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HYDRODYNAMIC ASPECTS ON EAF's SMELT METALLIC MIRROR

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ABSTRACT

Using the Physical and Mathematical knowledge, a new approach to EAF bath's hydrodynamic aspects is proposed to be developed in this paper. Experimental results and a mathematical equation package have been concluded that the metallic bath mirror has a ondulatory surface during steelmaking process. The shape of slag-metal interface depends on resultant of wave interaction. A higher contact surface between slag and metal correlated with a good velocity of the melted material, lead to a better exploitation of EAF.

KEYWORDS: EAF, wave, mathematical model, potential line, flow line, velocity

1. Introduction

Into EAF, after scrap's melting and the formation of the metallic bath, the interface slag-metal has a variation in time as well as shape and as surface. Around the three electrodes of the EAF, the bath mirror is rippling, forming waves that propagate to the furnace walls. The simultaneous effect of the waves started from the three electrodes is a complex movement, giving to the separation interface slag – molten bath a specific aspect, called hydro-dynamic spectrum.

2. Physical Modeling

The study on a physical model indicates that the 120^0 phase difference of the momentary electric potential applied to the three electrodes does not lead to a cancellation of these waves, due to their interference. The physical model on which the experiments were done was a vessel with the internal diameter of 88 mm and the electrodes circle diameter of 34 mm.

The metallic bath was represented by liquid mercury and the slag by a molar solution of natrium chloride. In paper [1] are fully presented aspects concerning the physical phenomenon of rippling the metallic bath around the three electrodes.

Bellow is presented a physical and a mathematical model of the hydro-dynamic spectrum for the molten metal mirror.

It will be first an analysis of the phenomenon that takes place at one electrode, in order to determine the banc movement by extrapolating and combining of the individual movements (the phenomenon is similar at all three electrodes).

The main parameters of the metallic bath hydro-dynamic spectrum are related to potential lines, stream lines, propagation velocity and flow.

The potential lines represent concentric circles (waves), with the origin in the centre of the source and the stream lines, lines that pass through the source and indicate the direction of the wave propagation.

If the current lines have the direction from the source to exterior, the source is called spring, and contrary is called fountain. In the contact zone of the electrode with the metallic bath are taking place complex phenomena of mechanic, electric, magnetic kind.

Practically, in the contact point between electrode and bath, an electrical discharge occurs and a part of this is transforming into mechanical energy. In this point, the metallic bath mirror is rippling and the waves are propagated towards the furnace wall. As the wave is moving away from the formation zone that we call source or spring, its energy decreases and together with this the height of the wave also decreases (fig.1).

At the contact with the furnace wall, the wave is broken and loses most of its energy.

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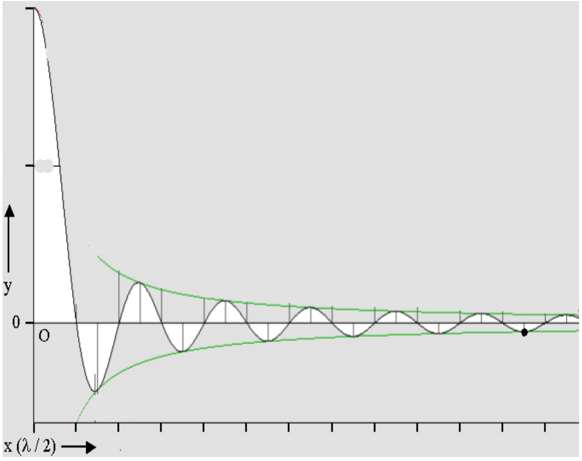


Fig. 1. *Wave's energy variation*

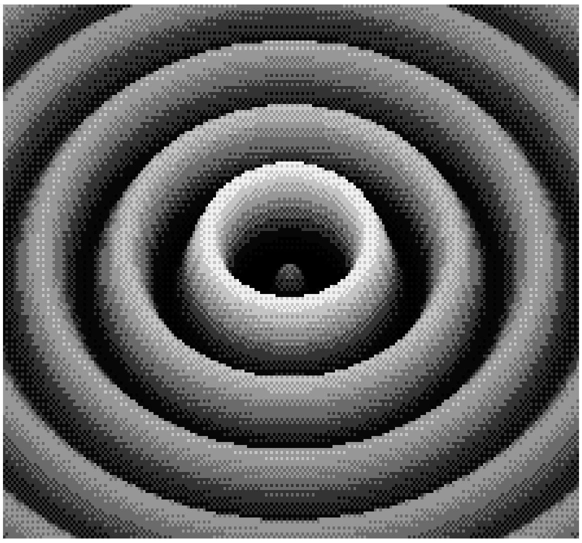
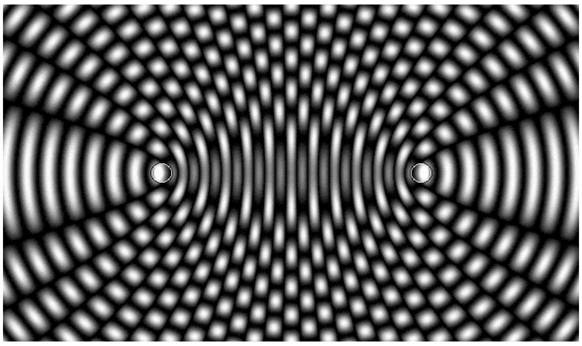
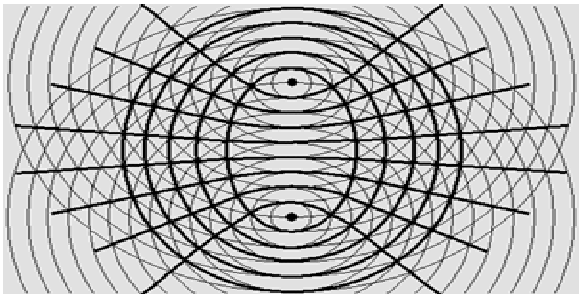


Fig. 2. *3-D wave simulation, one source*

A wave's origin and its propagation is simulated in fig. 2 [2]. If instead of one there are two sources, then the created waves will be interpenetrated and will influence each other. Interpenetration of the waves is named interference [2] and is graphicallz represented in fig.3a and 3b.



a)



b)

Fig. 3. *Wave interference, two sources*

The interference effect leads to different results, namely the amplifying, decreasing or even annihilating of the wave. The compound of the waves is graphically shown in fig. 4.

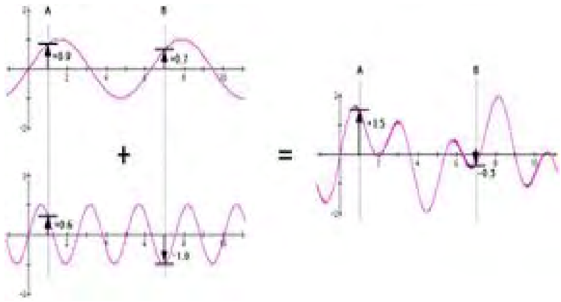


Fig. 4. *Wave's compound resultant*

In the case of three sources, the situation is greaterly complicated, the interference being a complex function of wavelength, electrode circle diameter and furnace internal diameter.

3. Mathematical Modeling

Considering the electrode zone a point source from which the waves are propagated concentrically to the furnace wall, the movement is described by the continuity equation (1) and Euler equations (2) and (3), [3, 7].

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$\frac{\partial u}{\partial t}+u\cdot\frac{\partial u}{\partial x}+v\cdot\frac{\partial u}{\partial y}=X-\frac{1}{\rho}\cdot\frac{\partial p}{\partial x} \tag{2}$$

$$\frac{\partial v}{\partial t}+u\cdot\frac{\partial v}{\partial x}+v\cdot\frac{\partial v}{\partial y}=Y-\frac{1}{\rho}\cdot\frac{\partial p}{\partial y} \tag{3}$$

where: $u = u\,(x,y,t)$, $v = v(x,y,t)$ are the variations in time of a liquid particle speed; $\frac{\partial u}{\partial t},\frac{\partial v}{\partial t}$ - local unit inertia force; $u\cdot\frac{\partial u}{\partial x}+v\cdot\frac{\partial u}{\partial y}$, $u\cdot\frac{\partial v}{\partial x}+v\cdot\frac{\partial v}{\partial y}$ -

convective unit inertia force; x, *y* - mass unit force; $\frac{1}{\rho}\cdot\frac{\partial p}{\partial x}$, $\frac{1}{\rho}\cdot\frac{\partial p}{\partial x}$ - pressure unit force.

To consider the function $\varphi = \varphi(x, y)$, a harmonic function for which:

$$u = \frac{\partial\varphi}{\partial x} \text{ and } v = \frac{\partial\varphi}{\partial y} \quad (4)$$

are solutions of the system (1), (2), and (3). The function $\varphi = \varphi(x, y)$ is called velocity potential.

In this case the stream lines equation for a plane movement is:

$$\frac{dx}{u} = \frac{dy}{v} \text{ or } -vdx + udy = 0 \quad (5)$$

The continuity equation (1) written in the form

$$\frac{\partial u}{\partial x} = \frac{\partial(-v)}{\partial y} \quad (6)$$

represents the condition for equation (5) to be the exactly total differential of a tuning function $\psi\ (x,y)$, and namely:

$$d\psi = \frac{\partial\psi}{\partial x}dx + \frac{\partial\psi}{\partial y}dy = -vdx + udy \quad (7)$$

therefore

$$u = \frac{\partial\psi}{\partial y} \quad \text{and} \quad v = \frac{\partial\psi}{\partial x} \quad (8)$$

Function ψ is called stream function. It can be easily verified that the expressions (8) are also solutions of the equations systems (1), (2) and (3).

From the equations (4) and (8) it may be noticed that:

$$\frac{\partial\varphi}{\partial x} = \frac{\partial\psi}{\partial y} \quad \text{and} \quad \frac{\partial\varphi}{\partial y} = \frac{\partial\psi}{\partial x} \quad (9)$$

The functions ψ and φ are conjugation harmonic functions and both of them verify the Cauchy-Rieman conditions.

In this case the functions $\varphi = \varphi\ (x, y)$ and $\psi = \psi\ (x, y)$ represent the real and respective the imaginary part of a function, *f(z)* of a complex variable with this form:

$$f(z) = \varphi\ (x,y) + i\ \Psi\ (x,y) \quad with \quad z=x+iy \quad (10)$$

named complex potential of movement.

Therefore, to a plan potential movement it can associate a monogyny function of a complex variable.

The complex potential analysis of the movement, function *f(z)* respectively, points out the following aspects:

- the real part of the complex potential *f(z),* (the harmonic function $\varphi = \varphi\ (x,y)$) represents the velocity potential, and the curves family $\varphi\ (x,y)$ = constant, the potential lines family (fig. 5);

- the imaginary part of the complex potential *f(z),* (the harmonic function $\psi = \psi\ (x,y)$) represents the stream function, and the curves family $\varphi\ (x,y)$ = constant, the stream lines family (fig. 5).

The graphic representation of the potential lines family and of the stream lines family is called the hydro-dynamic spectrum of the movement (fig. 5).

In case of a movement produced by a punctual source, the complex potential has the form:

$$f(z) = C\cdot\ln z\ , z \neq 0, \quad C \in R\{C>0\} \quad (11)$$

which written in polar coordinates, r,θ and z = r $e^{i\theta}$ becomes:

$$f(z) = \varphi + i\cdot\psi = C\cdot\ln(re^{i\theta}) = C\cdot\ln r + i\cdot C\cdot\theta \quad (12)$$

Through identification, these two functions are:

$$\varphi = C \ln r \ ; \ \Psi = C\ \theta \quad (13)$$

These elements established, the main features of the movement can be determined, namely:

- the potential lines:

$$\varphi = C\cdot\ln r = \beta \quad \text{or} \quad r = e^{\frac{\beta}{C}} = \beta_1 \quad (14)$$

representing concentric circles, with the origin in the centre of the source;

- the stream lines:

$$\psi = C\cdot\theta = \lambda \text{ or } \theta = \frac{\lambda}{C} = \lambda_1 \quad (15)$$

representing straight lines that pass through the origin having the direction from the source to the outside;

- the velocity components;

$$V_r = \frac{\partial\varphi}{\partial r} = \frac{C}{r} \text{ and } V_\theta = \frac{1}{r}\cdot\frac{\partial\varphi}{\partial\theta} = 0, \quad C>0 \quad (16)$$

- the flow rate for any wave (circle):

$$Q = \int V_r dS = \int_0^{2\pi}\frac{C}{r}d\theta = 2\pi C \quad (17)$$

the constant value *C* being $C = \frac{Q}{2\pi}$

In these conditions the complex potential may be written like this:

$$f(z) = \frac{Q}{2\pi}\cdot\ln z \quad (18)$$

or in the case when the punctiform source is placed in a certain point of the complex plane $z_0 - x_0 + iy_0$:

$$f(z) = \frac{Q}{2\pi}\cdot\ln(z - z_0) \quad (19)$$

The phenomena that occur at the other two electrodes are identical with those presented above. Therefore, in the interior of the electric arc furnace used for steel manufacture are three sources (each electrode, E_1, E_2, E_3, represents an independent source – fig. 5) from which concentric waves are propagated toward outside (the furnace wall). These waves are interfering and influencing each other, forming a complex waving surface of the metal bath. Knowing the complex potential of the movement of the three punctiform sources the compound movement can be analyzed.

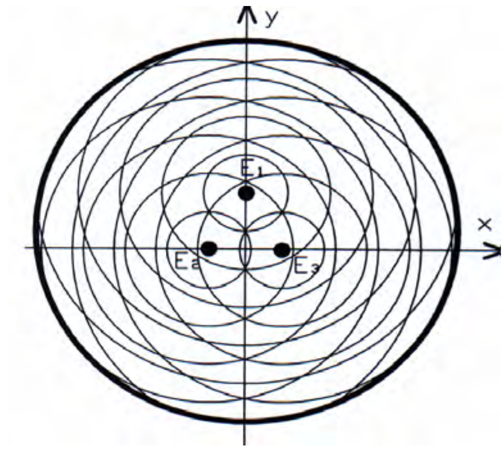


Fig. 5. *Potential and flow lines into EAF.*

The compound of the movements is made taking into account the sources position (electrodes) in the complex plane, pertain to a suitable chosen axis system.

The complex potential of the three punctual sources has the form (11) and is given by the relations:

$$f_1(z) = C \cdot \ln(z+a) \text{ for } E_1 \text{ source} \quad (20)$$

$$f_2(z) = C \cdot \ln(z-a) \text{ for } E_2 \text{ source} \quad (21)$$

$$f_3(z) = C \cdot \ln(z+ib) \text{ for } E_3 \text{ source} \quad (22)$$

The equation of the compound movement is: $f(z) = \sum_{k=1}^{3} f_k(z)$

or

$$f(z) = C \cdot [\ln(z+a) + \ln(z-a) + \ln(z+ib)] \quad (23)$$

Equation (23) represents the compound movement equation, on the basis of which the hydro-dynamic spectrum of the metallic bath mirror from the electric arc furnace can be analyzed from a mathematical point of view. The paper could be detailed by an advanced study of an interference complex function in the form of [5], [6]:

$$\Omega = f(\lambda_i, \omega, \delta_{el}, \delta_{ce}) \quad (24)$$

where: λ is the wavelength of the wave's series for the electrodes; ω-a factor that takes into account the electric parameters of the furnace; δ_{el} – electrode circle diameter; δ_{ce} – furnace's internal diameter

4. Metallurgical Effects and Conclusion

From the metallurgical point of view it is important that the metal bath surface swows wave of so that the oxygen transfer from the slag to the bath should be greater. On the other hand it is pursuing that the settling of the products resulting after the different chemical reactions that are taking place in the bath should be more advanced.

The electric driving of the furnace and the putting in phase or phase difference of the electricity at the three electrodes may constitute an important element in obtaining an optimal charge time, a higher quality by realizing a lower nonmetallic inclusion level and a good life of refractory liners. It is known that a plane smelt mirror has a negative effect on vault. So, the EAF steelmaking workers should know the right procedure to be followed, to reach the proposed goal.

References

[1]. Tripşa Iosif, 1969, *Etude d'un phenomene physique sur la surface interphasique acier-latier dans les fours electric a arc,*Centre National de Investigationes Metalurgicas-CENIM, Espania.

[2]. Frenier La, Gabriel, *Matter is made of Waves*, 2007, Cycle Research Institute.

[3]. Duncn, J.W., s.a, 1981, *Mecanics of Fluids*, Edward Arnold, London.

[5]. Mustaţa, T. Costică, 2000, *Cercetări de optimizare şi posibilităţi de conducere automată a proceselor siderurgice folosind modelarea*, Teza de doctorat, Universtiatea Politehnica Bucuresti.

[6]. Iacob, Caius, 1959, *Introduction Mathematique a la Mecanique des Fluides,* Editura Academiei Romane, Bucuresti.

[7]. Carafoli, Elie, Oroveanu, Teodor, 1952, *Mecanica fluidelor*, Editura Academiei Romane, Bucureşti.