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PARAMETRIC OF DIMENSIONAL ANALYSIS ON IRON BATH GASIFIER

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In this paper, an iron bath gasifier is designed to handle organic solid waste. A 1:8 water model is constructed to study the effects of the various parameters on the mixing time. The empirical formula between the mixing time and dimensionless groups was determined by multiple linear regression. The study results show that the flow rate of bottom nozzle, flow rate of side nozzle, top lance position, and tracer height have a great impact on the mixing time. By substituting previous experimental data into the empirical formula, the calculated and experimental values of the dimensionless group of mixing time are found to be highly relevant.

Keywords: iron, bath, mixing time, dimensional analysis, multiple linear regression

INTRODUCTION

The organic waste is blown into the molten pool of iron bath gasifier and converted into gas, which is different from the traditional converter steelmaking. The reactor needs to blow the organic solid waste particles into the converter through the top lance for the decomposition reaction, so making out the melting tank transmission behavior characteristics of the converter is a crucial step. In the field of melting tank transmission, many researchers have done considerable works on mathematical simulation and physical simulation. L Ming used a transparent water model to investigate the effects of the bottom blowing position and gas flow rate on mixing phenomena [1]. Li et al studied the fluid flow characteristics in the top and bottom blowing converter, obtained the main factors affecting the mass transfer in the bath and the appropriate volume of top and bottom blowing [2]. T Mario took nozzle diameter, radial position and gas flow rate as variables, indicating that the mixing time decreases with nozzle diameter getting smaller. C Bo verified that adding the side blowing greatly shortened the mixing time of the converter, and reducing the consumption of steel materials [3]. For the analysis of unknown laws in physical phenomena, dimensional analysis is one of the essential methods. By Analyzing Relevant Physical Parameters, we construct them into dimensionless forms with combined quantities. The originally dimensional physical quantitative relations are replaced by dimensionless relations, revealing the internal connection and logic of different physical quantities. This physics analysis can draw a series of qualitative or even semi-quantitative conclusions, and such findings can guide experimental studies and mechanistic analysis. Dimensional analysis can provide important information in understanding observed phenomena. It is a very effective analysis method for exploring the unknown laws of physical phenomena and studying new phenomena, so it is widely used in multidisciplinary fields. This paper explores the intrinsic connections between the different factors by dimensionality analysis of the previous experimental results.

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EXPERIMENTAL METHODS

The physical experimental model of iron bath gasifier is made of Plexiglass based on the actual furnace type, its ratio is 1:8. Physical simulation experimental research is used to use liquid at room temperature to simulate metallurgical melt at high temperature. In practice, the water is usually simulated with the iron liquid in the molten tank. In order to simulate the role between molten slag and liquid iron in the water model, the oil medium of the simulated slag layer should meet the same ratio of the power viscosity. The existing material parameters of steel liquid, protective slag and water. As shown in the Table1, HFV-M200 high vacuum pump oil is used to simulate the slag in the melting tank to meet the similarity requirements. Various blowing gases in the actual furnace, such as oxygen, nitrogen, argon and hydrogen, are replaced by compressed air. Figure 1 and is the experimental device.

Table 1 **Physical parameters of the experiment**

	Density / kg/m^3	Kinematic viscosity / m^2/s
molten iron	7 000	9×10^{-5}
Water	1 000	1×10^{-6}
Air	1,205	$1,5\times10^{-5}$
Slag	3 000	$1,33\times10^{-4}$
Vacuum oil	860	$6,8\times10^{-5}$

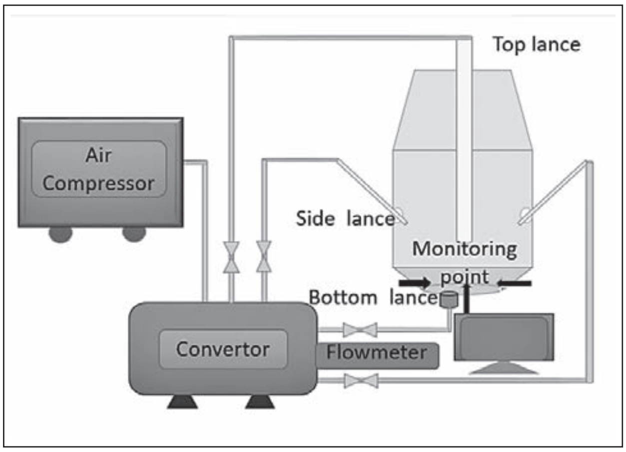

Figure 1 Schematic diagram of experimental equipment

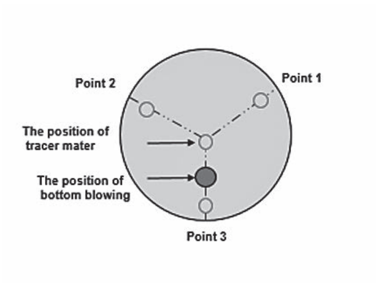

Figure 2 Schematic diagram of location of the test points

Table 2 **The parameters of the dimensional analysis**

Variable	Symbol	Unit /
Density	ρ	$kg \cdot m^{-3}$
Viscosity	υ	$m^2 \cdot s^{-1}$
Surface tension	σ	$kg \cdot s^{-2}$
Acceleration of gravity	g	$m \cdot s^{-2}$
Mix energy	ε	$kg \cdot m^2 \cdot s^{-3}$
Mixing time	τ	s
Diameter of model furnace	D_f	m
Height of oil phase	H_{oil}	m
Height of water phase	H_w	m
Height of Side gun	H_S	m
Diameter of Bottom blow	D_b	m
Diameter of Side gun	D_s	m
Diameter of Top gun	D_t	m
Height of tracer	H_i	m
Depth of side gun	h_s	m
Speed of Side gun flow	V_s	$m \cdot s^{-1}$
Speed of Top flowing	V_t	$m \cdot s^{-1}$
Speed of Bottom blowing	V_b	$m \cdot s^{-1}$
Top gun position	H_t	m
Side gun flow	Q_s	$m^3 \cdot s^{-1}$
Top gun flow	Q_t	$m^3 \cdot s^{-1}$
Bottom gun flow	Q_b	$m^3 \cdot s^{-1}$

Dimensional analysis

The aim of research was to construct a relationship between the mixing time and experimental variable. Thorough water model experiments, the experimental mixing time was obtained. The first thing is to select the initial parameters which closely related to the mixing time. The mixing time was mainly affected by the following factors as shown in the Table 2. Factors can be divided into two categories, the first class is the material parameters, such as density, motion viscosity, surface tension, etc. another class is related to operation setting, such as the location of top gun, side gun blow, side gun insertion depth, bottom gun blow flow, etc. The next step is to assemble those initial parameters into a dimensionless groups. According to Buckingham's theorem (π-principle), the independent variables were found out. In this study, 19 initial factors were selected to determine dimensionless groups with quantified mixing time.

There are three basic classes in International System of Units, namely mass / M/kg, length / L/m, time / t/s. The other physical quantities except these three basic dimensions serve as derived quantities, and they form the expression of π with the power equation of the basic quantity, and then solve the exponent in each π expression with the power expression of each dimension to form the number of π. At the same time, many factors were constant in the course of this study, such as furnace body height, diameter, side gun height, side gun diameter, etc. The setting of these parameters will allow room for future changes of such different parameters. In this section, after excluding a series of constant terms in this study, According to the correlation law of similar principles, it can be expressed as a dimensionless equation in the form of Equation 1:

$$\pi = \rho^a \upsilon^b \sigma^c \tau^d g^e \varepsilon^f D_s^{\,g} V_s^{\,h} V_t^{\,i} V_b^{\,j} H_t^{\,k} H_{oil}^{\,l} H_w^{\,m} H_i^{\,n} hs^o Dt^p Q_s^{\,q} Q_t^{\,r} Q_b^{\,s} \quad (1)$$

According to the consistency principle of the dimension, obtaining Equation 2;

$$\pi = \left(\frac{\upsilon}{Vt\,Ds}\right)^b \left(\frac{\sigma}{\rho\, V^2 t\, Ds}\right)^c \left(\frac{\tau Vt}{Ds}\right)^d \left(\frac{g\,Ds}{V^2 t}\right)^e \left(\frac{\varepsilon}{\rho\, V^3 t\, D^2 s}\right)^f \left(\frac{Vs}{Vt}\right)^h \left(\frac{Vb}{Vt}\right)^j \left(\frac{Ht}{Ds}\right)^k \left(\frac{Hoil}{Ds}\right)^l \left(\frac{Hw}{Ds}\right)^m \left(\frac{Hi}{Ds}\right)^n \left(\frac{hs}{Ds}\right)^o \left(\frac{Dt}{Ds}\right)^p \left(\frac{Qs}{D^2 s Vt}\right)^q \left(\frac{Q_t}{D^2 s Vt}\right)^r \left(\frac{Q_b}{D^2 s Vt}\right)^s \quad (2)$$

Table 3 **The dimensionless groups**

Symbol	Name	Expression
Re	Reynolds number	$\frac{V_s Ds}{\upsilon}$
Ca	Capillary number	$\frac{\rho \upsilon V_s}{\sigma}$
La_1	Lagrange group	$\frac{\varepsilon \upsilon}{\rho V^4 s D^3 s}$
Ho_1	Homochronous number	$\frac{\tau V_s}{Ds}$
KF	Capillarity-buoyancy number	$\frac{g \rho^4 \upsilon^4}{\rho \sigma^3}$
Z	Ohnesorge number	$\frac{\rho \upsilon}{(\rho \sigma Ds)^{\frac{1}{2}}}$

Because both Re and Ca are velocity-dependent bases, and Re/Ca is a constant, so the Re is represented by

Ca. KF/Z^2 and Dt/Ds are also constants in this study, it was removed again.

$$\tau = C\frac{Ds}{Vt}[(Ca)^a (La1)^b \left(\frac{Vs}{Vt}\right)^c \left(\frac{Vb}{Vt}\right)^d \left(\frac{Ht}{Ds}\right)^e \left(\frac{Hoil}{Ds}\right)^f \left(\frac{Hw}{Ds}\right)^g \left(\frac{Hi}{Ds}\right)^h \left(\frac{hs}{Ds}\right)^i \left(\frac{Qs}{D^2 s Vt}\right)^j \left(\frac{Q_t}{D^2 s Vt}\right)^k \left(\frac{Q_b}{D^2 s Vt}\right)^l \quad (3)$$

RESULTS AND DISCUSSIONS

Ca is selected for three different landmarks because the three different blowing position are in different media; The material parameters of the gas-water-oil phase should be selected for dimensional analysis. Since the side nozzle and top nozzle and the tracer addition positions were conducted in the oil phase, the material parameters of the oil phase were selected for calculation. The bottom blowing position was performed in the water phase, and the material parameters of the water phase were selected for calculation. To change the parameters of the Ds to the corresponding length basic dimension, to change the flow to the ratio between each other; 19 dimensionless number groups are obtained, so the equation can be obtained as Equation 4.

$$\tau = C\frac{Ds}{Vt}[Ca^{a1} Ca_s^{a2} Ca_b^{a3} La_{1t}^{b1} La_{1s}^{b2} La_{1b}^{b3} \left(\frac{Vs}{Vt}\right)^c \left(\frac{Vb}{Vt}\right)^d \left(\frac{Ht}{Dt}\right)^e \left(\frac{Ht}{Hoil}\right)^f \left(\frac{Ht}{Hi}\right)^g \left(\frac{Hoil}{Hoil+Hw}\right)^h \left(\frac{Hi}{Hoil}\right)^i \left(\frac{Hi}{Hw}\right)^j \left(\frac{hs}{Hoil}\right)^k \left(\frac{hs}{Ds}\right)^l \left(\frac{Qt}{Qs}\right)^m \left(\frac{Qs}{Qb}\right)^n \left(\frac{Qb}{Qt}\right)^o \quad (4)$$

The a, b, c, d, e, f, g, h, I, j, k, l, m, n, o is an empirical coefficient, it is calculated from the experimental data. The relationship between mixing time and dimensionless number groups will be obtained by dimensionality analysis of each influencing factor. The experimental data were replaced into Equation 5, the regression coefficients value and standard error by multivariate linear regression can be obtained. the equation of the mixing time can be obtained as follows,

$$\tau = C\frac{Ds}{Vt} Ca_t^{1,01} Ca_s^{-1,14} Ca_b^{-0,93} La_{1t}^{-0,95} La_{1s}^{0,65} La_{1b}^{-0,10} \left(\frac{Vs}{Vt}\right)^{-4,46} \left(\frac{Vb}{Vt}\right)^{-16,80} \left(\frac{Ht}{Dt}\right)^{-0,76} \left(\frac{Ht}{Hoil}\right)^{2,38} \left(\frac{Ht}{Hi}\right)^{-1,62} \left(\frac{Hi}{Hoil}\right)^{-1,62} \left(\frac{hs}{Hoil}\right)^{-0,76} \left(\frac{hs}{Ds}\right)^{0,76} \left(\frac{Qt}{Qs}\right)^{-8,62} \left(\frac{Qs}{Qb}\right)^{-0,42} \left(\frac{Qb}{Qt}\right)^{16,90}] \quad (5)$$

Figure 3 shows the relationships between the experimental value and calculated value, The results show that the equation computed values and experimental values are well correlated, and most of the 54 sets of data points from the previous experiments fell within the confidence range.

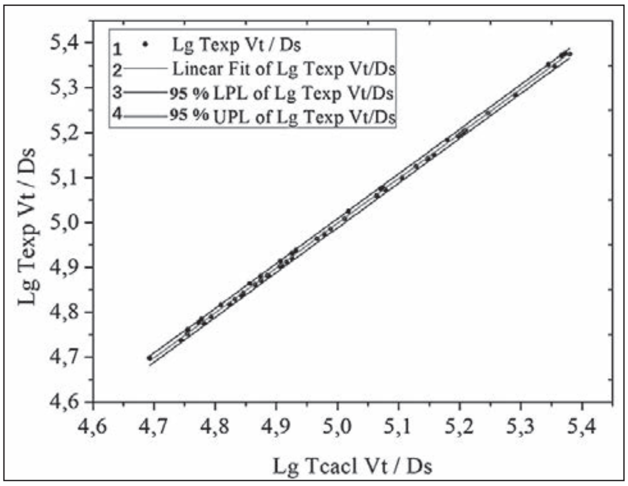

Figure 3 Schematic diagram of comparison between experiment and calculation

CONCLUSIONS

In the process of physics simulation of fluid flow, changing various gun layout and blowing parameters is of considerable significance, However, there is lack of mechanistic research and exploring the internal connection and internal logic between the parameters, In this paper, we get the empirical formula between mixing time and dimensionless groups based on the experimental research and data analysis, According to the study, the bottom blowing flow, side blowing flow, top gun position and tracer height have a great impact on the mixing time, By verifying the calculated and experimental values, it can be seen that data was well correlated, and most of the 54 sets of data points from the previous experiments fell within the confidence range, So subsequent researchers meet similar explorations, can firstly take preliminary calculation and prediction for experiment, can reduce unnecessary detours.

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Note: The responsible for English language is: H, Zhang, Shanghai, China