

# Research on New Technology of Semi-steel Dephosphorization in Ladle Based on Water Simulation Experiment

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**Abstract.** Dephosphorization in the ladle is a new type of dephosphorization method. The water simulation experiment of semi-steel dephosphorization in 100t ladle of Chengde steel has been carried out. The best mixing time has been investigated for various process parameters of blowing oxygen lance and bottom blowing. It turns out to be that the best location of the pure bottom blowing is 0.7R-120°, the best bottom blowing flow rate is 100L/min; and the best of the top bottom blowing rate is 3000 Nm<sup>3</sup>/h, top gun angle is 60°, top lance height is 500mm. The order of three elements on influencing the mixing time is as follows: Top blowing flow > top gun height > top gun angle. The average of dephosphorus efficiency is 51.8% in industrial experiments.

## 1 Introduction

Chengde area is rich in vanadium titanium magnetite resources. Semi-steel has higher phosphorus rate, in order to reduce BOF load, semi-steel dephosphorization pretreatment is necessary. Converter tapping process has a relatively short time, generally 4-6 minutes. Using semi-steel dephosphorization in ladle is a new dephosphorization technology. The use of oxygen top blowing gun and bottom argon blowing can create a dynamic condition for dephosphorization reaction, which made good effects of dephosphorization<sup>[1]</sup>. Among them, the mixing time is one of the main reference indexes<sup>[2]</sup>. In this paper, by analyzing the water model, we can find the shortest time to satisfy dephosphorization reaction speed and argon blowing in ladle cycle.

## 2 Establishment of Model

According to the similarity principle, physical model established in this experiment of 100t ladle. The geometric model and the prototype remain similar and make sure that the geometric similarity ratio is 4:1. The geometric size of prototype and model is shown in table 1.

Table 1. Geometric parameters of prototype and model

	Prototype/mm	Model/mm
Top diameter	2900	725
Bottom diameter	2482	620.5
Deep of furnace	3520	880
Height of liquid level	2860	715
Thickness of slag layer	60	15

Determination of the gas parameters. In the calculation of gas flow in ladle in this experiment, the bottom blowing gas of prototype is argon, the model gas is nitrogen; the top blowing gas of prototype and model are both oxygen. The calculated numerical flow of bottom blowing and top blowing gas of the model are shown in table 2-3.

Selection of the model of slag medium. According to the similarity principle, water model experiment needs to meet the equal kinetic parameter We. For the simulation of slag layer, simulation medium should be selected according to the calculation results of the number of We. Select liquid paraffin as the steel slag simulated medium.

Table 2. Bottom blowing gas flow of prototype and model

Prototype flow/(L·min <sup>-1</sup> )	40	60	80	100	120	140
Model flow/(L·h <sup>-1</sup> )	33.2	49.8	66.4	83	99.6	116.2

Table 3. Top blown gas flow of prototype and model

Prototype flow/(m <sup>3</sup> ·h <sup>-1</sup> )	2000	2500	3000
Model flow/(m <sup>3</sup> ·h <sup>-1</sup> )	23.6	29.5	35.4

Determination of mixing time. The two electrodes are placed in two different positions at the bottom of ladle model. The saturated KCl solution is used as the tracer, each furnace 50ml. Through the observation and comparison of two electrode conductivity curve, the time when the two curves are stabilized and begin of coincidence is the end mixing time<sup>[3-4]</sup>.

### 3 Experiment result and analysis

#### 3.1 Determination of bottom blowing position

The bottom blowing is a constant of 80L/min, and mixing times are shown in table 4.

Table 4. Mixing time of different bottom blowing

Radii	0.4R				0.5R				0.6R				0.7R			
Angle/°	60	90	120	180	60	90	120	180	60	90	120	180	60	90	120	180
Mixing time/s	81	69	60	92	69	80	74	86	81	70	59	72	66	62	60	75

From Table 4, we can know that when the two flow streams are close to each other, the mixing time is generally longer. The main reason is that the interaction process of two streams in the rise of stirring liquid steel, which cancels each other out of a part of the mixing energy. When the two streams flow distance is too far, the mixing time is also relatively longer. More obvious scheme is that when the angle of two holes' radii is 180°, mixing time is generally longer than other schemes. The mixing time of 0.7R-120° is the shortest, which means the scheme is the best bottom blowing scheme. From figure 1 and figure 2, we can ultimately ensure that the best bottom blowing scheme is 0.7R-120°.

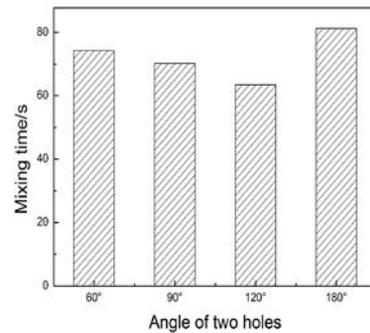
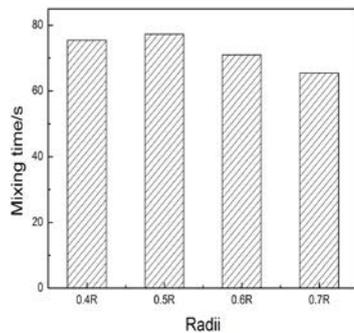


Figure 1. Average mixing time at different radii      Figure 2. Average mixing time at different angle

#### 3.2 Determination of bottom blowing flow

Through the changes at different bottom blowing flow rate to the effects of mixing time based on the actual situation to determine the best bottom blowing flow rate.

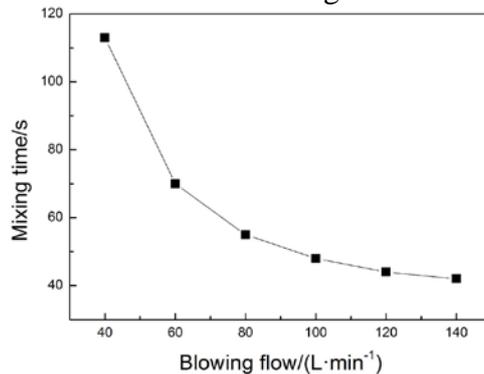


Figure 3. Mixing time with blowing flow rate

Analysis to Figure 3 shows that the mixing time reduces with increasing bottom blowing flow rate. Combining the actual comprehensive on-site factors we ultimately selected bottom blowing flow rate as 100L/min.

### 3.3 Analysis of orthogonal experiments

After reaching the optimal bottom blowing location 0.7R-120° and bottom blowing flow rate 100L/min, the orthogonal test has been taken for the research on the mixing time. Combining with the two top lances, we did the orthogonal experiment, and obtained the flow of top blowing flow, top gun angle, impact of top lance height on the mixing time, see table 5.

Table 5. Factor level

	A Top blowing flow/(Nm <sup>3</sup> ·h <sup>-1</sup> )	B Top gun angle/°	C Top gun height/mm
1	2000/23.6	58	600/150
2	2500/29.5	59	500/125
3	3000/35.4	60	400/100

Table 6. Results of orthogonal test

	1	2	3	4	
Factor	Top blowing flow/(Nm <sup>3</sup> ·h <sup>-1</sup> )	Top gun angle/°	Top gun height/mm		Time/s
Scheme1	23.6	58	150	1	72
Scheme2	23.6	59	125	2	64
Scheme3	23.6	60	100	3	56
Scheme4	29.5	58	125	3	46
Scheme5	29.5	59	100	1	44
Scheme6	29.5	60	150	2	50
Scheme7	35.4	58	100	2	33
Scheme8	35.4	59	150	3	39
Scheme9	35.4	60	125	1	30
Average1	64.000	50.333	53.667	48.333	
Average2	46.667	49.000	46.333	49.000	
Average3	33.667	45.000	44.333	47.000	
Range	30.333	5.333	9.334	2.000	

Table 6 is orthogonal experiment results in the bottom position 0.7R-120°, bottom blowing flow rate of 100L/min. The order of factors is top flow, top gun angle, and top lance height.

From table 6, the smallest top blowing flow rate in the orthogonal experiment of mixing time is 35.4Nm<sup>3</sup>/h, top lance height is 125mm, top gun angle is 60°, corresponding to the actual injection scheme that top blowing flow rate is 3000Nm<sup>3</sup>/h, top lance height is 500mm, and top gun angle is 60°, and the lowest mixing time is 30s. The order of three factors of effect on liquid steel stirring was blown flow > top lance height > top gun angle.

## 4 Industrial Experiments

Industrial Experiments were done by 20 furnaces in 100t ladle. Dephosphorization slag was added in two batches. Oxygen blowing started when steel pouring 5~7s. Scheme of semi steel dephosphorization was shown in table 7.

Table 7. Scheme of semi steel dephosphorization

CaO/kg	CaF <sub>2</sub> /kg	FetO/kg	Slag/kg	Oxygen flow/(Nm <sup>3</sup> ·h <sup>-1</sup> )	Oxygen Time/min
500	210	690	1400	3000	4

Argon was blown by ladle bottom blowing two points (radius 0.7R, angle 120°), bottom blowing amount is 100L·min<sup>-1</sup>. Dephosphorization lance design parameters was shown in table 8.

Table 8. Main design parameters of dephosphorization lance

Hole number	Mach	Oxygen flow /( $\text{Nm}^3 \cdot \text{h}^{-1}$ )	Height/mm	Angle/ $^\circ$	Throat diameter /mm	Outlet diameter /mm
1	1.4	3000	500	60	45	48

Industrial experiments show that dephosphorization slag had a good performance in slag melting and degree of foaming is higher. The arrangement of dephosphorization oxygen blowing lance and bottom blowing is more reasonable. Oxygen utilization rate is better, the slag had moderate content of FeO. The average dephosphorization rate is 51.8%. Dephosphorization results were shown in figure 4.

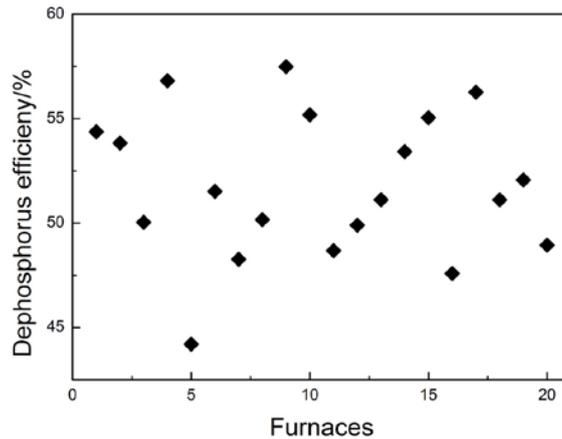


Figure 4. Dephosphorization results

## 5 Conclusions

(1) Through the pure bottom blowing experiments to yield the best bottom blowing location and bottom blowing flow rate that match the field. Bottom blowing location is  $0.7R-120^\circ$ , while the best bottom blowing flow rate is 100L/min.

(2) Through the orthogonal experiment of top and bottom blowing to get optimal blowing program. Top blowing flow is  $3000 \text{ Nm}^3/\text{h}$ , top gun angle is  $60^\circ$ , and top lance height 500mm.

(3) The order of elements influencing the mixing time is: top blowing flow > top lance height > top gun angle.

(4) Industrial experiments show that the arrangement of dephosphorization oxygen blowing lance and bottom blowing is more reasonable. The average of dephosphorus efficiency is 51.8%.

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