C. X. LI, X. MENG, Y. ZHANG, P. ZHAO, H. J. SHEN, Z. K. FENG, Z. H. JI

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STUDY ON THE PARTICIPATION OF BLOWING CO_2 IN STEELMAKING REACTION OF Fe-C BINARY ALLOY

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Based on the concept of green low-carbon and high-efficiency smelting, Fe-C alloys were prepared using industrial pure iron and high-purity graphite powder, and thermal experiments were carried out using a high-temperature tube furnace, and it was found that with the increase of blowing time, the carbon content in the molten pool was reduced subsequently; The reaction rates of CO_2 with (C) were 11,03 %, 12,94 %, 16,51 %, and 18,75 % at blowing flow rates of 10, 20, 30, and 40/ml·min-1, respectively; The decarburization rate increased from 0,0172 %/min to 0,0289 %/min, and the decarburization reaction rate is subsequently increased 1,68 times.

Keywords: Fe-C alloy, steelmaking, CO_2, flow rate, decarburization

INTRODUCTION

The steel industry is an important pillar of the national economy. The annual global crude steel production in 2023 was 1 888,2 million tons, and China's crude steel production was 1 019,08 million tons, with the share of steel production in the ball about 53,9 %. In 2023, the total global carbon emissions reached 37,4 billion tons, and China's carbon emissions reached 12,6 billion tons, of which carbon emissions from the iron and steel industry reached 1,89 billion tons, accounting for about 15 % of the country's total carbon emissions [1,2]. Under the background of "Carbon Peak, Carbon Neutral", it is imperative to reduce carbon emissions in the iron and steel industry, so the research and development of new processes and technologies for CO_2 resource utilization to reduce carbon emissions have become a key research topic.

S Chen [3] et al. studied the new process of CO_2 instead of Ar, and found that CO_2 can reduce the oxygen content in steel, homogenize the composition, reduce the content of inclusions in steel, and save the cost; Z Li [4] et al. first found that CO_2 can reduce the oxygen consumption by establishing the energy-connected analytical model of CO_2 used for dephosphorization; G Wei [5] et al. investigated the metallurgical reaction behavior of CO_2 as a RH lift gas and found that CO_2 had comparable or even superior dehydrogenation effects to Ar; Y Gu [6] et al. By bottom-blowing CO_2 gas, it was found that CO_2 gas could increase the desulfurization; H Wang [7,8] et al. The use of CO_2-O_2 mixed blowing instead of pure oxygen blowing reduces the temperature of the molten pool, strengthens the intensity of stirring, reduces the partial pressure of oxygen, and optimizes decarburization and chromium preservation.

C. X. Li (E-mail: lichenxiao34@163.com), X. Meng, Y. Zhang, P. Zhao, H. J. Shen, Z.K. Feng, Z. H. Ji Metallurgy and Energy College, North China University of Science and Technology, Tangshan, China.

Under the converter steelmaking link, CO_2 will also have weak oxidizing properties at high temperatures, thus reacting with the molten pool elements. It is necessary to study the law of CO_2 participation in steelmaking decarburization under the iron-carbon system, to provide theoretical basis and data support for better application in industry.

EXPERIMENTAL MATERIALS AND METHODS

Experimental materials

The Fe-C alloy used in the experiment was prepared by mixing YT01 industrial pure iron and high-purity graphite powder, and its composition is shown in Table 1.

Experimental program

CO_2 blowing flow for the decarburization reaction within the liquid steel is an important parameter in the steelmaking process, the size of the CO_2 blowing flow directly affects the size of the carbon content in the liquid steel, this paper mainly applies the method of controlling variables, limiting the experimental temperature and the initial carbon content, the main observation of the blowing flow of the carbon content in the liquid steel, the experimental program as Table 2

In the experiment, the initial carbon content of the formulated alloy material was 4 %, due to the difference in melting situation in each furnace during the experiment, so the initial carbon content of the samples did not fully meet the requirements of the formulation, so the concept of CO_2 decarburization rate was introduced to further analyze the decarburization law.

ANALYSIS OF EXPERIMENT RESULTS

Theoretical analysis

CO_2 is stable and belongs to inert gas, meanwhile, it has a weak oxidizing property itself, which can react chemically with the elements in the molten pool at high temperatures. The variation of ΔG^{θ} for the reaction of CO_2 with the main elements in the molten iron to obtain simple oxides between 1 500 K and 2 000 K versus the temperature T was obtained by calculation, as shown in Figure 1.

The standard Gibbs free energy of $CO_2(g)+(C)=2CO(g)$ is 137 890-126,52 T. At temperatures between 1 500 k and 2 000 k, the standard Gibbs free energy change ΔG^{θ} of the reaction is negative, and the oxidation reaction can be carried out at steelmaking temperatures, and the reaction proceeds more adequately when equilibrium is reached, so that, thermodynamically, the industrial Therefore, from the thermodynamic point of view, it is completely feasible to introduce CO_2 to participate in the melt pool reaction in industry.

In the oxidation of elements, CO_2/O_2 involved in the steelmaking reaction has a great influence on the melting pool temperature, considering the physical heat absorption change of the oxygen source, the specific heat capacity of the gas is commonly used to calculate the heat absorption change, assuming that the temperature of the melting pool is 1 450 °C (1 723 K), through the search for literature to get the relationship between the temperature and the molar constant pressure specific heat capacity of the relevant reactant and oxidized product in the melting pool, and according to the formula, thus calculate the physical heat capacity of CO_2 under 1 723 K, and then calculate the temperature. The physical heat absorption of CO_2 is 91,31 KJ/mol at 1 723 K, while the physical heat absorption of O_2 is 53,40 KJ/mol. In the oxidation reaction of CO_2 as an oxidizing gas on the (C) element in the melt, it is found that the chemical heat of the reaction $\Delta H>0$, and the reaction is an adsorptive reaction, which is exothermic when reacting with (Si)(Mn), but the exothermic heat released is smaller compared to that of the reaction of O_2 with elements of the melt pool; and the temperature change inside the molten pool when CO_2

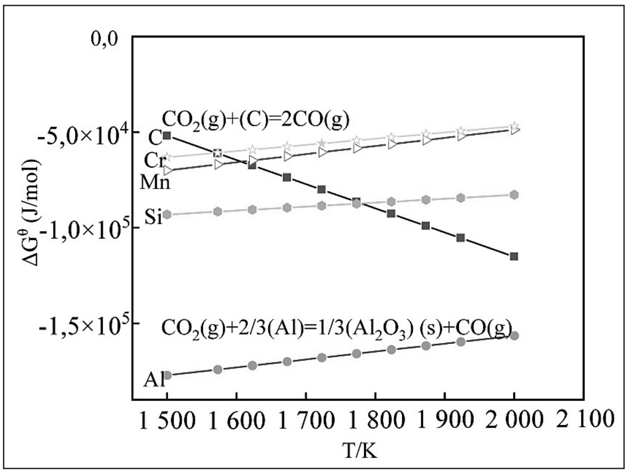

Figure 1 ΔG^{θ} for the reaction of CO_2 with each element as a function of temperature T

Table 1 **Raw material component/wt.%**

Raw Materials	Elemental						
	Fe/%	C/%	Si/%	Mn/%	P/%	S/%	Ni
YT01	99,963	0,002	0,005	0,013	0,0045	0,0025	0,01
Graphite Powder	-	99,99	-	-	-	-	-

Table 2 **Experimental scheme of different CO_2 blowing flow rates in the melt pool reaction**

gas	Temperature/°C	Mass/g	(C)/%	blowing rate /ml·min^{-1}
CO_2	1 500	500	4	10/20/30/40

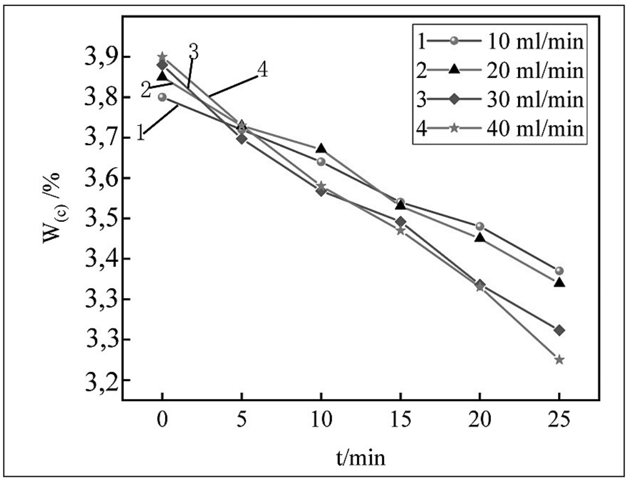

Figure 2 Variation of (C) content at different blowing flow rates

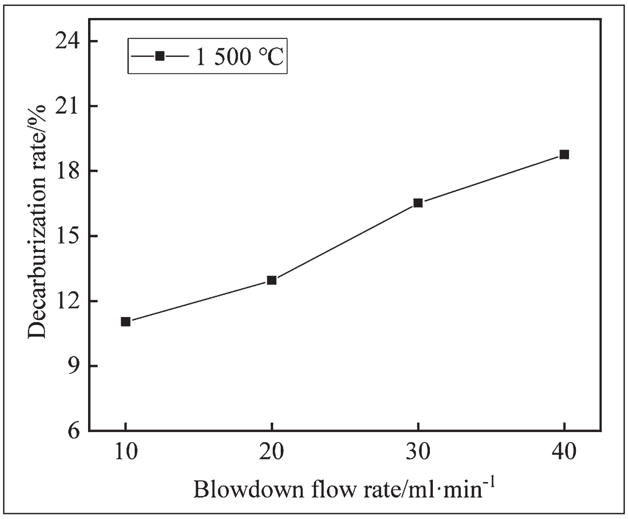

Figure 3 Decarburization rate of (C) at different blowing flow rates

Table 3 **Fitted relational equations**

volumes (ml/min)	fitting formula	R^2
10	$W_{(c)} = -0{,}0172t + 3{,}9$	0,9809
20	$W_{(c)} = -0{,}0202t + 3{,}947$	0,9932
30	$W_{(c)} = -0{,}0254t + 3{,}95$	0,9895
40	$W_{(c)} = -0{,}0289t + 3{,}988$	0,9957

reacts with the main elements in the liquid iron is relatively less drastic, which can play a temperature control role to a certain extent.

Effect of blowing flow rate on carbon According to the experimental data obtained by the carbon content changes in the different blowing rates under the carbon content of the changes in the graph, content as shown in Figure 2.

As can be seen from Figure 2, with the increase of blowing time, the carbon content in the melt pool is reduced, and the CO_2 decarburization rate at different blowing rates at 1 500 °C (1 773 K) is calculated and plotted in Figure 3.

From Figure 3, when the blowing flow rate is 10 ml/min, the reaction rate of CO_2 and (C) is 11,03 %, and at this time, the CO_2 blowing into the molten pool is less capable of participating in the reaction of the molten pool, and the effect of decarburization is poor, which is mainly since the amount of gas blowing into the molten pool is too small; and when the blowing flow rate is increased to 20, 30 and 40 ml/min, the reaction rate of CO_2 and (C) is increased to 12,94 %, 16,51 % and 18,75 %, respectively, and with the increase of blowing flow rate, the ability of CO_2 to oxidize the carbon elements in the molten pool increases significantly, and CO_2 and (C) is increased significantly. When the blowing rate was increased to 20, 30, and 40 ml/min, the reaction rates of CO_2 and (C) increased to 12,94 %, 16,51 %, and 18,75 %, respectively. With the increase of the blowing flow rate, the ability of CO_2 to oxidize the carbon elements in the molten pool was strengthened, and the reaction rates of CO_2 and (C) were subsequently improved. When kept at a low flow rate of 10, 20 ml/min, the increase in the reaction rate of CO_2 and (C) is not obvious; elevated to a larger flow rate of 30, 40 ml/min, the reaction rate of CO_2 and (C) rises significantly, this is because with the increase in flow rate, CO_2 blowing into the molten pool of the work done to increase the stirring effect of the molten pool is better, the mobility in the molten pool increases, and the participation in the reaction is more adequate, thus effectively improving the reaction of the molten pool. more fully, thus effectively improving the decarburization effect.

Effect of blowing flow rate on decarburization rate

Based on the data of carbon content change, the relationship equation of (C) content with time under different flow rates was obtained by linear fitting, and the relationship equation is shown in Table 3. It can be seen that the fitting degree of the equation of (C) content in the molten pool versus time is relatively high, reaching more than 98 % under different blowing flow rates. It can be analyzed that the reaction level of the (C) element in the molten pool with CO_2 is 0, which is a zero-level reaction, that is, the reaction rate of its decarbonization reaction is independent of the initial content of the reactant (C). And further differentiation of the data in the table, the relationship between the reaction rate and flow rate is obtained, as shown in Figure 4. It can be analyzed that with the increase of blowing flow rate, the decarburization rate of CO_2 increased from 0,0172 %/min to 0,0289 %/min, and the reaction rate increased by 1,68 times, which indicates that the decarburization rate is accelerated with the increase of blowing flow rate, which is more conducive to the occurrence of the reaction.

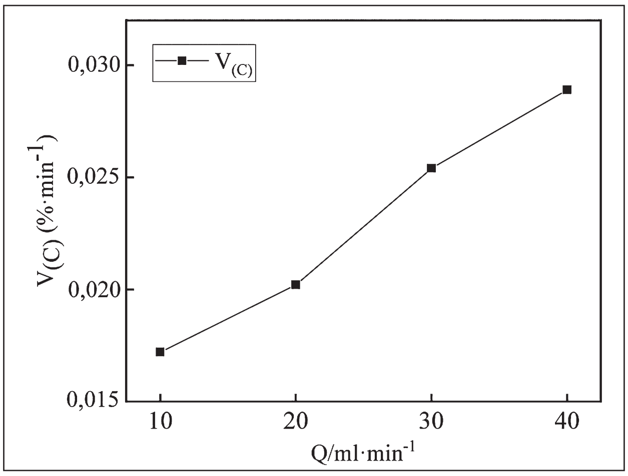

Figure 4 Decarbonization rate variation with flow rate

CONCLUSION

Through thermodynamic calculation, in the temperature interval of 1 500 K-2 000 K, the standard Gibbs free energy change ΔG^θ of CO_2 and C reaction are negative, and the oxidation reaction can be carried out at the steelmaking temperature; comparing CO_2 and O_2, CO_2 participates in the reaction in the melting pool with a better temperature control effect;

Under the blowing flow rate of 10, 20, 30, 40/ ml·min^{-1}, the reaction rates of CO_2 and (C) were 11,03 %, 12,94 %, 16,51 %, and 18,75 %, respectively; under each blowing flow rate, with the increase of time, the carbon content in the molten pool showed a decreasing trend.

The fitting degree of the equation of (C) content in the molten pool versus time reaches more than 98 %, and the oxidation reaction of CO_2 and (C) belongs to the zero-grade reaction, with the increase of the blowing flow rate, the decarburization rate increases from 0,0172 %/min to 0,0289 %/min, and the reaction rate increases by 1.68 times, and the decarburization rate accelerates with the increase of the blowing flow rate, which is more favorable for the reaction to take place.

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Note: The responsible translator for English language is Y. ZHANG - North China University of Science and Technology, China