Experiment research and simulation analysis of regenerative oxygen-enriched combustion technology

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Abstract

As a kind of high temperature combustion technology, oxygen-enriched combustion is widely used in the fields of glass industry, metallurgical industry and thermal power engineering. In order to further increase the combustion temperature and save energy simultaneously, this paper researched and analyzed the combustion mode which combines the regenerative combustion technology and oxygen-enriched combustion, and contrastively analyzed each combustion features of regenerative oxygen-enriched combustion technology. CFD engineering simulation software FLUENT is adapted to simulating combustion under the operating condition. Through comparison of simulation and experimental result, the influence of oxygen concentration on combustion in furnace and temperature is confirmed; meanwhile under this condition, energy consumption is reduced. The research result indicated that this technology not only increases temperature and decrease operating cost, it also has more widely application scope.

Keywords: Oxygen-enriched combustion, super high temperature, high temperature air combustion

1. Introduction

In industrial production, electric furnace is adopted to heating, smelting with over 1800°C super high temperature at the present stage. Fuel into electric energy efficiency is not over 38%, then after electric energy into thermal energy, overall efficiency is less than 30%, general fuel gas smelting combustion device only can rise the furnace temperature less than 1400°C which cannot reach the technological requirements. Nowadays, when reasonable use regenerative medium, widely applied high temperature air combustion technology (HTAC) can recycle 85% exhaust gas waste heat, and the exhaust gas temperature of reheating furnace can fall to 150°C, but it can only rise the furnace temperature to 1700°C or so, which cannot reach the technological requirements as well.

In order to reach the temperature requirement of super high temperature production, the paper uses combustion mode which combined regenerative combustion and oxygen-enriched combustion technology, and make some calculation and analysis and experimental simulation on regenerative oxygen-enriched combustion technology.

2. Feasibility analysis
2.1 Calculation and description of main energy saving technical index

With natural gas as fuel, calculate the combustion energy saving rate respectively under the condition of different preheating temperature, different oxygen content, as shown in Table 1:

<table>
<thead>
<tr>
<th>Combustion air oxygen content (%)</th>
<th>Air preheating temperature (°C)</th>
<th>Fuel saving rate of HTAC(%)</th>
<th>Fuel saving rate of oxygen-enriched combustion (%)</th>
<th>Saving rate of total fuel (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.9</td>
<td>1000</td>
<td>30.76</td>
<td>0</td>
<td>30.76</td>
</tr>
<tr>
<td>35</td>
<td>20</td>
<td>15.52</td>
<td>15.52</td>
<td>30.76</td>
</tr>
<tr>
<td>35</td>
<td>1000</td>
<td>30.76</td>
<td>15.52</td>
<td>46.28</td>
</tr>
</tbody>
</table>

Thus this proves, when the fuel is natural gas (or other high heating value fuel), use both high temperature air combustion technology and oxygen-enriched combustion technology to compare with the ordinary air combustion (including preheating air), obvious energy saving effect can be obtained; which compare with only use regenerative high temperature air combustion technology, the fuel availability can further rise over 15%.

2.2 Calculation and description of main temperature technical index

Take natural gas for example, combustion temperature in different preheating temperature and oxygen-enriched condition is as shown in Table 2:

<table>
<thead>
<tr>
<th>Combustion air oxygen content (%)</th>
<th>Air preheating temperature(°C)</th>
<th>Theoretical combustion temperature(°C)</th>
<th>Furnace temperature factor</th>
<th>Actual combustion temperature(°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.9</td>
<td>20</td>
<td>1964</td>
<td>0.65</td>
<td>1276</td>
</tr>
<tr>
<td>20.9</td>
<td>1000</td>
<td>2685</td>
<td>0.65</td>
<td>1745</td>
</tr>
<tr>
<td>32</td>
<td>1000</td>
<td>3338</td>
<td>0.65</td>
<td>2170</td>
</tr>
<tr>
<td>35</td>
<td>1000</td>
<td>3495</td>
<td>0.65</td>
<td>2272</td>
</tr>
</tbody>
</table>

Thus this proves, use air regenerative combustion technology that the furnace chamber temperature can reach 1700°C or so, while use the combustion technology which combined air regenerative combustion technology and oxygen-enriched combustion technology that the chamber temperature can reach 2200°C in the condition of 35%air oxygen content, the temperature almost rise 30%.

3. Hot state experiment and result analysis of regenerative oxygen-enriched combustion experimental facility

Beijing Shenwu environment & energy technology Co., Ltd adopt the technology which combined regenerative combustion and oxygen-enriched combustion to build regenerative high temperature furnace experimental facility of oxygen-enriched combustion, system flow is as shown in Figure 1:

Because of the limited experiment condition, this experimental facility adopts bottled liquefied petroleum gas as fuel. The system includes regenerative combustor, liquefied petroleum gas pipeline system, oxygen pipeline system, compressed air system, waste gas system.

The experimental process is divides into two kinds of operating condition, one is regenerative combustion operating condition, the furnace temperature can rise to 1600°C or so, fuel consumption is about 1.8Nm³/h; The other is regenerative oxygen-enriched combustion operating condition that is the furnace temperature rise to 1600°C or so and no longer rise, then mix oxygen into compressed air to get oxygen-
enriched combustion supporting gas with specified oxygen-enriched concentration, meanwhile reduce fuel quantity, rise the furnace temperature to 2100°C above, and the fuel consumption is about 1.5Nm³/h now.

Comparative analysis of experimental results

Liquefied petroleum gas regenerative combustor only can rise the furnace temperature to 1600°C or so when material in furnace is in good sealing condition, but regenerative oxygen-enriched combustion can rise the furnace temperature to 2100°C or so in the condition of oxygen-enriched 32%.

Compare to the regenerative combustion technology, the regenerative oxygen-enriched combustion technology can further increase fuel availability over 15%.

4. High temperature furnace 3D hot state numerical simulation

FLUENT software is used to do 3D hot state simulation for regenerative combustion technology and regenerative oxygen-enriched combustion technology respectively. Based on super high temperature furnace in laboratory, simulate temperature field distribution of the whole furnace chamber. This paper is mainly observing flame combustion zone located in the surface of air and gas nozzle centreline.

4.1 Numerical simulation process

According to component of liquefied petroleum gas, O₂ content of air inlet is set to 20.9% in regenerative combustion simulation, the temperature is set to 1500K; O₂ content of air inlet is set to 32% in simulation which combined regenerative combustion and oxygen-enriched combustion, the temperature is set to 1873K, and according to simulated result to adjusting.

4.2 Result analysis of numerical simulation

4.2.1 Temperature distribution of regenerative combustion operating condition

Temperature distribution of combustion is as shown in Figure 5, maximum temperature in combustion zone is 2570K, that is 2297°C, temperature in furnace is 1680°C, which is conform to the prior presumed result basically. Flame profile which displayed in figure is cone, the length is about 600mm.

4.2.2 Temperature distribution of regenerative oxygen-enriched combustion operating condition

Temperature distribution of combustion is as shown in Figure 3 maximum temperature in combustion zone is 3250K, that is 2970°C, temperature in furnace is 1900°C, which is conform to the prior presumed result basically. Flame profile which displayed in figure is cone, the flame is symmetrically, stable and homogeneous, length of the flame is about 500mm which belongs to typical diffusion flame.

Because the gas sprays in as per the crossing angle of the gas nozzle and centre line, the gas mixes with high temperature air quickly to combustion when the gas sprays out at high speed through nozzle. It can meet the requirement of super high temperature smelting production.

4.2.3 Comparison of experiment and simulation temperature for two operating conditions

The graph of experimental data and simulation calculation result is as shown in Figure 4,
Under two kind of operating conditions, temperature experimental data is basically in line with the simulation calculation result under the same condition, error is about 5%. The temperature of regenerative oxygen-enriched combustion is 300°C higher than temperature of regenerative combustion.

The flame maximum temperature point of regenerative oxygen-enriched combustion is about 450mm, while the flame maximum temperature point of regenerative is 550mm; regenerative oxygen-enriched temperature maximum point is closer to operation position (that is centre of furnace chamber).

5. Conclusion

(1) In super high temperature smelting process, compared to regenerative combustion, regenerative oxygen-enriched combustion mode can further increase fuel availability more than 15%. In case of only increase air oxygen-enriched content, the furnace chamber is 2100°C or so, temperature of furnace chamber is increase by about 30%.

(2) In the process of CFD simulation, the temperature of flame which combined regenerative combustion and oxygen-enriched combustion can reach 2200°C with high speed, that can mix fuel more drastic, reflux is formed at outlet face rapidly, which make the temperature in furnace more uniform, meanwhile ensure the temperature of working area.

(3) When use regenerative oxygen-enriched combustion technology with applicable refractory and insulation material, over 2100°C super high temperature smelting can be realize in gas furnace, and exhaust temperature is under 200°C, combined efficiency of fuel is over 90%, which compared to the electric heating mode, comprehensive energy consumption is significantly reduced, and energy use efficiency is significantly increased, economic benefit and social benefit is prominent.

References

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