Design and Application on the Gas Jet Double Preheated Ladle Baker

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Abstract. In this paper, the design and application of the gas jet double preheated ladle baker were investigated. This technology was mainly based on the double preheating technology of air gas, which was emerging from the current steel works. A new type of gas jet double preheating ladle baker was designed by means of fan speed measurement, finite element analysis, theoretical analysis and project practice. Compared with the traditional baker, it saves the traditional blast powerplant, and has the advantages of automatic ignition, automatic air distribution, strong impact force of flame, full burning, energy saving and so on.

1. Introduction
The ladle baking is an important part in the production process for steel-making. It is mainly used for the baking of various steel (iron) water tanks for new, cold repair, drying, turnover and online rapid heating up. The performance of baking device has great influence on the steel tapping temperature, operation rate and so on. At present, the commonly used ladle baker mainly includes the traditional casing roaster and the regenerative ladle roaster. The traditional casing ladle baker adopts the way of fan air supply, which can not regulate combustion air and mixed the air and gas. Besides, the gas is not preheated, the baking temperature is not high, and the combustion efficiency is low. The regenerative roaster takes advantage of the regenerator to recover the waste heat from the exhaust gas, which is used to heat the combustion air and gas, so as to achieve a certain energy saving effect. However, because of the lower temperature of ladle baking, it is often employed to extend the baking time to meet the requirements of tapping. In addition, the regenerator is prone to block, which causes the air and gas transport to be unsmooth and affects the baking efficiency of the ladle[1].

In this paper, in the light of the problems such as difficult ignition, uneven baking temperature and serious waste of energy in the ladle baker with low heat value blast furnace gas at present, a technology with using the residual heat flue gas released from the combustion device during the baking process was put forward, and then the preheated air gas was reused for combustion. This new technology can better save gas resources, accelerate the reaction speed of gas chemical combustion, and improve the speed of flame injection and combustion temperature. The main contents of the study include: (1) research on flame jet velocity; (2) research on the best air fuel ratio; (3) structural design; (4) finite element analysis; (5) practical application analysis.

2. Experiments
2.1. Principle of gas jet double preheating ladle baker
The gas jet dual preheating ladle baker adopts the Bernoulli principle (when the flow is high speed, the local pressure is generated by changing the cross section of the fluid in the pipeline and then the combustion air is realized) [2]. The local flow velocity of the gas is increased, and the local negative pressure is formed through the special device (conical valve 2 in the preheating box 3). As the combustion air is sucked into the combustion tube 1 of the preheating box 3, the turbulence effect is formed to achieve a mixture of the gas and the combustion air. Through adjusting the opening degree of the conical valve 2 and the area of the air inlet (adjustment of the size of the air inlet through the wind regulating device 4), the amount of gas and combustion air is adjusted. The preheating box 3 increases the temperature of the gas and the air by absorbing the released residual heat flue gas, realizing the double preheating of the gas and the combustion air, thereby improving the burning temperature of the gas. The schematic diagram of the work principle is shown in Fig.1.

Figure 1. Working principle diagram of ladle baker

2.2. Structure design of preheating box

The structure design of the double preheating of air gas is mainly determined by the structure design of the preheating box. The main preheated heat source comes from the residual heat of the middle combustion tube and the gas from exhaust gas into the cavity of the preheating box. The cavity structure formed a closed chamber is made of outer arc plate, inner arc plate, lower seal plate and guide plate. There is a jet tube at the center of the inner arc plate and a gas inlet on the right end face of the outer arc plate, as shown in Figure 1.

2.3. Research on the flame jet velocity

The core of gas jet dual preheating technology is based on the research of gas combustion velocity. As long as the gas burning rate reaches a certain speed, and the length and stiffness of the combustion flame reach the best state, the temperature of the baking ladle can achieve the desired result [3]. In this section, a simplified fan model is used to investigate the flow velocity problem. Figure 2 shows a specific centrifugal fan experimental model.
Figure 2. Fan experimental model

In the experiment, the fan is a centrifugal blower with the air volume parameter and wind pressure of the centrifugal blower are 1100~200 m$^3$ and 1~4.6 Kpa, respectively. The interface form of the experimental model as follows:

The tuyere of the centrifugal blower device 6 was connected to a 800mm long 219×4.5 mm DN200 seamless steel pipe 5. The seamless steel pipe 5 was butted to a manual butterfly valve device 3, so as to realize adjustment of the wind turbine model air volume. Then, device 3 was connected to a 1200 mm long pipe 2 (DN100 seamless steel pipe), and the end of the pipe 2 was connected to the DN100 flange 1.

When the centrifugal blower 6 is opened, by changing the wind pressure of the centrifugal fan and measuring the wind speed in the DN100 pipeline, combined with the continuity equation of the fluid in the pipe\(^{(4)}\), we can get the wind speed of different wind pressure passing through the round hole plate 4 with a diameter of 40 mm. The result was shown in Table 1.

### Table 1. The results of test

| Pressure (Kpa) | Wind speed of the pipe with inner diameter of 100 mm | Conversion results of wind speed through a Φ 40 mm pipe |
|---------------|-----------------------------------------------|--------------------------------------------------|
| 4             | 11 m/s                                        | 68.75 m/s                                       |
| 3             | 9.6 m/s                                       | 60.00 m/s                                       |
| 2             | 8.2 m/s                                       | 51.25 m/s                                       |
| 1             | 6.2 m/s                                       | 38.75 m/s                                       |

When the diameter of the pipe is changed in the gas pipeline, the flow velocity is also changed. The following is combined with the data of the table 1 to be verified.

According to the fluid continuity equation $V_1d_1^2 = V_2d_2^2$, when the wind pressure was 1 Kpa, the outlet flow velocity of the DN100 flange 1 was measured by a special anemometer, which was $V_1=11$ m/s. Through conversion, the flow velocity through the Φ 40 mm circular hole plate 4 $V_2=68.75$ m/s inside the DN200 pipe was achieved. The flow velocity of Φ 40 mm circular hole plate 4 was converted under different wind pressure conditions (1~4 Kpa). It was concluded that the factors affecting the flow velocity of gas jet are proportional to the pressure. For the gas jet ladle baker, the higher the gas pressure, the more obvious the effect of the jet is obtained in the range of safe pressure.

2.4. Research on the optimum air-fuel ratio
The experimental model of burner is designed based on the wind velocity data, aims to research on the optimum air-fuel ratio problem for the low heating value blast-furnace gas. The key point of the
design is to select the diameter of the combustion tube and the size of the air duct, so as to achieve the best air-fuel ratio.

The burner model is sustained by a triangular support bracket. A number of air inlet is provided at the end cover of the combustion tube. The end of the combustion tube is connected to the gas pipe, and the other end is connected to the fastening bolt. The end of the gas pipe is the gas wire head. The gas enters the jet port and passes through the cone valve to speed up the flow velocity to realize the local negative pressure.

In order to improve the efficiency of gas utilization, the optimum air-fuel ratio is obtained by studying the proportion relation among the combustion tube, the air inlet and the jet port. Table 2 shows the experimental data obtained by repeated experiments.

Table 2. Experimental data of research

| group | Inner diameter of combustion tube (mm) | Inlet diameter (mm) | Nozzle diameter (mm) | Inner diameter of combustion tube / Inlet diameter | Inner diameter of combustion tube / Nozzle diameter | Inlet diameter / Tube diameter | Nozzle diameter / Tube diameter | Nozzle diameter / Inlet diameter |
|-------|--------------------------------------|---------------------|----------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------|--------------------------------|-------------------------------|
| 1     | Φ100                                 | Φ28.28              | Φ14.94               | 3.54                                          | 0.2828                                       | 0.1494                     | 0.5283                          |
| 2     | Φ100                                 | Φ34.64              | Φ19.66               | 2.89                                          | 0.3464                                       | 0.1966                     | 0.5676                          |
| 3     | Φ124                                 | Φ42.75              | Φ23.55               | 2.9                                           | 0.3447                                       | 0.1899                     | 0.5508                          |
| 4     | Φ124                                 | Φ35.35              | Φ19.29               | 3.5                                           | 0.285                                        | 0.1555                     | 0.5456                          |

The experimental burner was connected to the gas pipeline to test, and then the design ratio of each part of the burner was obtained. After a long period of applied research, the first group and the fourth group of data was found to be the best matching relationship.

2.5. Finite element simulation analysis

The stress and deformation of the parcel cover, the frame and the rocker arm are analyzed through the finite element ANSYS software [5], as shown in Figure 4.
Figure 3. Simulation results of the parcel cover: (a) cloud picture of equivalent effective stress; (b) cloud picture of displacement

Figure 3 (a) shows that the simulation results of the parcel cover, it can see that the maximum equivalent stress of bolt connection area is 135 MPa, less than 235 MPa (yield strength of Q235 material). Therefore, the force of bolted connection is within the scope of safety permission. As shown in Figure 3 (b), the maximum strain of the bolt through the panel is 0.1485 mm, and the strain is also in a safe range.
3. Practical application results

3.1. The effect of baking
The designed roaster was applied to the project practice of the steelshop with Shandong Qingdao Iron and Steel Group Co. Ltd., and the internal condition of the ladle baker was shown in Figure 4. As shown in Figure 4 (a), it can be seen clearly that the inner color of the gas jet double preheating ladle bake is yellow, which means that the temperature difference between the upper and the bottom of the ladle is relatively small. This also proves that the baking temperature is fairly uniform and higher. In contrast, Figure 4 (b) is the internal condition of the ladle baker during the roasting process before the transformation. It can be seen that the yellow region at the bottom of the ladle was high temperature area, and the red area of low temperature was more. This indicates that the temperature distribution in the ladle baking is uneven and the baking temperature is low. Therefore, it can be concluded that the gas jet dual preheated ladle baker has ideal baking effect compared with the previous roaster.

![Figure 4. The internal condition of the ladle baker: (a) good temperature evenness; (b) Uneven temperature](image)

3.2. Energy saving effect
In this study, the original ladle roaster gas consumption is not measured and the modified ladle roaster is expected to save gas consumption on average for 452.16 m³/h. In addition, the annual total gas saving, saving gas generation capacity and saving electricity consumption of the fan are 2712960 m³/h, 754910 kW/h and 18000 kW/h, respectively. The annual energy-saving benefit is estimated to be 517849 RMB/year. Therefore, it can be seen that a roaster can save 517000 RMB/year through the practice analysis.

4. Conclusions
1. The fan experiment showed that the flow velocity of the gas jet was proportional to the pressure. The effect of the jet was obvious within the scope of the safety clearance.
2. The optimum air fuel ratio of the gas jet double preheated ladle baker with the corresponding core parts was obtained through the study of the model burner.
3. The optimum design of the roaster was obtained through the ANSYS finite element analysis.
4. The analysis of effect for the practical application showed that the gas jet double preheated ladle baker had a great technical advantage.

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