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Experimental research on the application of HTAC in small-size heating furnace

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Abstract: High temperature air combustion (HTAC) technology, which is also known as regenerative combustion technology, has realized energy saving, CO_2 and NOx emissions reduction and low-noise combustion. It has been widely applied in various types of heating furnace and has achieved good energy-saving effect. However, there is little application of this technology in small-size furnace. In this paper, a small-size regenerative heating furnace was built in the laboratory and experiments were carried out on it. The result shows that, if the transport frequency was set to a group per min, the center temperature of processed workpiece at the rated conditions (i.e. burner power is 300 kW and switching time is 60s) reached 1133℃. And the efficiency of the heating furnace was 36.8%. Then the derived comprehensive heat transfer coefficient was 168 W/(m^2 • ℃).

1. Introduction

High temperature air combustion (HTAC) technology, which is also known as regenerative combustion technology, is a new technology in the field of fuel combustion successfully developed by Japan in the 90s of last century [1, 2]. It injects preheated air into the furnace and maintains a low oxygen state. Simultaneously, the fuel is transported to the air stream for combustion. The inducted air can be preheated to about 800-1000℃ while the oxygen content in the combustion zone is 2%-21%. Compared with the traditional combustion, high temperature air combustion technology has realized energy saving, CO_2 and NOx emissions reduction and low-noise combustion, which made it one of the key combustion technologies in the 21st century [3].

High-temperature air combustion technology can dramatically improve efficiency in a variety of industrial furnaces and thus save energy. China has recently made excellent achievements in the research and application of HTAC technology [4-6]. However, the application of HTAC in small-size heating furnaces is rarely reported, mainly because their compact structure is difficult to transform into regenerative furnace. There are a lot of

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small-size heating furnaces in China with extremely low thermal efficiency at present. How to realize the efficient use of energy in these furnaces and retain their original volume and special process are urgent problems. In this paper, a small-size regenerative heating furnace was built in the laboratory, and experiments were carried out on it to master the application characteristics of HTAC technology in small-size heating furnace.

2. Introduction of small-size regenerative furnace

Figure 1 shows the schematic of HTAC technology. The system consists of a pair of burners, regenerators and switch valves and the corresponding controller. When introduced through the burner B, the ambient temperature air absorbs heat from the preheated high-temperature regenerator, and then enters the furnace to be mixed and burn with the natural gas. After heat exchange in the furnace, the flue gas is exhausted through burner A and release heat to the regenerator. After a specific time, the burner A is switched to be the inlet for air via the switch valve while the burner B becomes the outlet. The system repeats the above behaviors periodically to accomplish heat storage and regeneration.

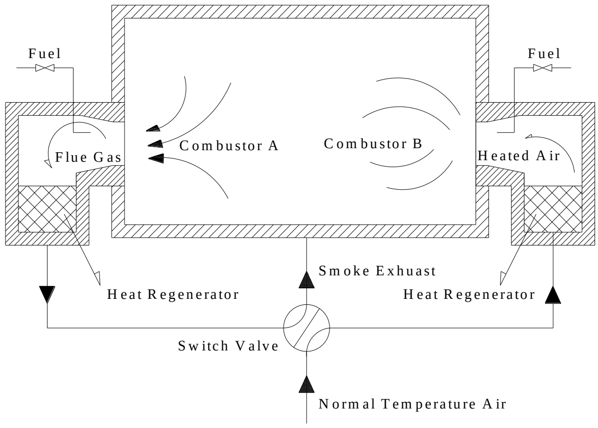

Figure 1. Schematic diagram of regenerative combustion technology

The size of the experimental furnace is designed according to Industrial Furnace Design Manual. The size of heated workpiece is Φ60×150mm. The gap between the workpieces is about 0.5 times of their length, that is, 70mm. The workpieces are placed into 4 rows. The designed furnace width is 590mm. The furnace height is 10 times of the thickness of the workpiece, i.e., 600mm and the length is 4000mm.

Figure 2. Actual picture of a small-size experimental furnace

The design production capacity of the furnace is 1.2t/h and the design efficiency are 60%. After calculation, the design power of the burners is 294kW, which can be approximately treated as 300kW. Figure 2 shows the actual picture of a small-size experimental furnace, which consists of burners, induced draft fan, exhaust draft fan, gas transport pipes and etc.

3. Experimental results and analysis

As the static temperature rise of the heated workpiece mostly reflects the intrinsic performance of the burner and the heating furnace, the static state of the workpiece is discussed firstly in this paper. Figure 3 shows the temperature of air, flue gas and workpiece center at rated conditions (i.e. burner power is 300kW and switching time is 60s). The temperature of preheated air oscillates with the switch process periodically and rises in general, which can reach 800℃. The temperature of flue gas oscillates in the same way and the maximum temperature is below 200 ℃,showing the most significant feature of regenerative high temperature air combustion.

The measured workpiece was located in the center of the furnace and the thermocouple was buried in the center of the workpiece. As shown in Figure 3,the center temperature of workpiece keeps steadily rising, only slow down at around 727℃. This is due to the fact that the crystal structure of iron changes from pearlite to austenite at 727℃ where the specific heat capacity increases sharply [7]. Thus, there is a turning point for the center temperature of workpiece. Then, as the specific heat capacity back to normal, the temperature continues to increase and reaches 1200℃ at 4500s.

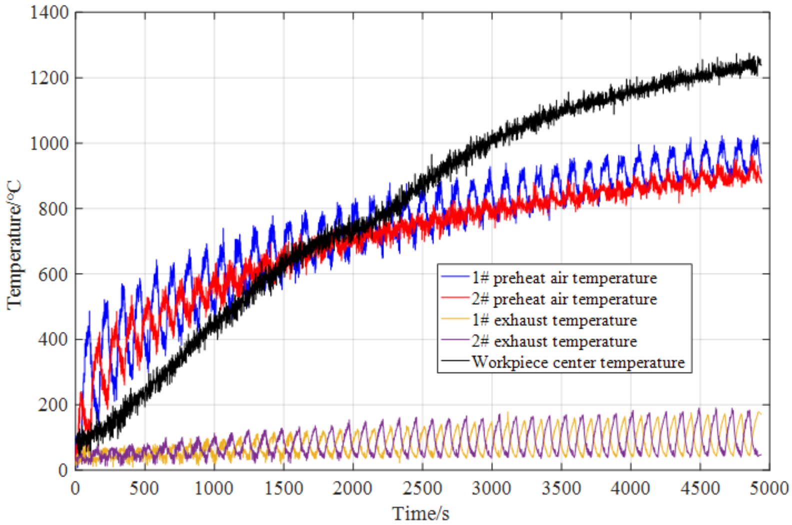

Figure 3. The temperature of air, flue gas and workpiece center at rated conditions

Figure 4 shows the average furnace temperature along the length direction of the furnace. It is observed that the lower furnace temperature of left side is much lower than that of right side. This observation can be explained by the fact that the left discharge port is not closed. When the burner on this side worked, a large quantity of cold air was sucked into furnace and greatly reduced the temperature around the left outlet. On the contrary, the right inlet was sheltered a lot, so the temperature was relatively uniform. The upper space of the furnace was less affected by external cold wind, so the temperature is more uniform.

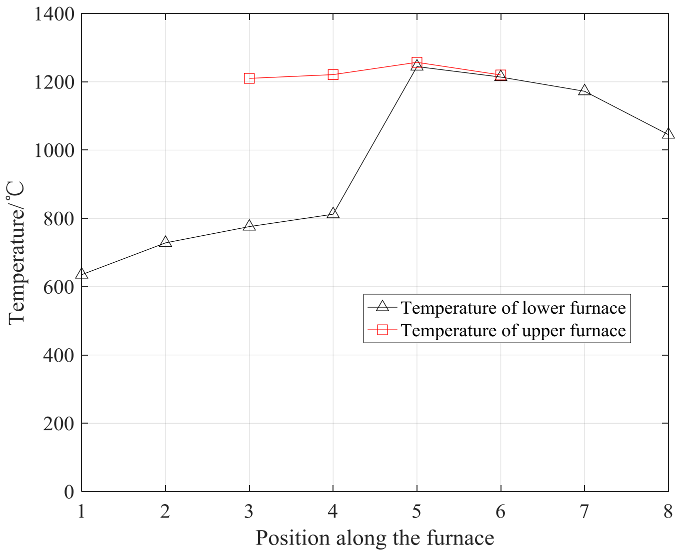

Figure 4. The average temperature along the length direction of the furnace.

Dynamic experiments were carried out on small-size regenerative furnace that included a pair of 300 kW burners and switched air induction direction every 60s. In the experiment, the furnace was burned without workpieces for 30-60 minutes until reached periodic steady state, i.e., the temperature of furnace exceeded 1100℃ and the temperature of the preheated air exceeded 800℃. reached periodic steady state. Then the first batch of workpieces was transported into the furnace. When there were workpieces discharged from the outlet, the second batch of workpieces were transported in and their temperature was measured continuously. Simultaneously, the temperature, pressure, flue gas composition and air flow rate of furnace were measured.

Figure 5 shows the temperature of the workpiece center and furnace center when the transport rate was a group per min. The center temperature of processed workpiece reached 1133℃, which had satisfied the requirements of heat treatment. And the efficiency of the heating furnace was 49.85% via calculation.

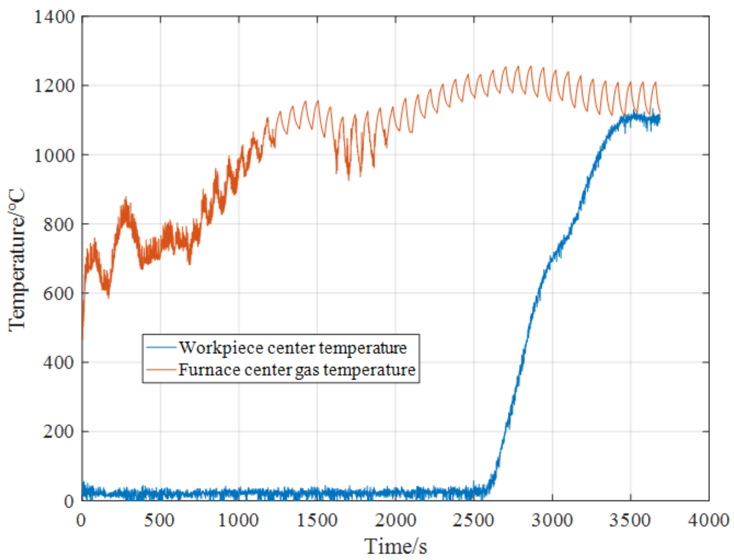

Figure 5. The temperature of workpiece center and furnace center

4. Analysis of comprehensive heat transfer coefficient

Flow and heat transfer in the furnace is a complex process. Due to uniform temperature distribution and low airflow rate in the small regenerative furnace, the difference along the length direction was ignored. A simplified model was developed to simulate the dynamic thermal behavior of workpiece. The simplified model is shown in Figure 6.

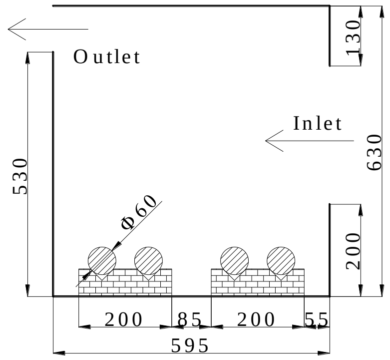

Figure 6. The schematic diagram of simplified model

In the simulation, the transport frequency was a group every 100s at rated condition. The commercial software FLUENT is used to calculate the transient variation of pressure and temperature in the furnace. The inlet was set to mass-flow-inlet. And in order to simulate the movement of workpieces at starting state, the temperature of inlet was set by UDF, which increased linearly from 300℃ to 1270℃ in 6 min. The compositional inlet mass for the numerical simulation is the same as the experimental conditions. The outlet was set to pressure-outlet and the gauge pressure was -10Pa. The convection boundary condition was used for the furnace wall. The heat transfer coefficient was set to 25 W/(m^2 • ℃) and the free stream temperature was 300K. The blackness of furnace wall was 0.6, while that of workpiece surface and corundum rail was 0.7, 0.85. The workpiece surface and corundum rails were set to coupled wall. The k-ε equation model, the DO radiation model and the composition PDF model were used in this simulation. Figure 7 shows the center temperature of workpiece via simulation and experiment.

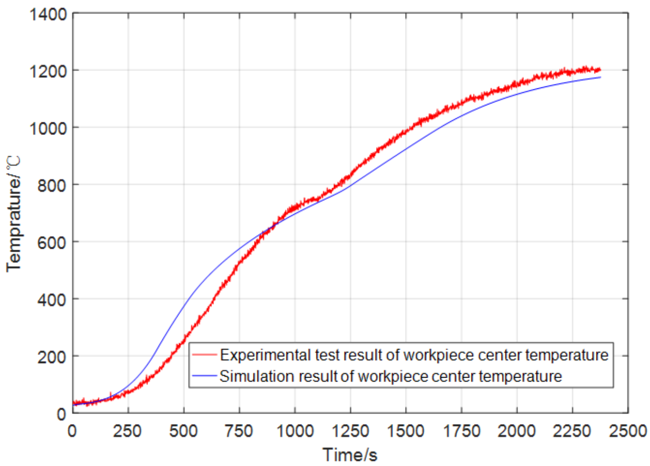

Figure 7. The center temperature of workpiece via simulation and experiment

The simulation results show good agreement with experiments. The center temperature of workpiece measured from experiment at steady state was 1201℃,while that calculated from simulation was 1175℃. The error was just 2.16%. The assume of uniform temperature distribution and ignorance of flow along length direction accounted for this error. Thus, the adopted mathematical model is suitable for the numerical calculation of thermal process in heating furnace. The comprehensive heat transfer coefficient can be derived from the simulation results, i.e., 130 W/(m^2 • ℃). Then the transport frequency was changed to a group per min while the other conditions were the same as above. Similarly, the comprehensive heat transfer coefficient was 168 W/(m^2 • ℃).

5. Conclusion

(1) The application of regenerative high temperature air combustion technology in small-size heating furnace can satisfy the requirements of heat treatment to workpieces. The temperature of preheated air oscillates with the switch process periodically and rises in general, which can reach 800℃. The temperature of flue gas oscillates in the same way and the maximum temperature is below 200℃.

(2) At the rated conditions (i.e. burner power is 300kW and switching time is 60s), if the transport frequency was set to a group per min, the center temperature of processed workpiece reached 1133℃, which had satisfied the requirements of heat treatment. Then the efficiency of the heating furnace was 49.85% via calculation.

(3) A simplified model was developed to simulate the dynamic thermal behavior of workpiece and its result was verified with experiments. If the transport frequency was set to a group per min, the comprehensive heat transfer coefficient at the rated conditions (i.e. burner power is 300kW and switching time is 60s) was 130 W/(m^2 • ℃). If the transport frequency was set to a group every 100s the comprehensive heat transfer coefficient at the rated conditions was 168 W/(m^2 • ℃).

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