

OPTIMALLY DESIGNING REGENERATIVE SOAKING PIT BY MEANS OF NUMERICAL SIMULATION

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Abstract: Gas consumption will be decreased if the combustion system of soaking pit is rebuilt applying high temperature air combustion technology. In addition, the temperature field uniformity in furnace will be improved. The flow field and temperature field in the furnace are investigated by numerical simulation in this paper. An optimum rebuilding scheme using high temperature air combustion system is proposed.

Keywords: soaking pit, regenerative combustion, high temperature air combustion, numerical simulation

1 Introduction\

High Temperature Air Combustion (HTAC) technology is a new kind of combustion technology developed from the first period of 90s' in the last century. In HTAC technology, the combustion air is heated up to 800 or 1000°C and the concentration of oxygen in combustion air is lower than 10 percent. There are some advantages in HATC, such as energy saving, high heat utilization efficiency, low NO_x emission and decreasing the scale of furnace.

In order to rebuild the combustion system in a soaking pit, three rebuilding schemes are proposed in light of actual heating process in this paper. On the base of comparison between them, twelve cases for one of schemes are investigated by numerical simulation. An optimum rebuilding design is confirmed on base of analysis of heat utilization efficiency, flow field and temperature field, which realizes the scientific demonstration before the soaking pit is rebuilt.

2 Outline of furnace and rebuilding scheme

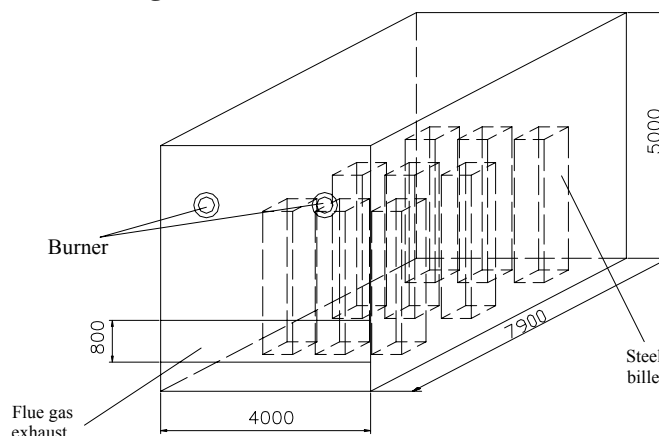


Fig.1 schematic drawing of furnace structure and burner location

There are two burners in the furnace and nine steel billets as usual. The furnace structure and burner location are shown in figure1. The burner is rotational type where the center jet is gas jet and the outside annular-jet is air jet. The parameters of present burner are listed in Table 1. If the combustion air is preheated up to 1000°C and the gas is preheated up to 400, 600, 800 and 1000°C respectively, the gas consumption would decrease when the heat quantity imports are the same. The gas savings in above mentioned cases are listed in Table 2. At the mean time, the air consumption would decrease, which means the fan energy consumption decreases.

Table 1 Parameters of the present burner

number	Item	unit	content
1	gas kind		mixed gas(coke gas + blast gas)
2	calorie value of gas	kJ/Nm ³	2200×4.18
3	temperature of gas	°C	390
4	flow of gas	Nm ³ /h	2159
5	pressure of gas	Pa	3000
6	flow of air	Nm ³ /h	5149.5 (excess air coefficient=1.1)

7	pressure of air	Pa	3500
8	temperature of air	°C	550

Table 2 Fuel flow and fuel saving ratio corresponding to different rebuilding item

item	Unit	before rebuilding	rebuilding			
			1000	1000	1000	1000
preheated air temperature	°C	550	1000	1000	1000	1000
preheated gas temperature	°C	390	400	600	800	1000
heat quantity import	kW	6952	6952	6952	6952	6952
quantity of gas flow	m ³ /h	2159	1891	1845	1799	1752
quantity of air flow	m ³ /h	5149.5	4510.3	4400.6	4290.9	4178.8
gas saving ratio	%		12.41	14.54	16.67	18.85

Since three soaking pits are set side by side in practice and the furnace covering can be removed, the burners must be set in the front wall or the back wall. Therefore, the rebuilding schemes are proposed as follows:

- i. The regenerative burners are set on the front wall and the back wall of the furnace and the original flue gas exhaust is remained;
- ii. The regenerative burners are set on the front wall and the back wall of the furnace and the original flue gas exhaust is cancelled;
- iii. The integrated regenerative burners are set on the front wall of the furnace and the original flue gas exhaust is kept.

Two pairs of burners are set on the front wall and the back wall in the first and the second scheme mentioned above. High temperature flame appears in two ends periodically and alternately, which improves the convective heat transfer and radiation heat transfer between flue gas and steel billets. In addition, the heating uniformity is also increased. The first scheme is in favor of adjusting flue gas pressure because the original flue gas exhaust is kept. Since the combustion air nozzle and the flue gas exhaust are set together and integrated with gas nozzle on the front wall in the third scheme, it is difficult to arrange burner due to a lot of regenerators in the front wall.

The first rebuilding scheme is selected on the base of comparison among them. Numerical simulations are carried out to study this scheme.

3 RESULTS AND DISCUSSION

The combustion air jet velocity is set as about 40m/s in order to avoid the flame scouring against the opposite wall. The central gas nozzle diameter is 0.3m. Two combustion air nozzles are set on the two sides of the gas nozzle in the horizontal direction. The combustion air nozzle diameter was also 0.3m. The elevation of nozzle was 4.1m, which was the same as the original nozzle. The spacing between gas nozzle and combustion air nozzle was selected as 0.51m, 0.57m and 0.63m respectively in order to investigate the mixing process of gas jet and air jet.

$k-\varepsilon$ turbulence model, Probability Density Function combustion model and Discrete Ordinates radiation model are applied in the numerical simulation. The steel billet surface temperature is assumed as 1000°C and the heat loss from furnace wall 1000W/m². The parameters in simulation are listed in Table 3.

Table 3 Parameter of simulation calculation

Case	preheated gas temperature/°C	preheated air temperature/°C	gas jet velocity/ms ⁻¹	combustion air jet velocity/ms ⁻¹	spacing between nozzles/m
Original soaking pit	390	550	46.36	45.75	rotational type
1	400	1000	18.32	41.32	0.51
2	400	1000	18.32	41.32	0.57
3	400	1000	18.32	41.32	0.63
4	600	1000	23.19	40.32	0.51
5	600	1000	23.19	40.32	0.57
6	600	1000	23.19	40.32	0.63
7	800	1000	27.79	39.31	0.51
8	800	1000	27.79	39.31	0.57
9	800	1000	27.79	39.31	0.63
10	1000	1000	32.10	38.29	0.51
11	1000	1000	32.10	38.29	0.57
12	1000	1000	32.10	38.29	0.63

The flow line figures for the original soaking pit and the rebuilt scheme in two cycles are shown in Figure 2, Figure 3 and Figure 4 respectively. The temperature distributions in the cross section of furnace are shown in Figure 5 and Figure 6.

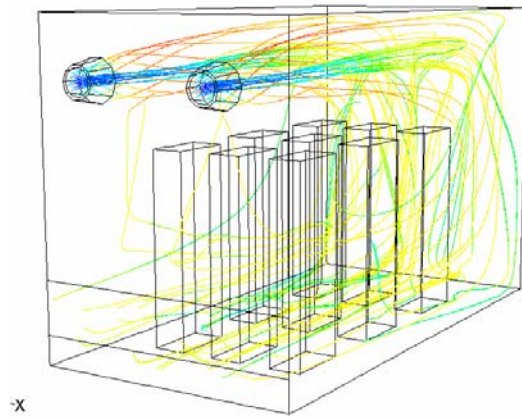


Fig.2 flow line of soaking pit before rebuilding

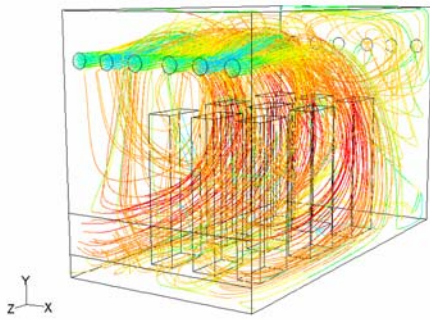


Fig 3 flow line in soaking pit during during one cycle after rebuilding

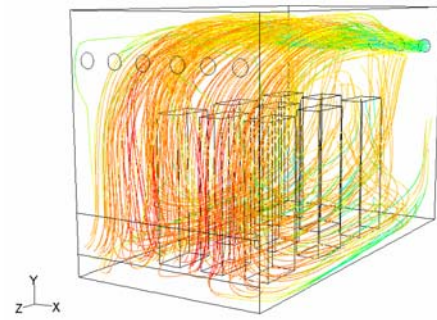


Fig 4 flow line in soaking pit during another cycle after rebuilding

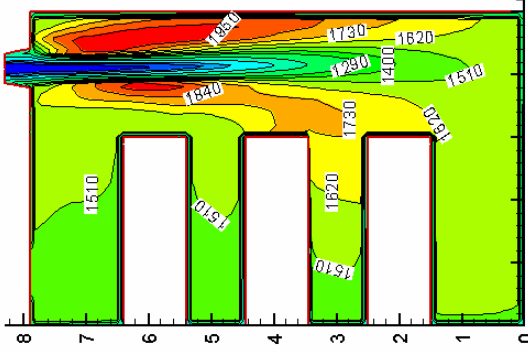


Fig.5 Temperature distribution in the cross section of soaking pit before rebuilding

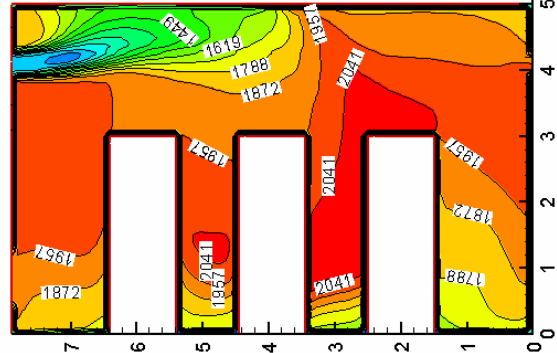


Fig.6 Temperature distribution in the cross section of soaking pit after rebuilding

R_{tu} is the temperature distribution non-uniformity coefficient, which is $\sqrt{\sum \left(\frac{T_i - \bar{T}}{\bar{T}} \right)^2}$ in this paper, where \bar{T} is the

average temperature in furnace. The temperature distribution results are listed in Table 4. The maximum temperature in furnace is 71~226K higher than the original furnace since gas and combustion air are preheated up to high temperature. In addition, the average temperature increases 302~363K. R_{tu} decreases from 33.18 to 18 or so, which demonstrates that the uniformity of temperature in furnace is better than the original soaking pit.

Table 4 Simulation results of temperature distribution in furnace

Case	maximum temperature in furnace, K	average temperature, K	temperature difference between maximum temperature and average temperature in furnace, ΔT , K	R_{tu} (K)
0	2086	1606	480	33.18
1	2202	1930	272	28.43
2	2212	1908	304	32.14
3	2192	1925	267	29.68
4	2183	1965	218	23.42
5	2189	1954	235	25.36
6	2185	1962	223	24.41
7	2166	1969	197	18.69
8	2171	1952	219	22.22
9	2157	1959	198	20.77
10	2188	1946	242	17.95
11	2176	1935	241	21.45
12	2181	1938	243	19.28

CONCLUSION

i. If the combustion system of soaking pit is rebuilt by applying high temperature air combustion technology, the gas saving ratios will be 12.41%, 14.54%, 16.67%, 18.85% respectively when the combustion air preheated temperature is 1000°C and the gas preheated temperature is 400°C, 600°C, 800°C, 1000°C respectively.

ii. Since the flow direction of flue gas changes periodically, the temperature uniformity will be increased. The temperature non-uniformity coefficient decreases from 33.18 to 18 or so.

iii. The maximum temperature in furnace, the average temperature and the temperature difference in Case 9 are lower than others, and the temperature non-uniformity coefficient is relative low. Case 9 is therefore selected as the optimally designing scheme.

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