared to other equipment.

2. Research and Development Plan

2.1. Technical Solution General

According to the continuous operation, high waste heat recovery, high content of vitreous principle, in view of the blast furnace slag granulation, the characteristics of the interior of the outer crust molten to study.

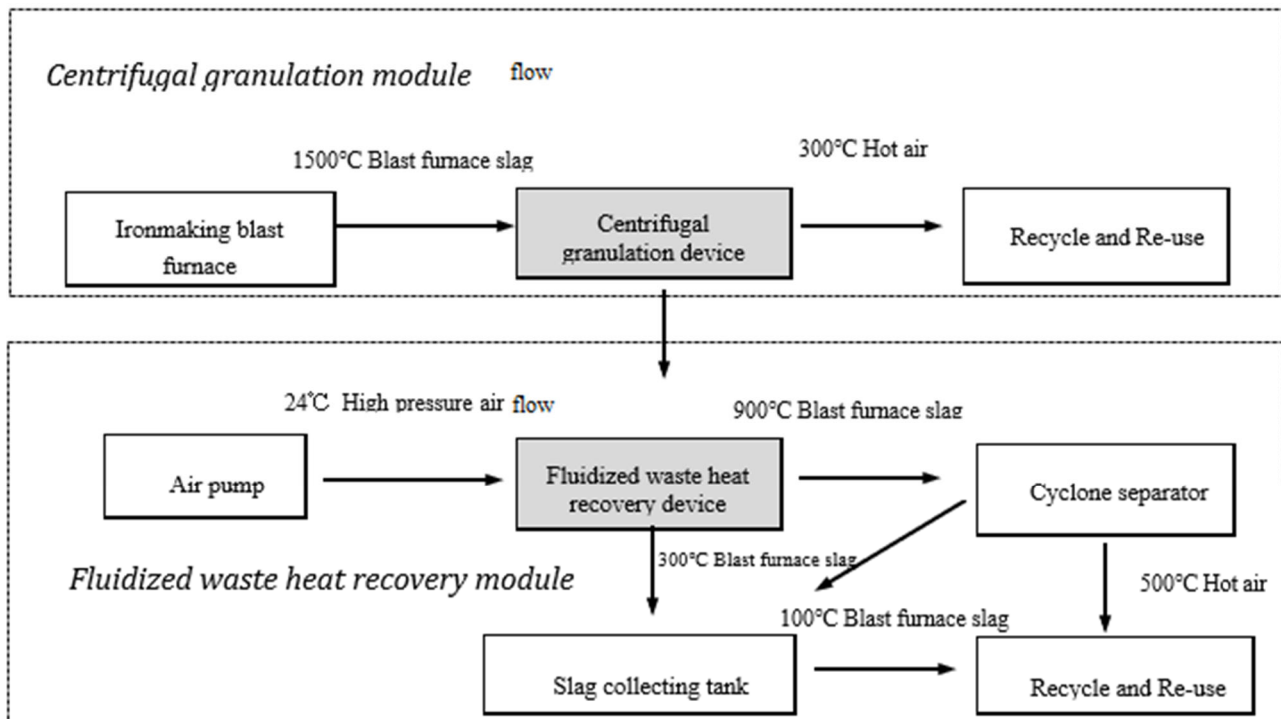
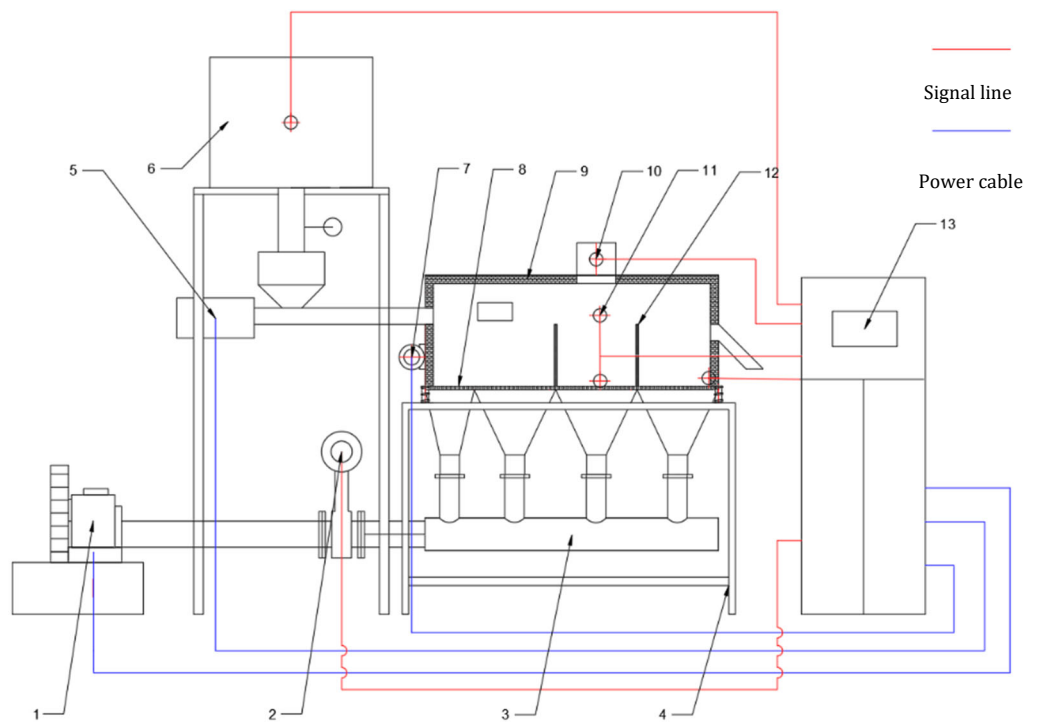


Figure 1. Technical solutions

The technical solutions shown in Figure 1, in order to achieve the goal of continuous heat exchange of slag, high waste heat recovery efficiency, and high content of blast furnace slag glass after heat exchange, a composite blast furnace slag heat exchange equipment was developed, using a bedroom fluidized combined bed.[8-9] A surging bed plus [10-11] three bubbling beds [12]. In order to prevent particles from accumulating in the fluidized bed and causing dead bed and channeling, a vibration device is added to the bed to excite the slag particles in the vertical direction. It makes the slag particles easier to fluidize, avoids dead corners, accumulation, and slag particle adhesion in the bed, thereby improving the heat exchange efficiency of blast furnace slag. The composition of the fluidized heat exchange system is shown in Figure 2.

2.2. Device Composition

The fluidized heat exchange equipment system is mainly composed of a heating device, a fluidized bed device, a vibration device, an air cooling device, and a system control device. The physical diagram of the fluidized heat exchange system is shown in Figure 3.



1. High pressure fan 2. Vortex flow meter 3. Air inlet pipe 4. Support frame 5. Feeding device
6. Heating furnace 7. Vibration motor 8. Air distribution plate 9. Fluidized bed 10.
Temperature sensor 11. Pressure sensor 12. Partition 13. Control cabinet

Figure 2. System composition



Figure 3. Physical image of fluidized heat exchange system

(1) The main body of the fluidized bed. The device includes wear-resistant insulation bricks, partitions, air distribution boards, air chambers, pre-distribution components, etc. The space in the bed is divided into four parts, consisting of a surge space and three bubbling spaces, where the blast furnace slag undergoes a fluidized heat exchange process.

(2) Heating device. The device includes high-aluminum inner wire-wound crucible resistance furnace, aluminum silicate insulation cotton, semi-closed switch, temperature transmitter, etc. The granulated slag can be heated to 1300°C for thermal experiment, and a screw feeder is installed below to quantitatively feed the fluidized bed for heat exchange.

(3) System control device. Devices include control cabinets, display instruments, detection devices, power sources, etc. The function of the device is to adjust the feeding speed and control the air inlet volume, display monitoring data, and automatically calculate and alarm.

(4) Air-cooled device. The devices include fans, gas flow meters, air inlet pipes, switches, etc. According to the measured value of the temperature transmitter, the cooling fan is adjusted after the system calculation to realize the change of the air inlet volume in the fluidized heat exchange process.

(5) Vibration device. The device includes a vibration spring, a vibration motor, a vibration motor variable frequency controller, and a fixed frame. According to the detected data, the frequency amplitude of the vibrating motor is changed, and the blast furnace slag fluidization process is adjusted to reduce the phenomenon of slag particle adhesion.

3. Experiment

3.1. Experimental Content

In order to make the heat exchange efficiency of the slag granulated particles in the fluidized bed reach more than 80%, the fluidization experiment of the slag particles was carried out on the developed fluidized heat exchange device, by changing the particle size of the blast furnace granulated slag. The through hole rate of the air distribution plate and the air volume of the air inlet can obtain several groups of optimal fluidization state parameters. Based on the traditional fluidized bed, a continuous fluidized bed suitable for the fluidized heat exchange of granulated blast furnace slag was developed, and the three important parameters of the air distribution plate through hole rate, particle size, and air intake were developed. Perform actual measurement analysis.

3.1.1. The Influence of the Through-Hole Ratio of The Air Distribution Plate on the Fluidization of Slag Particles

The through-hole rate of the air distribution board has a very important impact on the structural rigidity of the air distribution board. With the increase of the through-hole rate, the structural rigidity of the air-distribution board decreases, and the excessive through-hole rate affects the safety of production. The through hole rate of the air distribution plate also plays a decisive role in the fluidization of slag particles. For blast furnace slag particles, under different through hole rates, under the same air volume and wind speed, the fluidization state achieved is different. Therefore, the research on the through hole rate of the air distribution board cannot be ignored. For this reason, in combination with actual conditions, four different through hole rates of 5%, 10%, 15%, and 20% are selected. The wind panel is tested to find the best fluidized heat transfer parameters.

3.1.2. The Influence of Slag Particle Size on Slag Particle Fluidization

After granulation, the particle size of the blast furnace slag is generally within 0~2 mm. In order to obtain the best fluidized heat transfer effect, the slag particles are further classified according to the particle size. According to the granulation experiment, the slag particles are classified into three groups respectively. For group A (80% 0~1mm, 20% 1~2mm), group B (50% 0~1 mm, 50% 1~2 mm), group C (20% 0~1 mm, 80% 1~2 mm). These three groups of experiments to obtain the best fluidized slag particle size are shown in Figure 4.

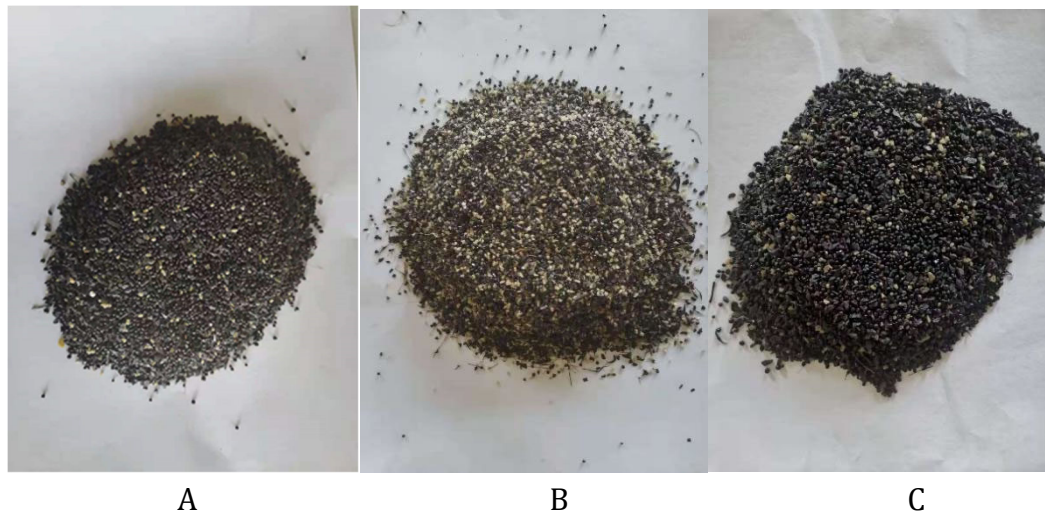


Figure 4. Diagrams of slag particles with different particle sizes

3.1.3. The Influence of Air Intake on the Fluidization of Slag Particles

In a fluidized bed, with the increase of the air intake, the bed material gradually enters the fluidized state from the static state. The larger the air intake, the more intense the movement of the slag particles. However, the larger the wind speed, the better. As the wind speed increases, the heat exchange efficiency of the slag particles increases, but at the same time the quality of the recovered waste heat decreases. Therefore, it is necessary to experiment with the air intake.

3.2. Test Results and Analysis

3.2.1. Change of Bed Pressure Drop with Gas Flow

In order to obtain the bed pressure drop that varies with the gas flow rate under different particle diameters and different air distribution plate through-hole ratios, a pressure drop meter is used to measure the pressure drop of the bed material with a height of 50 mm.

(1) (80% 0~1mm, 20% 1~2mm) mixed slag particles. The value of bed pressure drop with flow rate under different air distribution boards with different through-hole ratios is shown in Figure 5.

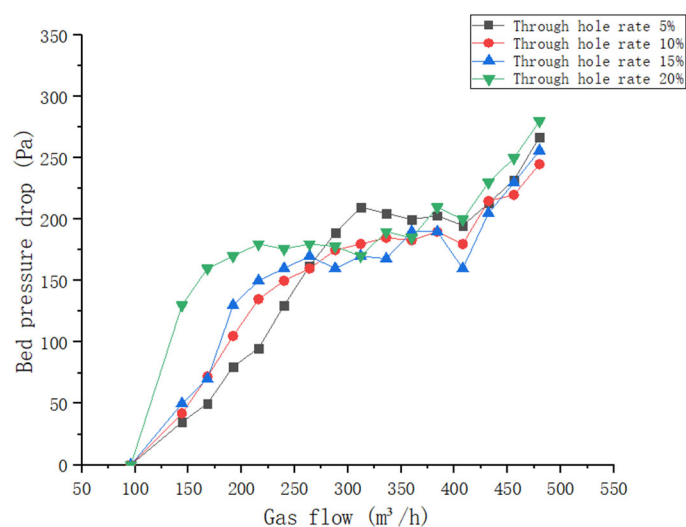


Figure 5. The bed pressure drop varies with the gas flow rate.

(2) (50% 0~1mm, 50% 1~2mm) mixed slag particles. The value of bed pressure drop with flow rate under different air distribution boards with different through-hole ratios is shown in Figure 6.

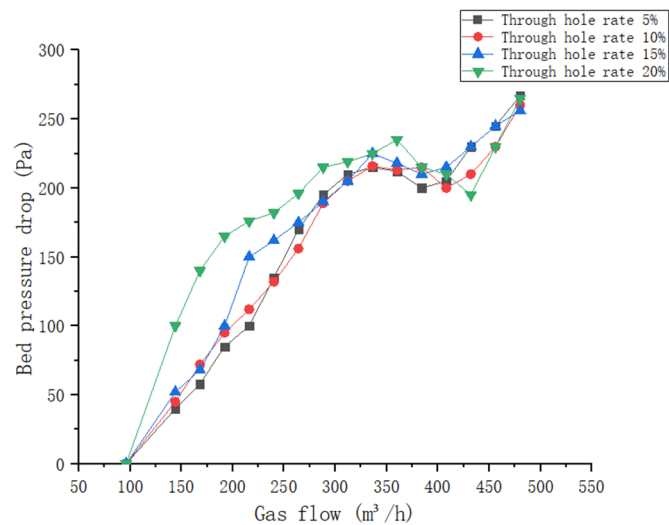


Figure 6. The bed pressure drop varies with the gas flow rate

(3) (20% 0~1mm, 80% 1~2mm) mixed slag particles. The value of bed pressure drop with flow rate under different air distribution boards with different through-hole ratios is shown in Figure 7.

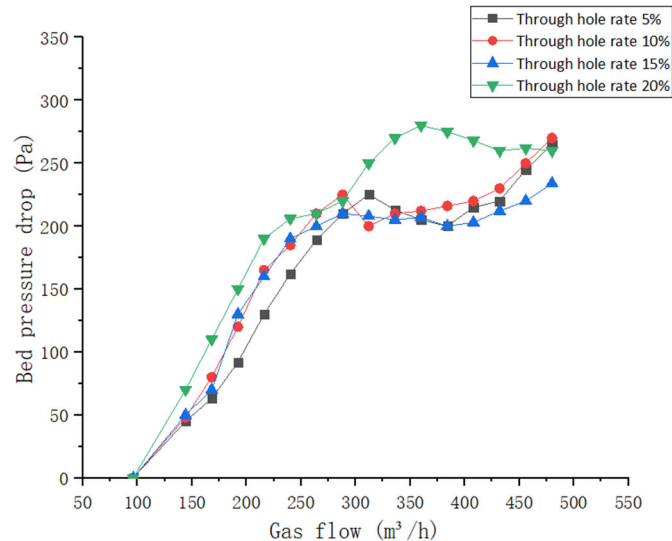


Figure 7. The bed pressure drop varies with the gas flow rate

It can be seen from Figure 5-Figure 7:

(1) The change trend of the bed pressure drop with the inlet air volume is that with the gradual increase of the air inlet air volume, the bed pressure drop rises sharply and then decreases and maintains a level up and down for a period of time. The air intake continued to increase, and the bed pressure drop subsequently continued to rise in a positively correlated trend. As shown in Figure 5, when the air volume of (20% 1-2mm, 80% 0-1mm) slag particles is from 144m³/h to 216m³/h, the bed pressure drop rises rapidly to 180pa. The pressure drop of the increased

bed is always lower than 180Pa , but when the inlet air volume exceeds $360\text{m}^3/\text{h}$, the pressure drop of the bed will rise again.

(2) With the increase of the air distribution board through-hole rate, the air inlet volume reaching the inflection point of the bed pressure drop is decreasing, and with the increase of the air distribution board through-hole rate, the air inlet volume range for maintaining the bed pressure drop at a certain level is expanding. It also shows that with the increase of the through hole rate of the air distribution plate, its fluidization state has a larger range of air intake. As shown in Figure 5, when the air distribution plate has a through hole rate of 5%, its fluidization state ranges from $288\text{m}^3/\text{h}$ to $408\text{m}^3/\text{h}$, and the air distribution plate has a through hole rate of 20%. At the time, the fluidized state range is $264\text{m}^3/\text{h}$ - $432\text{m}^3/\text{h}$, and the air inlet range of the fluidized state is increased.

(3) As the particle size of the slag particles increases, the value of the bed pressure drop reaching the inflection point increases. Under the same air distribution plate through-hole ratio, the larger the particle size of the blast furnace granulated slag, the critical fluidization wind speed will also increase. As shown in Figure 5, 6, and 7, the pressure drop inflection points are 210Pa , 215Pa , and 225Pa under the same air distribution plate through hole rate.

3.2.2. The Fluidization Effect of Different Air Distribution Boards Through Hole Rate

Detect the influence of the through-hole rate of the air distribution board on the fluidization effect. The wind speed is $V=1.287\text{m/s}$, $V=1.917\text{m/s}$, and the through-hole rate is 5%, 10%, 15%, 20%. High-speed shooting fluidization The effect is shown in Figure 8.

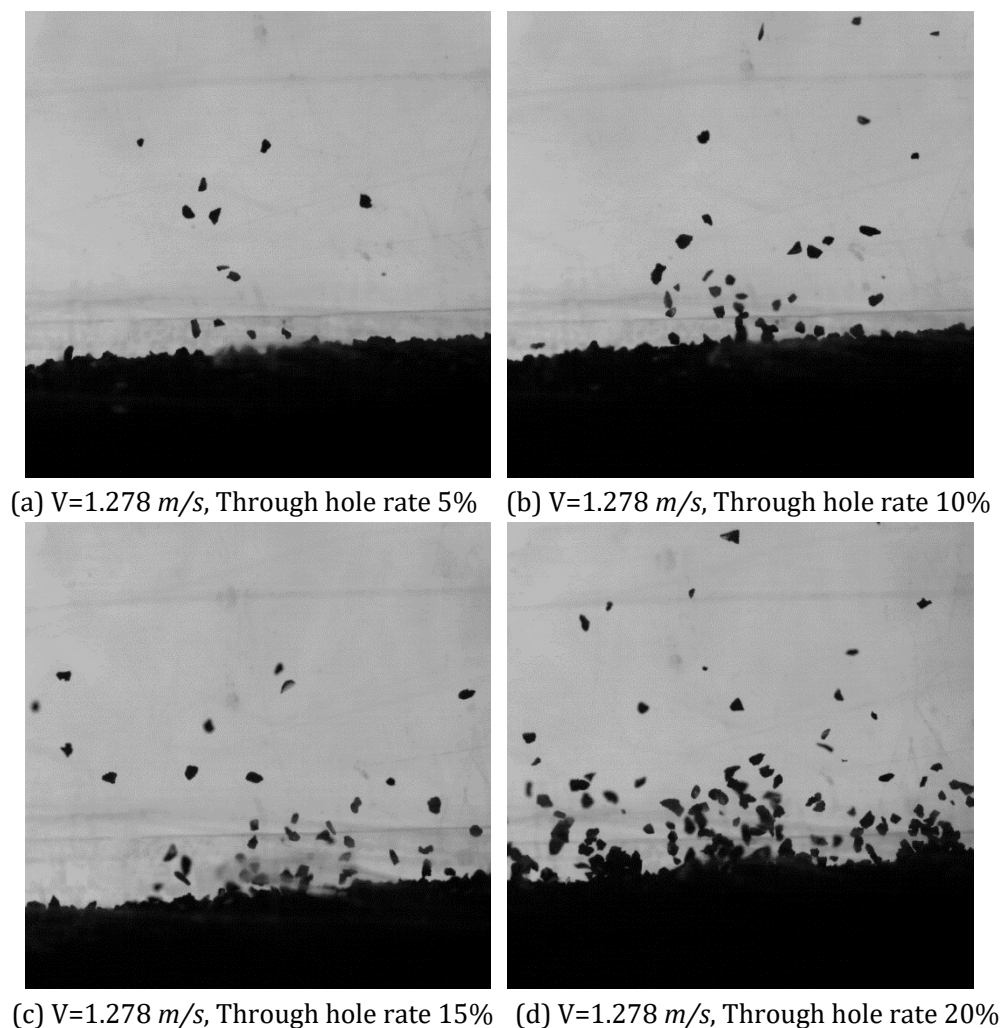


Figure 8. Blast furnace slag fluidization effect

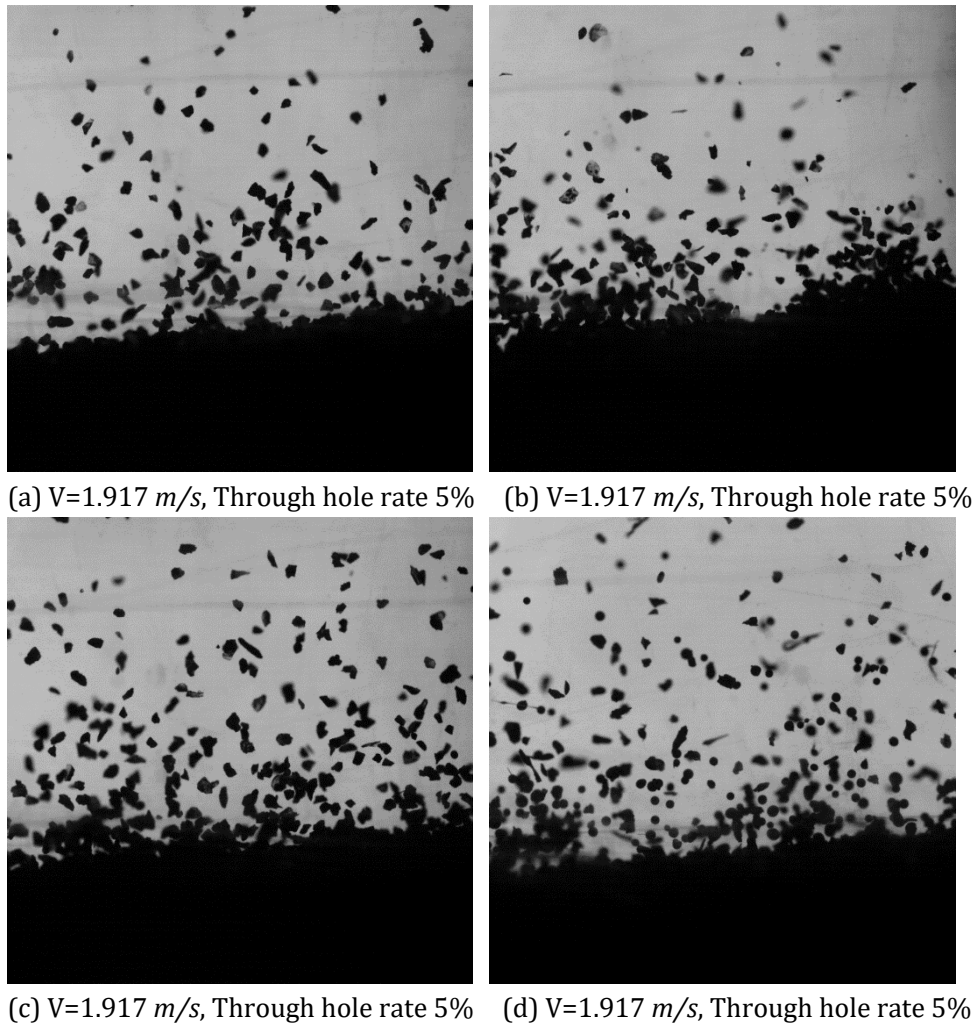


Figure 9. Blast furnace slag fluidization effect

It can be seen from Figure 9:

(1) With the increase of the air inlet of the fluidized bed, the slag particles gradually fluidize, and the bed volume fraction of the material is increasing. In the case of 15% air distribution plate through hole rate, with the gradual increase of the air intake, the slag particles change from a static state to a fluidized state, and the volume fraction of slag particles increases again.

(2) With the increase of the through-hole rate of the air distribution plate, although the highest position of the bed reached by the slag particles is decreasing, the fluidized state of the slag particles in the bed is more fully uniform. When $V=1.278\text{ m/s}$ and $V=1.917\text{ m/s}$ at low speeds, as the air distribution plate through hole ratio changes (5%,10%,15%, 20%), its fluidization state The more uniform under the high-speed camera, the accumulation speed of the bottom layer particles is also reduced.

4. Conclusion

In this article, we start from the background of blast furnace slag waste heat recovery, and through reading relevant literature, we have a comprehensive understanding of the current research status in the field. The structure and principle of the fluidized bed waste heat recovery device are briefly introduced. Aiming at the problems of low efficiency of waste heat recovery of blast furnace slag and low quality of recovered waste heat, the relationship between bed pressure drop and gas flow rate and the influence of bed through hole ratio and blast furnace

slag fluidization effect were studied. Finally, an experimental platform was built for cooling experiments, and some relevant results were obtained.

References

- [1] Information on https://www.worldsteel.org/zh/dam/jcr:f7982217-cfde-4fdc-8ba0-795ed807f513/WSIF_2020_CN.pdf
- [2] Information on <https://data.cnki.net/area/Yearbook/Single/N2020120303?z=D09>
- [3] Liu J, Yu Q, Peng L, et al. Cold experiments on ligament formation for blast furnace slag granulation[J]. *Applied Thermal Engineering*, 2012, 40(none):351-357.
- [4] Mizuochi T, Akiyama T, Shimada T, et al. Feasibility of Rotary Cup Atomizer for Slag Granulation[J]. *Transactions of the Iron & Steel Institute of Japan*, 2007, 41(12):1423-1428.
- [5] Centrifugal granulation performance of liquid with various viscosities for heat recovery of blast furnace slag[J]. *Applied Thermal Engineering*, 2015, 89:494-504.
- [6] F Taghipour, Ellis N, Wong C. Experimental and computational study of gas-solid fluidized bed hydrodynamics[J]. *Chemical Engineering Science*, 2005, 60(24):6857-6867.
- [7] Zhen H, Zhang D, Cheng B, et al. Pressure-Fluctuation Analysis of a Gas-Solid Fluidized Bed Using the Wigner Distribution[J]. *AIChE Journal*, 1997, 43(2):345-356.
- [8] Bing Z, Lu X, Lu G, et al. Development of a novel fluidized bed ash cooler for circulating fluidized bed boilers: Experimental study and application[J]. *Powder Technology*, 2011, 212(1):151-160.
- [9] Han X, Jiang X, Hui W, et al. Study on design of Huadian oil shale-fired circulating fluidized bed boiler[J]. *Fuel Processing Technology*, 2006, 87(4):289-295.
- [10] Gil J, Corella J, Aznar M P. Biomass gasification in atmospheric and bubbling fluidized bed: Effect of the type of gasifying agent on the product distribution[J]. *Biomass & Bioenergy*, 1999, 17(5):389-403.
- [11] Armesto L, Bahillo A, Veijonen K, et al. Combustion behaviour of rice husk in a bubbling fluidised bed[J]. *Biomass & Bioenergy*, 2002, 23(3):171-179.
- [12] Hamilton G S, Dowdeswell J A. Controls on glacier surging in Svalbard[J]. *Journal of Glaciology*, 1996, 42(140):157-168.