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# THE PROCESS OF DISSOLVING SOLID LUMP CARBONACEOUS FUEL (SLCF) IN THE OXYGEN CONVERTER - PHYSICAL MODELING

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The article presents the results of modeling research of hydrodynamic phenomena occurring in the oxygen converter during the addition of SLCF while blowing the liquid bath. The water physical model of the oxygen converter was used for the research. The oxygen lance of the model was equipped with a head with five nozzles at an angle to the lance axis. The research was aimed at determining the most favorable process parameters for the use of lump fuel in the oxygen converter.

*Keywords:* steel, oxygen-converter process, solid lump carbonaceous fuel, blowing the liquid bath; physical modelling

## INTRODUCTION

Many converter steel plants struggle with the problem of the technological stability of charge materials. This is especially true for scrap, slag-forming materials, etc. Cases of pig iron shortage are also not uncommon. In some countries, there is also an increased supply of scrap, exceeding their demand of the electric steel plants.

Therefore, attempts are made to increase the amount of scrap in the converter charge. However, this requires an increase in the thermal potential of the melts conducted in oxygen converters. This can be achieved by using solid lump carbonaceous fuel as an additional heat carrier [1,2]. This procedure, as compared to other known methods, does not require any investment costs in the form of additional devices and other equipment and the use of expensive scarce energy carriers. In connection with the technology of post-combustion of CO to $CO_2$ in the working space of the converter, it contributes to the efficient use of fuel and a further reduction of the share of pig iron in the charge. Effective use of lump fuel in the converter, however, requires solving many problems. The basic one is to determine the most favorable process parameters for this treatment. For basic reasons, the commonly used research method in this type of cases is physical modeling [3-7]. The article presents the results of tests carried out with the use of the water physical model of the oxygen converter. The research concerned the identification of the lump fuel behavior mechanism during the refining process.

## INVESTIGATED OBJECT

The tested facility is an oxygen converter with a nominal capacity of 320 Mg. Figure 1 presents the geometry of the oxygen converter model together with the basic dimensions. The physical model of the oxygen converter is made in the linear scale $S_L$ = 1:10 from transparent materials of the polymethyl-methacrylate (PMMA) type, what allows to conduct visualization research.

It is built according to the principles of the similarity theory [8,9]. The principle of conformity of characteristic critical numbers in the model and in the real device was used. The modified Froude number (Fr) in the form [10] was used as the dominant criterion of similarity:

$$N'_{Fr} = \frac{\rho_g \cdot v^2}{\rho_1 \cdot g \cdot L} \quad (1)$$

Where $\rho_g$ – gas density/ g / cm$^3$; $\rho_l$ – liquid density/ g / cm$^3$; $g$ – acceleration of gravity/ m / s$^2$; $L$ – characteristic dimension/ m; $v$ – velocity/ m / s$^1$.

On this basis, the dynamic similarity of the air flow through the oxygen converter model was determined using the scale method [11]. The air in the model simulates the oxygen used for refining process.

The geometric and dynamic parameters of the lance head nozzles in the water model were determined according to the method [8,9]. This method takes into account the properties of the de Laval nozzles used. It consists in calculating the flux pulse and the Mach number Ma:

$$I = \frac{i}{\rho_l \cdot g \cdot L^3} \quad (2)$$

$$Ma = \sqrt{\frac{2 \cdot \lambda^2}{(k+1) - (k-1) \cdot \lambda^2}} \quad (3)$$

Where I – dimensionless stream pulse; λ – dimensionless velocity factor; k – adiabat coefficient.

The basic parameters of the oxygen lance used in the model are presented in Table 1.

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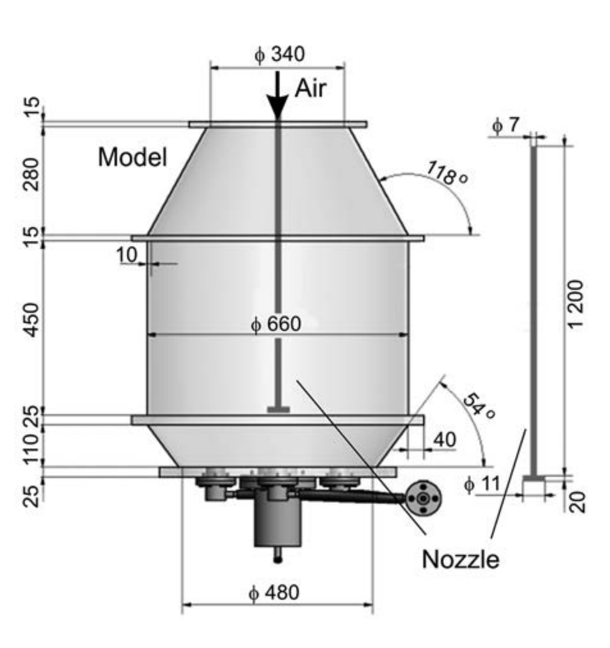


**Figure 1** Diagram of the physical model of the oxygen converter / mm

Table 1 **The oxygen lance used in model**

| Parameter | Dimension | Unit |
|---|---|---|
| Number of cylindrical nozzles | 5 | - |
| Inclination angle to the lance axis | 12 | ° |
| Outer diameter of the lance φl | 22 | mm |
| Nozzle diameters φd | 1,5 | mm |
| Diameter of the circle on which the nozzles are located | 5 | mm |

The model is described in detail in [12]. The model is equipped with specialized control and measurement equipment, which includes: a precise regulator of the air flow blown through the lance and the air supply system. To measure the change in conductivity of the model liquid, conductivity meters were used, mounted at a height of 150 mm from the bottom level on the perimeter of the converter.

Cork oak bark aggregate was used as the material representing the solid lump carbonaceous fuel (SLCF) in the water model. This material, with the dimensions of the pieces of 0,6 – 5 mm and the density of 250 × 300 kg/m$^3$, meets the criterion of similarity to the SLCF described in the works [8,9]. Before testing, cork aggregate was saturated with salt for 12 hours in an aqueous NaCl solution. All measurement signals are directed to the electronic recorder. Recorded data is transported to a computer, when it is processed an visualized in real time.

## RESEARCH METHODOLOGY

The research was aimed at determining the most favorable process parameters for the use of lump fuel in the oxygen converter. They were divided into two stages. In the first stage (Table 2), the value of the fuel mass that should be introduced into the converter to obtain the best efficiency of its use was determined. In the second stage (Table 3), the aim of the research was to determine the influence of: the distance of the oxygen lance face from the steel mirror surface and the intensity of the blown on the kinetics of the process of dissolving a given mass of fuel in a liquid bath.

Table 2 **Variants of the experiment - level 1**

| Blow value through the lance / m$^3$×min$^{-1}$ | The weight of the cork aggregate / kg | Blow value through the lance / m$^3$×min$^{-1}$ | Fuel mass / kg |
|---|---|---|---|
| Model | | Industry | |
| 0,285 | 0,110 | 1 200 | 2 |
| | 0,212 | | 4 |
| | 0,320 | | 6 |
| | 0,425 | | 9 |

Table 3 **Variants of the experiment - level 2**

| Parameter | | Experiment variant and value | | | | |
|---|---|---|---|---|---|---|
| | Experiment I | | | | | |
| Blow value through the lance / m$^3$×min$^{-1}$ | Model | 0,230 | | 0,285 | | 0,341 |
| | Industry | 900 | | 1 200 | | 1 500 |
| Distance of the lance / m | Model | 0,28 | | | | |
| | Industry | 2,8 | | | | |
| | Experiment II | | | | | |
| Blow value through the lance / m$^3$×min$^{-1}$ | Model | 0,285 | | | | |
| | Industry | 1 200 | | | | |
| Distance of the lance / m | Model | 0,08 | 0,18 | 0,28 | 0,38 | 0,48 |
| | Industry | 0,8 | 1,8 | 2,8 | 3,8 | 4,8 |

The experiments in all variants were carried out according to the following program: at the beginning, the model was filled with water to a height of 185 mm above the bottom level. The next step is to set the value of the air flow in the lance. After introducing the salt-saturated cork aggregate into the model liquid, the measurement started (changes in the electrical conductivity of the model liquid using conductometers). At the same time, the thickness and width of the SLCF layer were measured.

## RESULTS AND DISCUSSION

The results of the visualization made in the first stage of the research are shown in Figure 2.

They allowed to determine the geometry of the distribution of a certain mass of cork aggregate on the surface of the model liquid under the influence of the blown stream. Based on the analysis of this distribution, it was found that the most favorable distribution was obtained for variant c of the experiment, i.e. 0,320 kg of aggregate. In industrial conditions, this means 6 kg SLCF per ton of steel. This analysis was carried out with the assumption that the minimum width of the fuel layer and its maximum thickness favors an increase in fuel absorption by liquid metal.

The results of the experiments carried out in the second stage of the research allowed for the determination

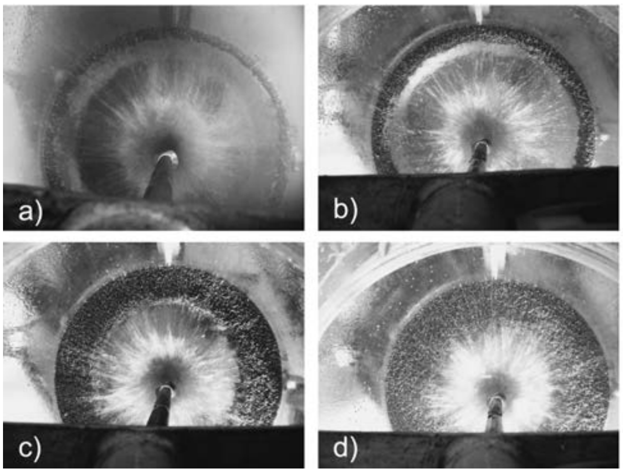


**Figure 2** The distribution of aggregate on the surface of the model liquid depending on its mass: a) 0,110 kg, b) 0,212 kg, c) 0,320 kg, d) 0,425 kg

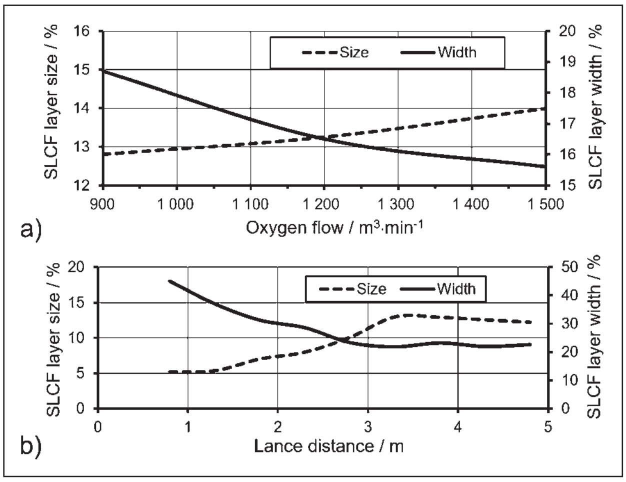


**Figure 3** The geometry of the SLCF layer: a) when changing the oxygen flow, b) at different positions of the oxygen lance

of further processing parameters. For this purpose, the results of modeling research were converted into industrial values and presented graphically in Figure 3, which illustrates the effect of changing the blown stream and the position of the oxygen lance on the geometry of the SLCF layer.

Based on the analysis of the obtained diagrams, it was found that the optimal distance of the oxygen lance from the surface of the steel mirror is 2,8 m (Figure 3a). The oxygen flow through the lance was similarly determined at 1 200 m$^3$/min (Figure 3b). These measurements (see Figure 2) were made for the variant corresponding to the addition of SLCF 6 - 8 kg per ton of steel.

The measurement results were confirmed by the dissolution kinetics of SLCF in liquid steel. This process was modeled by measuring the change in conductivity of the model liquid as a function of time as a result of washing out the cork aggregate soaked with NaCl solution. On their basis, graphs of dissolution curves were made. The graphs after conversion to real values are shown in Figure 4.

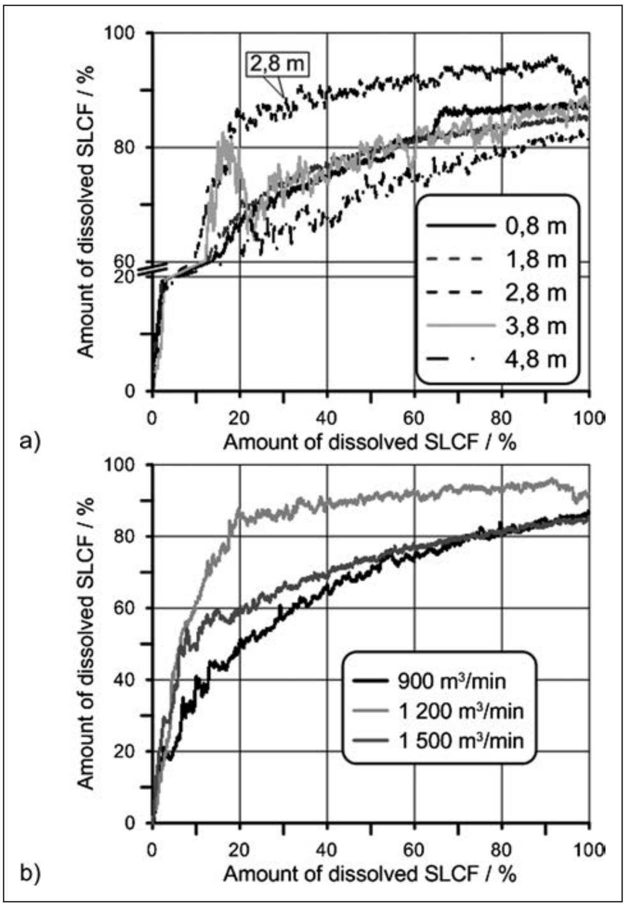


**Figure 4** SLCF dissolution curves in liquid metal: a) with different lance placement, b) with change in oxygen flow

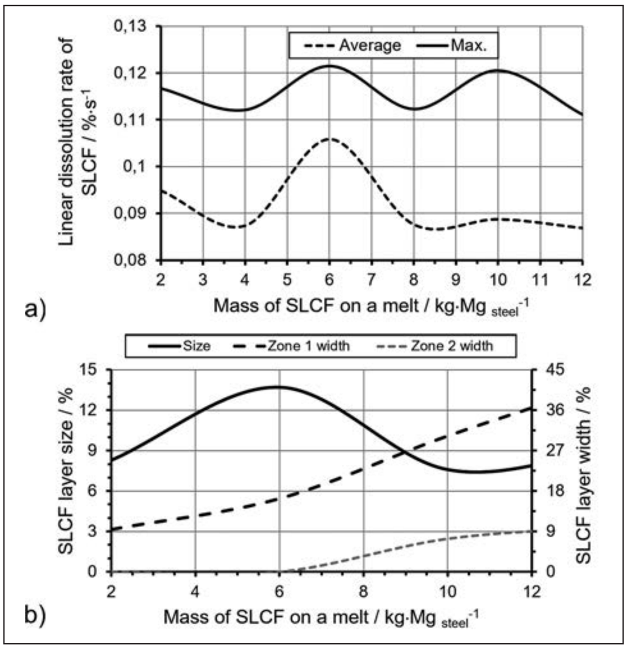


**Figure 5** Curves: a) linear dissolution rate of SLCF in liquid metal, b) dynamics of geometric changes of fuel layer size

The results obtained at this stage of the research also allowed for the preparation of curves of the linear dissolution rate of SLCF in the liquid metal (Figure 5a) and the dynamics of the change in the geometric dimension of the fuel layer depending on its mass at the oxygen flow of

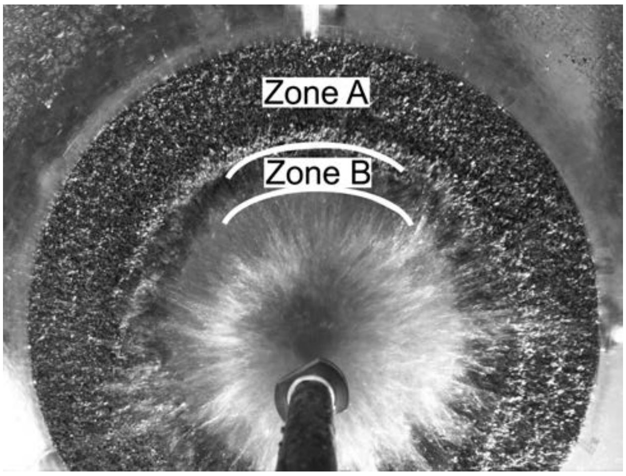


**Figure 6** The process of creating a passive zone.

1 200 $m^3$/min and the face of the oxygen lance from the surface of the steel mirror 2,8 m (Figure 5b). The analysis of these curves confirms the correctness of the optimal mass of added SLCF determined in the first stage of the tests, which is 6 kg SLCF per ton of steel. Then the maximum mean linear rate of fuel dissolution in the liquid bath is 0,105 %/s (Figure 5a), the thickness of the SLCF layer is 13 % of the bath depth and the small width is 18 % of the converter radius (Figure 5b).

It should be noted that increasing fuel consumption to 10 kg SLCF per ton of steel leads to a reduction in thickness and a twofold increase in the width of its layer, which reduces the average linear rate of fuel dissolution by 25 %. Also with a fuel mass of 10 kg SLCF per ton of steel, the maximum linear dissolution rate reaches a second maximum (Figure 5b), which explains the formation of a second zone where the fuel is actively mixed in the reaction zone.

Figure 6 shows the process of mixing the aggregate in the model mixture. Zone A is passive mixing and zone B is active mixing.

## SUMMARY AND CONCLUSIONS

The applied research method is fully functional and can be used to solve problems occurring during the basic oxygen furnace (BOF) process. Based on the research and analysis of the obtained results, the following conclusions can be drawn:

The most effective use of SLCF is obtained when its share is 6 - 8 kg per ton of steel. Exceeding this proportion above 10 kg per ton of steel is detrimental because it creates a passive zone.

The optimal distance of the oxygen lance from the steel mirror surface is 2,8 m with oxygen flow through the lance at 1 200 $m^3$/min. This ensures the correct geometry of the SLCF distribution in the zone of contact with oxygen blown.

The geometry of the SLCF distribution in the blown oxygen contact zone is as follows: SLCF layer size 13 % of the bath depth and narrow width 18 % of the converter radius.

For the determined processing parameters, the maximum mean linear degree of fuel dissolution in the liquid bath is obtained, equal to 0,105 %/s.

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**Note:** The responsible for English language is P. Pieprzyca.