A NOVEL TECHNIQUE FOR DETERMINATION OF MIXING TIMES IN PHYSICAL MODELS OF STEELMAKING REACTORS*

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Abstract
Mixing time is an important parameter when considering chemical and thermal homogenization in steelmaking reactors. It can also be relevant in the kinetics of chemical reactions. Different methods have been used to estimate mixing times in physical models of steelmaking reactors. In the present work a new method to estimate mixing times in physical models has been proposed. This method can be used when transparent fluids are used to simulate the liquid steel and the slag. Results of mixing times in a physical model of a BOF obtained with different techniques were compared. It was shown that the new method is more reliable and consistent than the common methods based on electrical conductivity measurements and colorimetric analysis.
Keywords: BOF; Cold Simulation; Refining reactions; Mixing Time.

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1 INTRODUCTION

Mixing time is an important parameter regarding chemical and thermal homogenization in steelmaking reactors. It can also be relevant in the kinetics of chemical reactions. Due to the difficulties associated to the determination of this parameter directly in the industrial reactors, the use of physical models represents and interesting alternative.
Some methods for determination of mixing time can be found in the literature, such as measurements of electrical conductivity and colorimetric analysis. The primary aim of the present paper is to present an alternative method for measurements of mixing times.
The present work used a luximetric method to determine the mixing time. This method consists of measuring the mixing time by varying the light captured by a sensor. The luxmeter evaluated the behavior of homogenization between metallic bath and slag, simulated in the physical model by water and oil, respectively. The luxmeter was created and patented by Walter D´ Arcy Ryan in 1909 and its function is to measure the light intensity, which reaches the sensor. With this instrument, it is possible to determinate the luminance value and it can be used in photography and work safety.
This device consists of an amperemeter connected to a photoelectric cell that generates an electric current when the light reaches it. Therefore, the semiconductor of the cell is positively charged and the metallic cell is negatively charged, resulting in a difference of current. This difference is measured and converted to lux.
According to Brazilian Association of Technical Standards, the luminance is given by the limit between the luminous flux in a surface and the surface area, when the surface area tends to zero. The luminance is:

$$L = \frac{\Phi.v}{\omega.A.(\cos\theta)} \text{ [cd/m}^2\text{]} \qquad \text{Equation 1}$$

Where:
Φv = Luminous flux (cd);
ω = solid angle in beam vision direction (rad);
θ = angle between the vision direction and the normal direction(rad);
A = surface area or source of luminous flux(m^2);

It can also be said that:

$$L = \frac{I}{A_{ap}} \text{ [cd/m}^2\text{]} \qquad \text{Equation 2}$$

Where:
I = Luminous intensity;
A_{ap} = apparent area of surface in beam vision direction (m^2)

The luxmeter method is based on luminance difference between the beginning and the end of the experiment, which occurs when all the tracer, that has dark color, achieves all the aqueous phase. The right way to implement the steps is described at Figure 1:

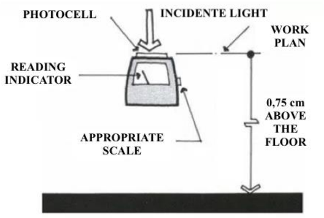

Figure 1*: Luxmeter scheme.*

On this basis, the determination of mixing time at cold model is fundamental for measuring the primary refining process efficiency.

2 DEVELOPMENT

The laboratory tests were developed in a 1/10 scale physical model of the converter of Ternium Brazil 338t BOF, available at the Laboratory of Process Simulation (LaSiP - Department of Metallurgical and Materials Engineering of UFMG). Figure 2 shows the BOF acrylic model.

***Figure 2:** BOF cold model structure in LaSiP.*

The system has a plexiglass vessel, twelve tuyères injection points located at the converter bottom. Each tuyère has individual flow control using rotameters. In addition, the model has a supersonic lance powered by compressed air with a nominal flow rate of 160Nm^3/minute at 1 MPa.

2.1. Conductivimeter method

The evaluation of the mixing time through this method is based on the electrical conductivity. A tracer (usually a salt) is added to the water. Electrical conductivity sensors are installed in the acrylic vessel. These sensors are connected to a computer running a software to gather and process the data, as illustrated in Figure 3. The tracer is a solution of KCl.

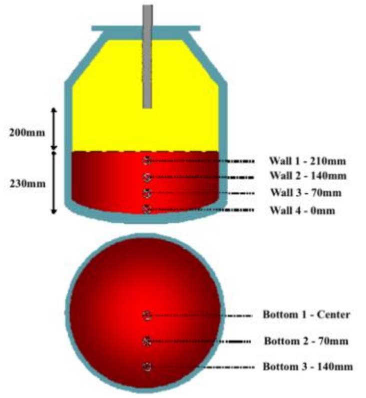

Figure 3: *Conductivity sensors position employed in developed tests. Modified from Maia (2007)*

The mixing time is determined when the conductivity achieve 95% of variation. The assessment criterion for evaluation of the mixing time is showed in Figure 4:

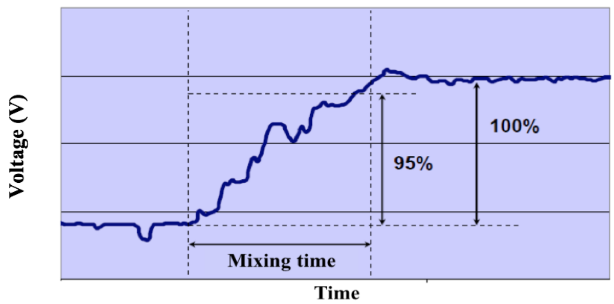

Figure 4: *Assessment criterion for mixing time evaluation. Modified from Maia (2007)*

2.2. Colorimetric method

This method consists of addition of a tracer, potassium permanganate, which has a dark coloration that is distinct from the bath (water). Thus, the bath mixing behavior can be observed and analyzed. The time spent for the tracer to reach the entire bath is considered as the mixing time. The colorimetric tests were recorded with a Canon T3i camera and three operators determined the time visually.

2.3. Luxmeter method

The luxmeter method consists of mixing time measure by the light variation detected by a luxmeter. Initially, 49 liters of water was added to the cold model of Ternium Brasil 338 tons converter and then 9 liters of paraffin oil or soil bean oil, previously dyed with black or blue oiled aniline was added. In a second moment, the light source of the system was adjusted using two spotlights LED 50W – white cold light –

that were positioned in one side of the cold model. During the tests, it was used a white digital Luxmeter model Hiraki HLX – 881. This sensor was located on the opposite of the light source.

Filming of the system during mixing was carried out using a Canon T3i camera. The camera was placed in order to frame the bath completely, capturing images of the water and oil simultaneously. The luxmeter was fixed to the external wall of the cold model, and the visor was placed next to it in a way that the information could be recorded, as shown in the Figure 5. The filming and blowing were started simultaneously and the test was ended when the lux value recorded remained constant.

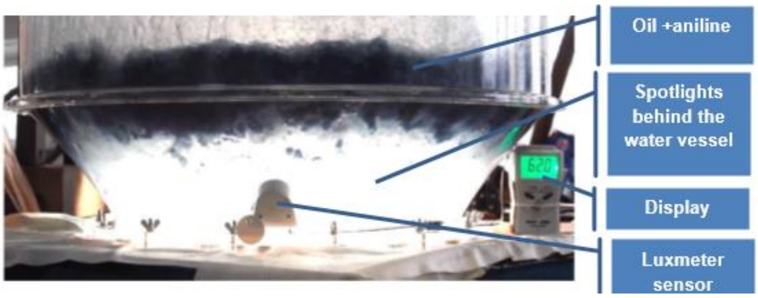

Figure 5: *Frame and position of the device*

3. RESULTS AND DISCUSSION

Comentado [B1]: Nesse item também inverter os resultados.

Creio que leitor terá clara noção da evolução da técnica vendo as curvas obtidas por conduvímetros pontuais x as atuais com luxímetro.

3.1 Conductivimeter Analysis

In the present work no experiments were performed using the conductivimeter method. In order to exemplify some results from this procedure the outcomes found by Maia (2007) were shown. The author analyzed the mixing time in BOF cold model in two measurements points, on the bottom and the wall of the vessel.

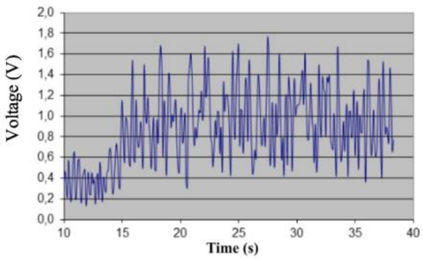

Figure 6: *Mixing time by measurement point on bottom position. Modified from Maia (2007)*

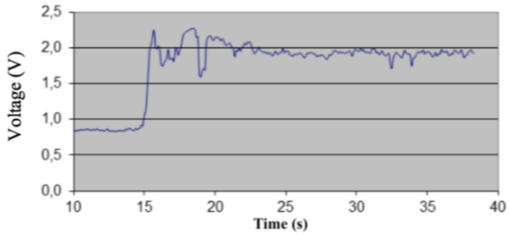

Figure 7: *Mixing time by measurement on the wall. Modified from Maia (2007)*

From the analysis of these results, it is possible to see that the mixing time depends on the location of the measuring point. These results also had large oscillations.

3.2 Colorimetric Analysis

The mixing times were also analyzed by the colorimetric method. Figure 8 and Table 1 present the bath behavior and mixing time results.

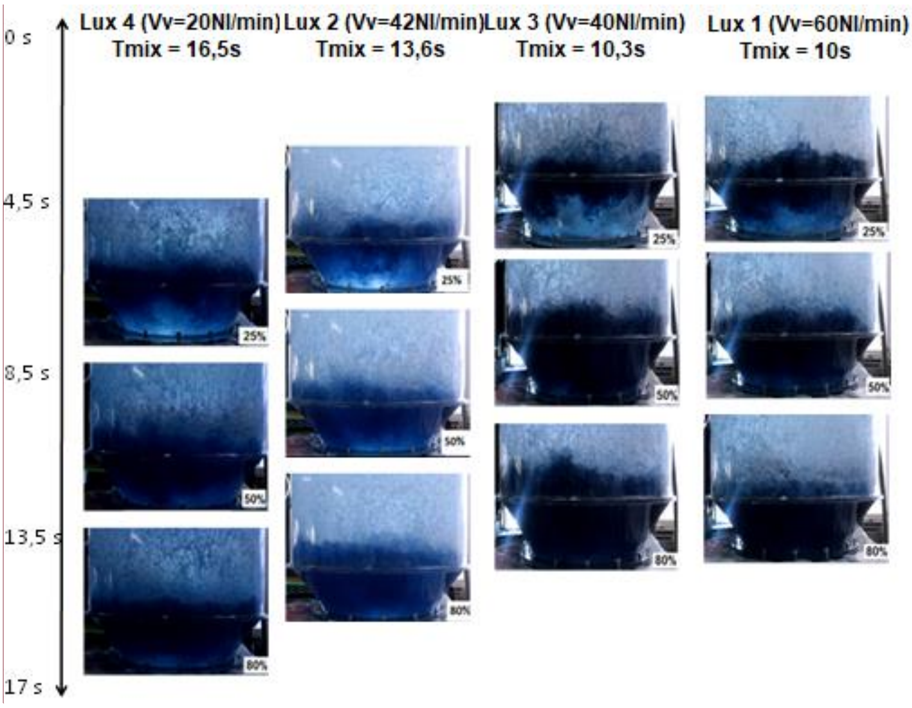

Figure 8: Mixed volume and mixing time based on the time of the test

Comentado [B2]: Tomei liberdade de aumentar figura

Table 1: Mixing time values and standard deviation obtained in each test

Test	Mixing Time (s)	Standard Deviation
Lux 1	10,0	2,0
Lux 2	13,6	4,8
Lux 3	10,3	2,5
Lux 4	16,5	9,3

3.3 Luxmeter Method

During the tests, the flow rate and configuration of tuyères were changed. Table 2 shows the parameters used in each test.

Table 2: Tests and their respective tuyères flow rate

Test	Tuyères Flow Rate (NL/min)
Lux1	60
Lux2	42
Lux3	40
Lux4	20

Figure 9 illustrates the carried-out tests using a constant lance flow rate of 160Nm³/h, varying configuration and tuyères flow rate.

Comentado [B3]: Valor junto com unidade de medida

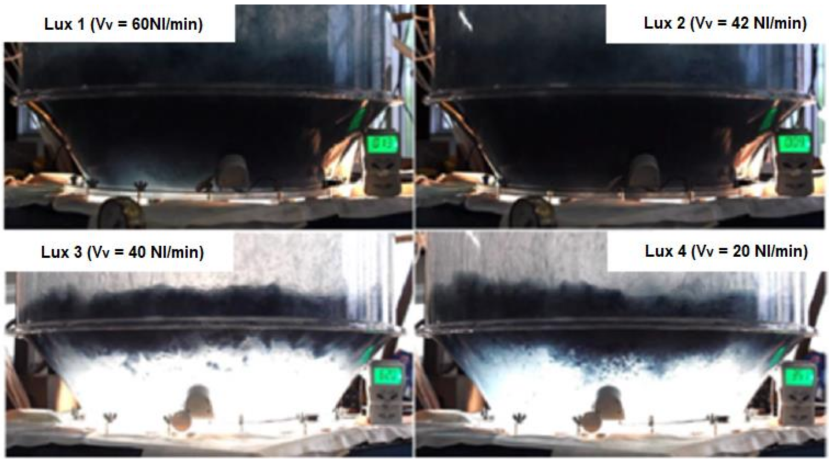

Figure 9: *Experiments behavior during the blowing*

Following the tests, the data treatment was carried out. The lux value was registered by means of shooting analysis and a table was created with the lux data and test time. Based on this table, a graphic was built for each test. The lux values were taken at regular intervals of 2 seconds. The Figure 10 shows the obtained graphic.

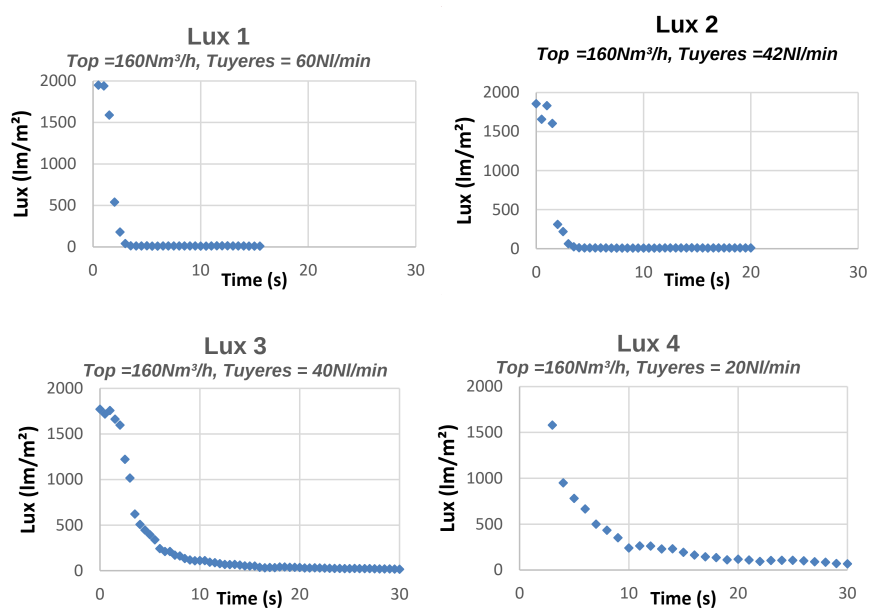

Figure 10: *Lux results recorded as a function of time of the test. All configurations of tests adopted a lance flowrate of160 Nm³/h and tuyères flow rate of 60Nl/min, 42Nl/min, 40NL/min and 20Nl/min, respectively.*

Comentado [B4]: Sugestão para alterar títulos

Ex.:

Lux 2 – Top =160Nm³/h Tuyeres =42Nl/min.

During blowing, the mixing between water and oil becomes more intense, thus the blue color reaches the entire bath. This dark color blocks the passage of light that came from the light source. The luminosity decreases over time and the lux value from the luxmeter also decreases.

It was possible to evaluate the mixing time of the bath considering the decrease of the light intensity.

The analysis was carried out based on the lux values obtained in each test. The following equation was used to estimate a non-dimensional light intensity.

$$L* = \frac{L_i - L}{L_i - L_f} \qquad \text{Equation 3}$$

Where: $L_{i=}$ initial light intensity = 0s;

$L =$ instantaneous light intensity;

$L_{f=}$ light intensity at the end of test.

A graphic of L* as function of the time was built. Figure 11 shows the behavior of the obtained curve from each test.

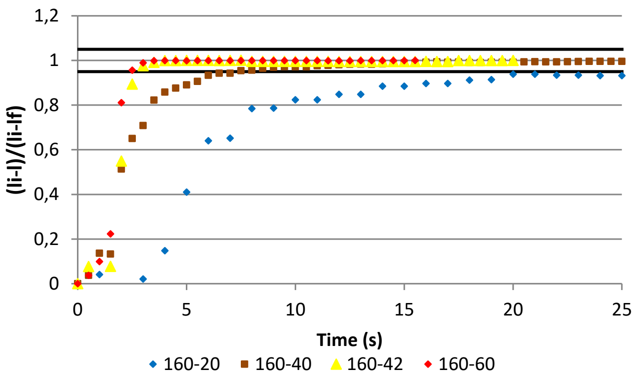

Figure 11: *Non-dimensional lux intensity results recorded based on the time of test*

Two horizontal lines were build considering an interval of 95% to 105% of variation of the non-dimensional light intensity. The mixing time was determined when the L* value remained stable within the interval above. The obtained mixing times and standard deviations are indicated at Table 3.

Table 3: Obtained mixing times for the configurations

Test	Mixing Time (s)	Standard Deviation
Lux 1	2,50	0,04
Lux 2	3,00	0,01
Lux 3	7,50	0,05
Lux 4	32,00	0,02

3 CONCLUSIONS

The performed experiments using the luxmeter and colorimetric methods resulted in very different mixing times. Unarguably the luxmeter method proposed in the present work has higher accuracy and smaller standard deviation. The conductivity method is

Comentado [B5]: Sugestão com base em informação recente.

Antes da conclusão inserir proposta para trabalhos futuros.

Atualmente está sendo estudado comparativo entre adição de traçador líquido ou pastilha averiguando os efeitos da diluição no tempo de mistura.

affected by the location of the sensor and tends to show oscillations on the results, thus it has lower reliability. The colorimetric method results are extensively influenced by the operators, this leads to higher standard deviation. Therefore, the luxmeter features smoother curves and hence easier reading and interpretation.

More studies regarding the luxmeter methodology are required. The use of more measurement points is a recommendation for the improvement of the mixing time results.

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