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REVIEW OF WASTE HEAT RECOVERY TECHNOLOGIES FOR HIGH TEMPERATURE SLAGS

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ABSTRACT

The molten slag discharged at high temperature between 1450°C~1450°C from the metallurgical industries, which is a kind of high-quality waste heat resource with extremely high utilization value. The various technologies of waste heat recovery of high temperature slags at home and abroad were summarized and compared in the paper. Through the technical comparison and analysis of the packed bed, fluidized bed and moving bed waste heat recovery scheme, it is concluded that the moving bed has significant technical advantages in recovering the waste heat of high temperature slags. The moving bed is the best solution to recover the waste heat from the high temperature slag.

Keywords: high temperature slag, waste heat recover, technology schemes, Iron and steel industry

1. INTRODUCTION

The metallurgical industry is a typical energy and resource-intensive industry, and it is also the pillar industry in China. The sensible heat per ton of slag is about 1260 MJ to 1880 MJ, which is equivalent to 60 kg of standard coal [1]. In 2018, Chinese steel industry produced a total of about 383 million tons of liquid slag, which contained about 22.97 million tons of standard coal. There is great potential for energy saving and emission reduction in Chinese metallurgical industry, so it is very necessary to adopt technologies to recycle the waste heat.

The particles produced by the granulation of the dry centrifugal granulation technology are still above 1100 °C. How to efficiently recycle the waste heat contained in the slag particles, there is no mature scheme. The main reason is that the diameter of slag particles are about 2mm, and there is a wide particle size range. The slag granulated is a typical semi-melting-wide screening particle group, which poses a great challenge to different waste heat recovery technologies. The technical solution process, working principle, technical advantages and disadvantages and development prospects of waste heat recover of high temperature slags were analyzed in the paper.

2. WASTE HEAT RECOVERY TECHNOLOGY SCHEMES

2.1 Development Status of Packed Bed Scheme

CSIRO, One Steel Limited and BlueScope Steel Research in Australia jointly carried out a scheme for slag waste heat recovery [2].The process flow chart presented by the team was shown in Figure 1.The system was mainly composed of granulation warehouse and counter-flow filled heat exchanger. The liquid slag was centrifugally granulated to form fine high-temperature slag droplets, and the slag droplets after granulation formed into solid particles having a certain vitreous content under cooling by cooling air. The solidified hot particles (<900℃)entered the countercurrent packed bed directly under the action of gravity, and the temperature decreased to the ambient temperature under the further cooling of the cold air. The experimental results shown the air temperature after the heat exchange is between 500℃~600℃, and the waste heat recovery efficiency of the system is about 50%.

POSCO of Korea[3] proposed a scheme for recovering the heat from the molten slag, as was shown in Figure2.The system used dry centrifugal granulation technology to granulate slag. The heat exchanger adopted an inclined design scheme to ensure that the high temperature particles produced by centrifugal granulation process could enter the packed bed heat exchanger smoothly. The pilot-scale test of the system

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was carried out in 2012 with a capacity of 2t·h^{-1}. The temperature of the air at the outlet was 460℃, and the instantaneous waste heat recovery rate was higher than 50%. It was reported that the team would plan to build a demonstration unit to meet the needs of industrialization in the future, with the expected slag treatment capacity of 20~40 t·h^{-1}.

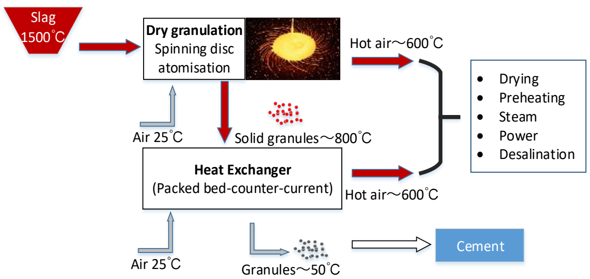


Fig 1 Conceptual diagram of waste heat recovery mode in CSIRO packed bed

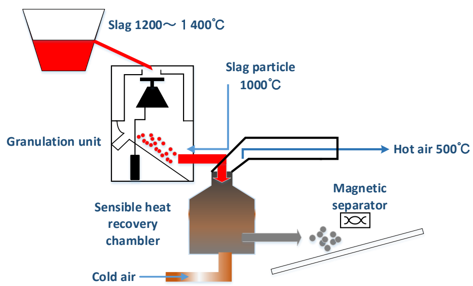


Fig 2 Waste heat recovery scheme of packed bed in POSCO IRON MAKING IN KOREA

Figure 3 shown the process flow chart of slag waste heat recovery developed by JFE in 2011[4]. The device used drum granulation technology to treat molten slag. The water-cooled roll made the slag spread and solidify it into slag sheet with high temperature, which was conveyed to the packed bed through conveyor belt and cooled by the air. In the pilot-scale experiment, when the mass of the residual slag in the packed bed was 4.8t, the maximum hot air temperature formed by gas-solid heat transfer was 700 ℃, and the waste heat recovery efficiency was about 43%.

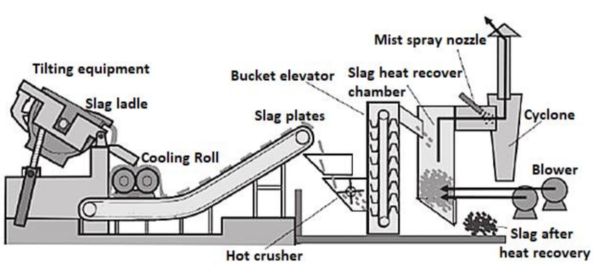


Fig 3 Flow chart of waste heat recovery industry of JFE

2.2 Development Status of Fluidized Bed Scheme

Pickering[5] took the lead in proposing a two-stage fluidized bed scheme for the waste heat recover from slag particles in 1985 (as was shown in Figure 4). The liquid slag was transported to the center of the granulator and granulated under the centrifugal force. Then the particles flew outward and impacted the chamber wall. Because the wall of the granulation chamber was cooled by water, the particles quickly cooled after contacting the wall, and it would not stick to the wall and then fall to the bottom of the primary fluidized bed. The particles in the primary fluidized bed were rapidly cooled and formed certain amount of vitreous slag particles which were then discharged into the secondary fluidized bed and cooled to the discharge temperature. The slag particle diameter was about 2mm and the vitreous content was more than 95%, accompanied by a small amount of slag cotton at the same time. The system could operate uninterruptedly, and the heat recovery efficiency can reach 59%.

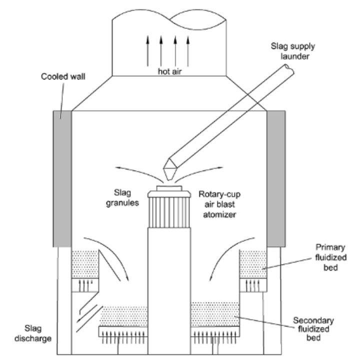


Fig 4 Schematic diagram of fluidized bed waste heat recovery scheme

Shimizu T [6]of Shimizu University in Japan proposed a scheme (as was shown in figure 5) to recover waste heat by fluidized bed. The boiler tubes is used as a buried pipe to recover the heat from blast furnace slag in the fluidized bed. The system was equipped with a slag-crushing device which could crush the slag formed by agglomeration after granulation and slags eventually discharged from the bottom completely. The device had a designed slag treatment capacity of 100 t/h and was expected to produce high temperature steam at 550 °C. The study on theoretical calculation and numerical simulation results shown that the device can recover the high-temperature particles produced by centrifugal granulation smoothly, and the feasibility of the fluidized bed scheme for waste heat recovery of blast furnace slag was also verified.

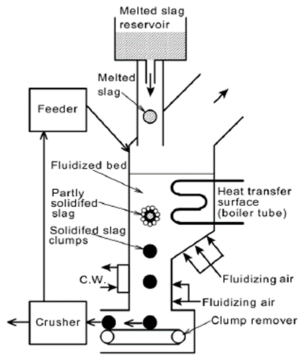


Fig 5 Schematic diagram of fluidized bed waste heat recovery scheme proposed by Niigata University

In 2012, Siemens VAI Metals Technologies[7] put forward a technical proposal to recover the waste heat of centrifugal granulated blast furnace slag by fluidized bed, the process chart as was shown in Fig 6.The device as a whole was spindle-shaped, showing the shape of "thick in the middle, thin at both ends". The upper progressive shrinkage design can reduce the entrainment of hot air to particles and decrease the dust removal pressure downstream of the system. At the same time, in order to ensure the cooling speed of particles, there were water-cooled heating surfaces around the heat exchanger. Not only that, in order to ensure that the particles have enough travel distance and promote cooling, the air inlet at the bottom of the fluidized bed was arranged at a certain angle to ensure that the granulated particles move in a circular trajectory in the bed, thus reducing the possibility of agglomeration between particles. The experimental results show that the amorphous rate of slag particles discharged is over 95%. It was estimated that the hot air temperature of the outlet about 400℃. After optimizing the design of supply and air ducts, the temperature of the hot air could reach 650℃.

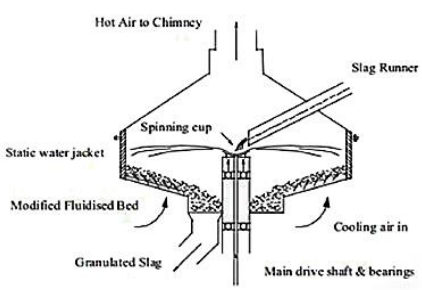


Fig 6 Siemens' scheme in fluidized bed

2.3 Development Status of Moving Bed Scheme

Shuzhong Wang[8] et al. of Xi'an Jiaotong University proposed to use the moving bed combined with water wall scheme to recover the waste heat of blast furnace slag. The structure of novel moving bed was shown in Fig 7. The moving bed was composed of a furnace wall and a receiving bin. Two symmetrical cavity chambers were formed around the furnace wall. An intermediate furnace wall separated two chambers, and a collection bin was arranged at the bottom of the chamber. The upper part of the conical cavity was arranged with buried pipes in the dilute phase region, under the lower part of the buried pipes in the dilute phase region was provided with scrapers. Under the scraper was equipped with the air distribution device, and the space arrangement between the air distribution device and the flat scraper had the buried pipe in the dense phase area. The device overcame the technical bottlenecks such as counter heating phenomenon of slag particles, bonding, low vitreous conversion rate and low waste heat recovery efficiency. It could effectively recover sensible heat of granulated blast furnace slag particles at high temperature.

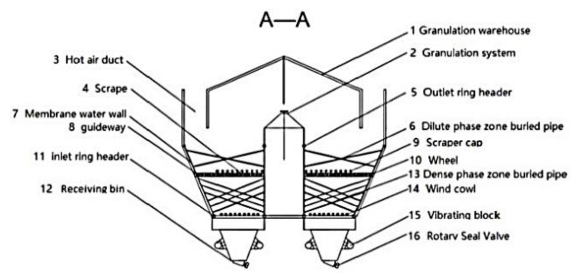
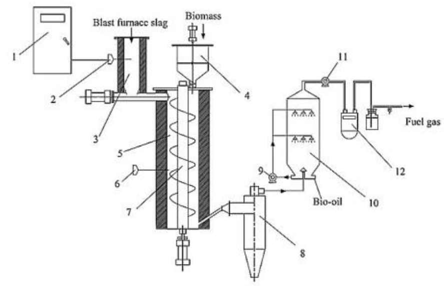


Fig 7 Moving Bed Recovery Scheme of Research Team of Xi'an Jiaotong University

Siyi Luo[9] of Qingdao University of Technology proposed technical scheme of biomass pyrolysis using waste heat from blast furnace slag(As was shown Fig8). High temperature slag particles produced by centrifugal granulation entered the biomass pyrolysis reactor from the upper part of the screw discharger, and steam entered the pyrolysis reaction with biomass from the lower part of the device. In order to ensure the full pyrolysis reaction, a helical blade was designed to stir in the pyrolysis reactor. The results shown that blast furnace slag has good catalytic performance in improving tar cracking, promoting coking gasification and hydrocarbon recombination. At the same time, with the increase of slag temperature and the decrease of particle size, the amount of gasification products increased, while the coke and condensate decrease. When the temperature of blast furnace slag is 1200 ℃ and diameter is less than 2mm, the gas yield and H_2 content reach 1.28 $Nm^3 \cdot kg^{-1}$ and 46.54% respectively.



1-Temperature control cabinet,2-Heater thermocouple,3-Blast slag spiral feeder,4-Biomass screw feeder,5-Gasification reactor,6-Thermocouple,7-Agitating device,8-A duster,9-Circulating pump,10-Spary tower,11-Roots blower,12-Gas flowmeter

Fig 8 Waste Heat Recovery Scheme for Moving bed of Qingdao University of Technology

Purwanto et al.[10] proposed a scheme for cement production by directly utilizing blast furnace slag materials and heat resource, the flowchart was shown in Figure 9.Limestone will decompose when the temperature exceeds 1500 ℃ .Before centrifugal granulation, fly ash and limestone were mixed into the slag and the granulator was fix up between the calciner and the rotary kiln. The centrifugal granulation process was carried out in a closed system. The recovered heat of the slag is used to provide energy for the calcination process and cement clinker production process. Then glassy slag particles produced by centrifugal granulation and other raw materials were directly fed into rotary kiln. High efficiency recovery of material and energy can achieve by directly utilizing high temperature waste heat in blast furnace slag and glass slag particles produced by centrifugal granulation in this way.

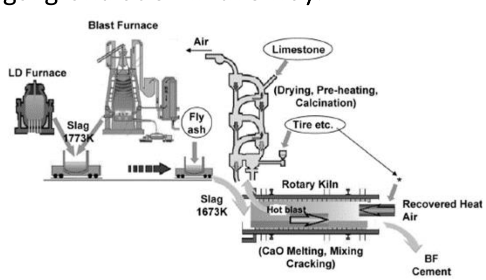


Fig 9 Direct blast furnace slag cement production plan proposed by Purwanto et.

3. CONCLUSION

The blast furnace slag, a by-product of the metallurgical industry, is a kind of high-quality heat resource with a large amount of emissions in steel making process. After granulation, the granulated particles are still at 1100 ° C, which is a typical semi-molten-wide sieving particle group. There is no mature method to recover the heat from the granulated slags currently. Compared with other schemes, the moving bed can avoid the problem of slag particles mixing and the high temperature slags and the air are subjected to countercurrent heat exchange, which can improve the waste heat recovery efficiency of the device and heat energy quality of the air. It realized the high quality and high efficiency utilization of the waste heat resources. The technology not only has high efficiency in recovering waste heat from high temperature particles, but also has large capacity for treatment. The moving bed has significant technical advantages in recovering the waste heat of high temperature slags, which is the best solution to recover the heat from high temperature slag.

ACKNOWLEDGEMENT

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REFERENCE

[1] Li QH, Meng AH, Zhang YG. Recovery status and prospect of low-grade waste energy in China. International conference on sustainable power generation and supply, 2009.
[2] Mackey PJ, Grimsey EJ, Jones RT, et al. Current status and future direction of low-emission integrated steelmaking process[J]. The Minerals, Metal & Materials Society. 2014, 6(20): 303-316.
[3] POSCO, Carbon report 2013, South Korea, (2013) [J]
[4] Shigaki N, Tobo H, Ozawa S, et al. Heat Recovery Process from Packed Bed of Hot Slag Plates[J]. ISIJ International. 2015, 55(10): 2258-2265.
[5] Pickering S J, Hay N, Roylance T F, et al. NEW PROCESS FOR DRY GRANULATION AND HEAT RECOVERY FROM MOLTEN BLAST-FURNACE SLAG[J]. Ironmaking & Steelmaking, 1985, 12(1)14-21[J].
[6] Shimizu T, Mikami G, Horinouchi K. Heat recovery from melted blast furnace [M]. Japan. 2011: 98-99.
[7] Mcdonald I, Werner A. Dry Slag Granulation-The Environmentally Friendly Way to Making Cement[C] asia steel international conference 2012. 2012. [J].
[8] Wang Shuzhong, Ma Liwei, Zhao Jun, etc. A moving bed device for recovering sensible heat of high temperature bulk material, CN108411054A[P].
[9] Luo S, Zhou Y, Yi C. Hydrogen-rich gas production from biomass catalytic gasification using hot blast furnace slag as heat carrier and catalyst in moving-bed reactor[J]. International Journal of Hydrogen Energy. 2012, 37(20): 15081-15085.
[10] Purwanto H, Kasai E, Akiyama T. Process analysis of the effective utilization of molten slag heat by direct blast furnace cement production system[J]. ISIJ International. 2010, 50(9): 1319-1325.

