High Efficiency and Clean Combustion of Converter Gas

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Abstract: The effects of water vapor concentration in air and inlet temperature of converter gas on converter gas combustion were investigated by numerical simulation. When water vapor concentration in air increases from 0 to 5%, the emission concentration of CO and NO and the peak flame temperature decreases. When the inlet temperature of converter gas is constant, water vapor concentration increases from 0 to 0.7%, CO concentration in converter gas decreases rapidly. When converter gas temperature varies from 1050 to 1150 K, the effect of water vapor on NO is more significant. When the inlet temperature of converter gas increases from 823 to 1153 K, CO emission concentration decreases, NO emission concentration and peak flame temperature increases. At water vapor occurrence, CO is mainly oxidized by OH free radical, it reduces the maximum flame temperature, thus the formation of thermal-NO_x is reduced.

1 Introduction

After more than 60 years development, oxygen converter is generally divided into top blowing, bottom blowing and mixed blowing. Top blowing oxygen steelmaking produces 85.5% of steel. Converter steelmaking keeps the advantage of the first steelmaking method in the world through technological innovation [1]. One of the characteristics of converter production is the production of a large amount of tail gas containing about 80% of carbon monoxide (CO). A large amount of harmful gases such as nitrogen oxides are produced in the process of combustion of steelmaking converter gas, which is the main pollutant produced by fossil fuel combustion [2].Therefore, it is a development trend of steelmaking converter to study the influence of various factors on combustion, to explore the formation mechanism of nitrogen oxide, and to take certain measures to reduce the emission of nitrogen oxide [3]. In order to realize the efficient and clean combustion of converter gas, it is necessary to study the important factor of water vapor [4].

2 Gas combustion model of steelmaking converter

2.1 Mathematical and physical models

There is a casing burner at the axis of symmetry on one side of the converter. Model data and boundary conditions are presented table1:

Table1: Model data and boundary conditions

Furnace length	500mm
Furnace diameter	50mm
Casing burner external diameter	16.8mm
Casing burner inner diameter	10mm
Nozzle length	20mm
Mass fraction of converter gas	
CO	65%
CO_2	34%
N_2	1%
Gas inlet velocity	20m/s
Air inlet velocity	20m/s
Excess air factor	1.05
Converter gas inlet pressure	1atm
Air inlet pressure	1atm
Air inlet temperature	300k

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Figure1. Schematic of simulated combustion

The model used in this paper is a cylindrical converter with a diameter of 500 mm and a diameter of 50mm, which is shown in figure1.

Because of the central symmetry of the cylinder, a two-dimensional model is used to simulate combustion, and only half of the model is simulated. The grids are two-dimensional structured, adequate grid independence is satisfied with 4999 × 248 mesh nodes (1234506 units) [5].The standard k- ε model is adopted in this paper [6-8].

2.2 Combustion model

The combustion is simulated by the flame wave method including non-equilibrium effect and PDF treatment to consider the turbulent combustion. In the un-premixed combustion model, the turbulent diffusion flame is considered as the laminar flame collection, and chemical reaction and heat transfer take place in the thin layer. The thermochemical calculation is pretreated and the table is checked in CFD program. The interaction between turbulence and chemistry is explained by a hypothetical shape probability density function (PDF) [9]. In the thermochemical calculation, a combustion mechanism of converter gas at high temperature containing 114 elemental reactions of 37 components was adopted [10, 11].

3 Results and discussion

In this study, the influence of inlet temperature of converter gas (T_{inlet}) and water vapor concentration in air ($C_{\text{H2O,inlet}}$) on the combustion of converter gas was studied in the T_{inlet} range of 823K to 1153K and the $C_{\text{H2O,inlet}}$ between 0 and 5%. A large number of simulation results were obtained by numerical simulation to determine the average concentration of CO and NO, at the converter outlet ($C_{\text{CO ,outlet}}$, and $C_{\text{NO,outlet}}$).

3.1 Effects of water vapor concentration and inlet temperature of converter gas on average CO emission concentration at converter outlet

In this paper, the cloud diagram of the change of $C_{\text{CO ,outlet}}$ with $C_{\text{H2O,inlet}}$ and T_{inlet} is obtained.

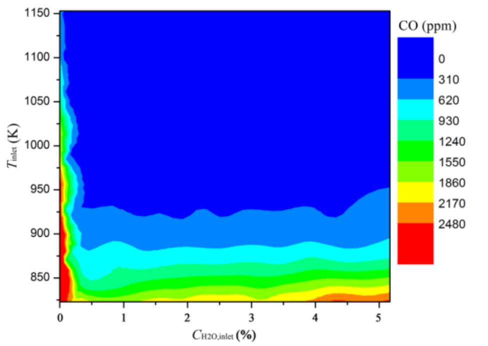

Figure 2：Effects of $C_{\text{H2O,inlet}}$ and T_{inlet} on $C_{\text{CO ,outlet}}$

From figure2 it can be seen that when T_{inlet} is constant, $C_{\text{H2O,inlet}}$ increases from 0 to 0.7%, and $C_{\text{CO ,outlet}}$ decreases rapidly. In this stage, the effect of $C_{\text{H2O,inlet}}$ on the combustion of CO is severe, then, the change is slow. In the range of $C_{\text{H2O,inlet}}$, $C_{\text{CO ,outlet}}$ decreases with the increase of T_{inlet}. From the pattern shown above, it can be concluded that when $C_{\text{H2O,inlet}}$ varies from 0 to 0.7%, $C_{\text{CO ,outlet}}$ decreases significantly because water vapor has a certain catalytic effect on combustion. It can promote the combustion and make the CO burning more fully. The increase of T_{inlet} also promotes the combustion of CO.

3.1.1Effect of water vapor concentration in air on CO emission concentration

In order to study the effect of $C_{H2O,inlet}$ on CO combustion, the CO reaction path diagrams with $C_{H2O,inlet}$ = 0 and > 0 were made for comparative analysis in this paper.

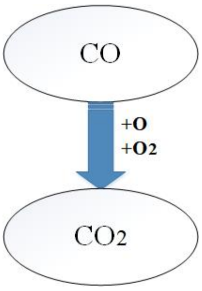

Figure3: The reaction path of CO when $C_{H2O,inlet} = 0$

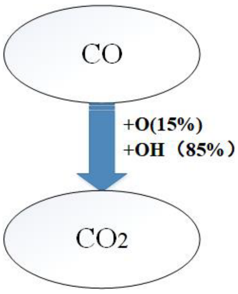

Figure4: The reaction path of CO when $C_{H2O,inlet} > 0$

It can be seen from figure3 and figure4 that when $C_{H2O,inlet}$ = 0, the CO reaction path is very simple, and CO directly produces CO_2 with O atoms. When $C_{H2O,inlet}$ > 0, it can be seen from the reaction path that the OH radical plays a very important role in the reaction, which provides sufficient O elements for the reaction, and the OH radical can react with CO more easily than the O radical. Among them, when $C_{H2O,inlet}$ = 0, the corresponding chemical reaction equation is as follows:

$CO+O=CO_2$ (R1)

$CO+O_2=CO_2+O$ (R2)

When $C_{H2O,inlet}$ > 0, the following reactions are added to R1 and R2:

$CO+OH=CO_2+H$ (R3)

3.1.2 Effect of inlet temperature of converter gas on CO emission concentration

In order to study the effect of T_{inlet} on $C_{CO,outlet}$, two different working conditions with the same $C_{H2O,inlet}$ = 0.222% and T_{inlet} = 823k and 988k were taken on the CO distribution cloud map to make a comparative analysis. The OH distribution cloud diagram under the above two working conditions is drawn to reflect the flame surface shape at different T_{inlet}. The distribution of OH free radical can be used to reflect the flame surface.

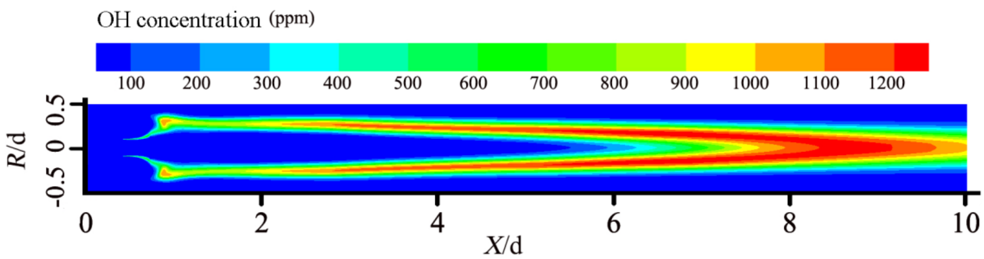

Figure5: Flame surface at T_{inlet} = 823K (where, *d* represents the furnace diameter, *R* represents the furnace radius, *X* represents furnace length, *X/d* and *R/d* represents dimensionless dimension)

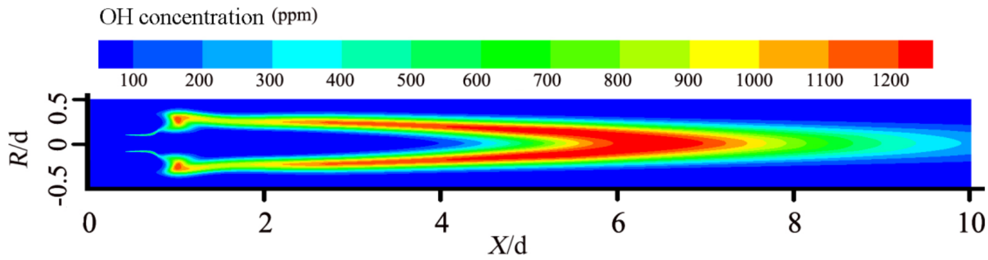

Figure6: Flame surface at T_{inlet} = 988K

From figure5 and figure6, it can be seen that the flame surface shrinks obviously when T_{inlet} increases, which indicates that the increase of T_{inlet} does accelerate the combustion rate of CO. Therefore, the temperature accelerates the combustion of CO by increasing the reaction rate and reducing the height of the flame surface, thus reducing $C_{\mathrm{CO\ ,outlet}}$. To sum up, increasing $C_{\mathrm{H2O,inlet}}$ and T_{inlet} plays a positive role in reducing $C_{\mathrm{CO\ ,outlet}}$ to achieve clean combustion.

3.2Effect of water vapor concentration and inlet temperature of converter gas on NO emission concentration at converter outlet

In order to study the influence of $C_{\mathrm{H2O,inlet}}$ and T_{inlet} on $C_{\mathrm{NO,outlet}}$, the distribution of $C_{\mathrm{NO,outlet}}$ with both of them was obtained in this paper.

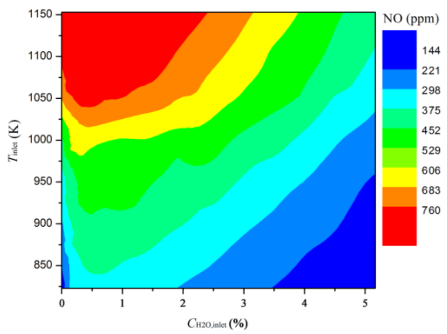

Figure7: Effects of $C_{\mathrm{H2O,inlet}}$ and T_{inlet} on $C_{\mathrm{NO,outlet}}$

It can be seen from figure7, when T_{inlet} is constant, the production of NO decreases with the increase of $C_{\mathrm{H2O,inlet}}$, and when $C_{\mathrm{H2O,inlet}}$ is constant, with the increase of T_{inlet}, the production of NO increases gradually. The effect of the two on NO production showed the opposite trend. At the same time, it is found that the law found in the cloud diagram of $C_{\mathrm{NO,outlet}}$ distribution is very similar to that of converter peak flame temperature distribution. As a result, this paper will analyze the two maps synthetically. The peak flame temperature distribution in the converter is shown in figure8:

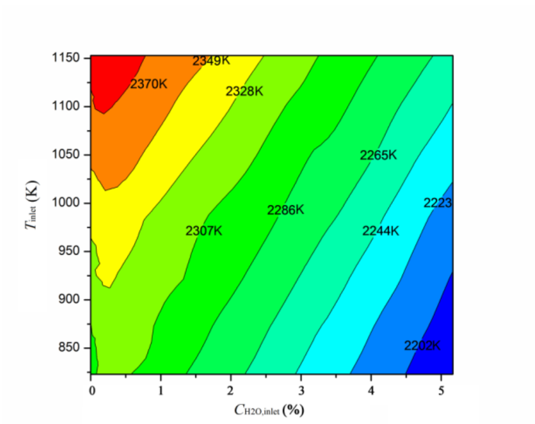

Figure8: Effects of $C_{\mathrm{H2O,inlet}}$ and T_{inlet} on flame maximum temperature

It can be seen from figure8 that the maximum temperature decreases with the increase of $C_{\mathrm{H2O,inlet}}$ at the same T_{inlet}. From the above analysis of CO, it can be seen that when $C_{\mathrm{H2O,inlet}}$ increases, water vapor provides a large number of OH free radicals for combustion, increases the height of the flame surface, and the temperature distribution in the converter is more uniform, so the maximum temperature of the flame decreases. So the concentration of thermal nitrogen oxides (mainly NO) decreased

In order to further study the reasons for the decrease of $C_{NO,outlet}$, this paper continues to study the mechanism of NO generation from the reflection path. The reaction mechanism is shown in figure8:

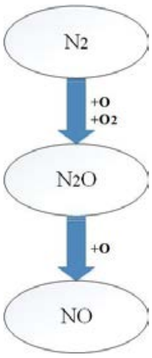

Figure9: The reaction path of NO

The corresponding chemical reaction equation is as follows:

$N_2+O_2=N_2O+O$ (R4)

$N_2+O=N_2O$ (R5)

$N_2O+O=NO+NO$ (R6)

As can be seen from figure9, the main reaction path of NO is relatively simple, and the increase of $C_{H2O,inlet}$ does not have much effect on the formation of NO in the chemical reaction path. The influence of $C_{H2O,inlet}$ on NO is mainly due to the thermodynamic change. Therefore, increasing $C_{H2O,inlet}$ does help to reduce $C_{NO,outlet}$ and play an active role in realizing clean combustion of converter gas.

4 Conclusions

1. Increasing $C_{H2O,inlet}$ is beneficial to reduce the emission of CO and NO, and to realize the high efficiency and clean combustion of converter gas.

2. The mechanism of the influence of $C_{H2O,inlet}$ on $C_{CO,outlet}$ is by changing the chemical reaction path. Among them, OH radical plays an important role in reducing the emission of CO. In addition, the effect of $C_{H2O,inlet}$ on $C_{NO,outlet}$ is mainly by lowering the maximum flame temperature, thereby reducing the thermal NO emission concentration.

3. Increasing T_{inlet} is beneficial to reduce $C_{CO,outlet}$, but it can also promote the formation of polluting gases such as NO. Therefore, T_{inlet} should be controlled within a reasonable range instead of blindly increasing T_{inlet}.

4. The influence mechanism of T_{inlet} on the emission of CO and NO is to accelerate the chemical reaction rate, reduce the height of flame surface and promote the formation of products. Accelerating the reaction rate can promote the conversion of CO to CO_2, but other reactants to NO. Therefore, T_{inlet} should be raised appropriately.

Acknowledgements

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