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The Design of the Oxygen Gun with the Powder Injection for Converter

The Design of the Oxygen Gun with the Powder Injection for Converter

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Abstract. For the process that massive limestone is added into converter directly, the problem of slow slagging and low dephosphorization rate can generate. The transformation of converter oxygen lance has been considered in the paper, realizing the oxygen lance blowing powder of granular limestone slag and the rapid slagging and high efficiency of dephosphorization. Based on 120t converter smelting, the consumption of limestone in this process has been calculated in this paper, and a multi-function oxygen gun has been designed to provide guidance for actual production.

1. Introduction

With the advantages of energy saving and energy saving, it is widely used in domestic steel mills[1-8]. However, the process has the problems of slow lime slagging and low phosphorus removal rate. The purpose of this paper is to realize the aim of accelerating slag and high efficiency dephosphorization by reforming the converter oxygen lance.

2. Design parameter selection

2.1. Parameter selection

Table 1 Process Parameters Settings

Item	Parameters
Converter nominal capacity	120 t
Steel weight	120 t
Converter smelting time.	37 min
Pure oxygen injecting time	16 min
Diameter of limestone particles	0.12-0.38 mm
Oxygen density	1.43 kg·m^{-3}
Limestone granule density	2930 kg·m^{-3}
Oxygen viscosity	1.85×10^{-3}
Ratio between powder and gas	10-50

Corresponding alternative ratio for limestone is 70%, 5% heat loss for hot metal, the initial temperature of 1375 ℃ [7] material balance is as follows.

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Table 2 Materials balance

Income items			Output items		
Items	mass/kg	%	Items	mass/kg	%
Hot metal	133471.31	83.07	Liquid steel	120000	75.25
Scrap	214.00	0.13	Slag	17205.98	10.79
Lime	2274.21	1.42	Furnace gas	17901.58	11.23
Limestone	9127.31	5.68	Spatter	1334.71	0.84
Fluorite	667.36	0.42	Dust	2002.07	1.26
Light-burned Dolomite	4999.17	3.11	Iron bead in slag	1032.36	0.65
Lining	400.41	0.25			
Oxygen	9515.27	5.92			
Total	160669.03	100	Total	159476.70	100

2.2. Design requirements
Table 2 illustrates that if one wants to inject limestone powder into the pool by the top oxygen lance, this must be ensured that, within the 1/3-1/2 of pure oxygen blowing time, blowing all the limestone powder should be injected, while keep blowing oxygen unchanged.

3. Converter oxygen gun design.

3.1. Velocity of free settlement of spherical limestone particles.
From table 1.1, the diameter of limestone is about 0.12mm ~ 0.38mm, therefore, dmax= 0.4mm is recommended as the maximum calculation diameter of limestone particles, and dmin= 0.12mm as the minimum calculation diameter of limestone.

Under dmax= 0.4mm, $Ar = \frac{d_{\max}^3 \times \rho_{\text{air}} \times (\rho_{\text{limestone}} - \rho_{\text{air}}) \times g}{\mu^2} = 7682.4$.

Referring to literature[8], Re=95.6 can be introduced. $V_{t1} = \frac{\mu \times Re}{d_{\max} \times \rho_{\text{air}}} = 3.09\ \text{m} \cdot \text{s}^{-1}$.

Under the condition of $d_{\min}$=0.12 mm, $Ar = \frac{d_{\min}^3 \times \rho_{\text{air}} \times (\rho_{\text{limestone}} - \rho_{\text{air}}) \times g}{\mu^2} = 207.4$. Re=7.16 can be obtained. $V_{t2} = \frac{\mu \times Re}{d_{\min} \times \rho_{\text{air}}} = 0.772\ \text{m} \cdot \text{s}^{-1}$.

In conclusion, the average value can be calculated, and which is Vt=1.93 m·s^{-1}.

3.2. Airflow velocity
According to table 2, the gas flow velocity of lime is selected approximately.

Table 3 Gas flow velocity V_a and solid terminal velocity V_t

Powder name	r_s (t·m^{-3})	V_t (m^3·s^{-1})	V_a (m^3·s^{-1})
Carbon powder（C）	1.2-1.5	8.7	20-30
Quartz sand（SiO_2）	2.3-2.8	6.8	25-35
Bauxite（Al_2O_3）	3.2-4.09	0.268	20-40
Aluminum powder（Al）	2.67-2.69	0.5	-
Lime powder（CaO）	2.0	-	26-30

From the above, the velocity Va=Vt+30=32 m·s^{-1}[9].

3.3. Oxygen and limestone mass flow.

Ignoring the effect of temperature on the oxygen flow, combined with the quality of blowing limestone, the seamless steel tube with a national standard of 73 × 4.5mm was selected in the spray gun to form a device for blowing particles in the middle of the oxygen gun. $Q_{\mathrm{oxygen}}=\frac{\pi\times d^2}{4}\times\frac{P_0}{P}\times V_\alpha=\frac{\pi\times(64\times10^{-3})^2}{4}\times8\times32=0.82\ \mathrm{m^3\cdot s^{-1}}$,
$G_{\mathrm{oxygen}}=Q_{\mathrm{oxygen}}\times\rho_{\mathrm{oxygen}}=0.82\times1.43=1.17\ \mathrm{kg\cdot s^{-1}}$.

Compared with 10-50, the maximum powder ratio can be set as 20. $G_{\mathrm{limestone}}=G_{\mathrm{oxygen}}\times\mu_s=1.17\times20=23.4\ \mathrm{kg\cdot s^{-1}}$. For the calculation of the amount of limestone blowing, the theoretical injection amount can be obtained in the 1/3 to 1/2 of the pure oxygen time which is about 5.3 min-8 min. $G_{\mathrm{theoretical}}=G_{\mathrm{limestone}}\times t=23.4\times(5.3\sim8)\times60=7441.2\sim11232$ kg. According to table 2, the actual required limestone amount is 9127.31 kg in the above range, so the design meets the actual requirements.

3.4. design of oxygen lance nozzle.

1) oxygen flow or oxygen supply intensity[7]

$$Q_{\mathrm{total}}=\frac{V_{\mathrm{o_2}}}{\tau}=\frac{9515.27\times22.4}{32\times16\times60}=6.94\ \mathrm{m^3\cdot s^{-1}},\quad Q_{\mathrm{ring}}=Q_{\mathrm{total}}-Q_{\mathrm{in}}=6.94-0.82=6.12\ \mathrm{m^3\cdot s^{-1}}.$$

where, $V_{\mathrm{o_2}}$ is consuming the total oxygen quality for 120t converter, which can be found in table 2, kg; The pure oxygen blowing time of 120t converter can be measured in table 1, min.

2) nozzle outlet Mach number Ma

The nozzle exit Mach number determines the size of the orifice exit velocity of oxygen, also determines the oxygen jet impact on molten pool mixing ability, oxygen lance nozzle exit Mach number at home and abroad is common about between 1.95 ~ 2.20, the choice Ma = 2.0 in here.

3) design working condition oxygen pressure.

According to isentropic flow table, when Ma=2.0, $P/P_0=0.1278$; The nozzle outlet pressure P=0.102 M Pa, then the nozzle stagnation oxygen pressure is 0.798 M Pa.

4) calculate the diameter of larynx.

The flow rate of each nozzle is as shown below. $q=\frac{Q}{5}=\frac{6.12}{5}=1.224\ \mathrm{m^3\cdot s^{-1}}$.

By the formula, $q=1.782C_D\cdot\frac{A_{\mathrm{larynx}}\times P_0}{\sqrt{T_0}}$, where , C_D=0.93, T_0=290K, P_0=0.789 M Pa (4), then, $d_{\mathrm{larynx}}=30\ \mathrm{mm}$.

5) throat length, the general range is 5~10 mm, so 8 mm is chose.

6) length of contraction section.

$l_1=(0.8\text{-}1.5)\ d_{\mathrm{larynx}}=1.0\times30=30$ mm.

7) the contraction section is half conical angle is 18°.

8) inlet diameter of contraction section.

$$d_1=d_{\mathrm{larynx}}+2l_1\times\lg\beta=30+2\times30\times\lg(18^\circ/180^\circ\times\pi)=50\ \mathrm{mm}$$

9) calculate the diameter of nozzle outlet. According to the isentropic flow table, when Ma=2.0, $A_{\mathrm{out}}/A_{\mathrm{larynx}}=1.6875$, and this means, $\frac{\pi}{4}d_{\mathrm{out}}^2=1.6875\times\frac{\pi}{4}d_{\mathrm{larynx}}^2$.

The diameter of outlet diameter is as showed. $d_{\text{out}} = \sqrt{1.6875}\, d_{\text{larynx}} = \sqrt{1.6875} \times 30 = 40\ \text{mm}$. The expansion segment, the semi-cone angle of the expansion segment is equal to 3.5°, and the length of the expansion segment is $L_{\text{e}} = \dfrac{d_{\text{out}} - d_{\text{larynx}}}{2\tan\alpha} = \dfrac{40 - 30}{2\tan 3.5^{\circ}} = 90\ \text{mm}$.

11) expansion segment diameter dexpansion, according to empirical formula $l_{\text{expansion}}$ =(1.2~1.5)$d_{\text{expansion}}$. $d_{\text{e}} = \dfrac{90}{1.5} = 60\ \text{mm}$.

Table 4 The dimensions of oxygen lance nozzle

Lance nozzle	Laval nozzle
Oxygen flow in a single nozzle/m3·s-1	1.224
Throat diameter /mm	30
The throat length /mm	8
Contraction length/mm	30
Half cone Angle of contractionβ/°	18
Diameter at the entrance of the contraction section /mm	50
Nozzle outlet diameter /mm	40
Divergent section /mm	90
Divergent section Diameter /mm	60

3.5. Diameter of lance gun

The time for oxygen injection is assumed as 16min, which is the same as the external oxygen supply time. In this case, the flow rate of external pipe diameter is as showed follows. Qsurround=Q_{total}-Q_{inside}=6.94-0.82=6.12 $m^3 \cdot s^{-1}$.

Then, the ring area is $A_{\text{surround}} = \dfrac{P}{P_0} \times \dfrac{Q_{\text{surround}}}{V_{\alpha}} = 0.0153\ \text{m}^2$, $D_1 = \sqrt{\dfrac{4A_{\text{total}}}{\pi}} = 0.152\ \text{m}$.

The thickness of the inner wall D_1 is generally 4 ~ 10 mm. After calculating the inner diameter of the inner pipe, the outer diameter of the inner tube should be chosen according to the size of the national steel pipe catalogue. If the inner tube diameter is 168 mm according to the national standard, the thickness of the inner pipe wall is 8 mm.

3.6. Pipe diameter of outer layer

According to the experience of production practice[7], the oxygen lance cooling water consumption Q = (100 t/h) was selected, the influent velocity of cooling water was V = 6 $m \cdot s^{-1}$, and the outlet velocity was 7 $m \cdot s^{-1}$ (as the water temperature increased, the volume increased, so $V_{\text{in}} > V_{\text{out}}$). The outer diameter of the central oxygen tube is 168mm, and the diameter of the oxygen tube is 168mm.

Area of water inlet ring is $F_2 = Q_{\text{water}} / V_{\text{in}} = 46.3\ \text{cm}^2$.

The area of water circulation is $F_3 = \dfrac{Q_{\text{water}}}{V_{\text{in}}} = 39.7\ \text{cm}^2$. So, the inner diameter of the middle pipe is $d_2 = \sqrt{\dfrac{4F_2}{\pi} + d_{1\text{out}}^2} = 18.5\ \text{cm}$.

The middle layer steel pipe is chosen as Φ 203 × 8, Inner diameter of outer steel pipe is as follows, $d_3 = \sqrt{\dfrac{4F_3}{\pi} + d_{2\text{out}}^2} = 21.7\ \text{cm}$.

The outer layer steel pipe is Φ 245 cm × 14 cm.

4. Conclusions

In this paper, based on 120t converter, the injection rate of limestone was calculated according to the results of physical balance calculation, and the settling velocity, airflow velocity, oxygen flow rate and mass flow rate of limestone were further calculated, and the oxygen lance nozzle was designed. The conclusion were as follows.

(1) The free settlement velocity of limestone was 1.93 $m \cdot s^{-1}$.

(2) The gas velocity was 32 $m \cdot s^{-1}$.

(3) The mass flow rate of oxygen was 1.17 $kg \cdot s^{-1}$, and the mass flow rate of limestone was 23.4 $kg \cdot s^{-1}$.

(4) Finally, the diameter of the inner layer, middle layer and outer layer of the oxygen lance were designed.

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