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Experimental and numerical investigations on heat transfer of a water-cooled lance for blowing oxidizing gas in an electrical arc furnace

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ABSTRACT

This paper investigates numerically and experimentally the radiative heat transfer of electric arc furnaces and convective heat transfer of a cooling system for oxygen blowers. The furnaces under study are composed of cooling panels both on the wall and roof, electrodes for creating a magnetic field, a basket containing iron (iron scrap, iron ore & Direct Reduced Iron (DRI)), burners and oxygen/carbon blowers. A 3D model of an electric arc furnace (EAF) with a nominal power of 105 MW and a nominal capacity of 120 T equipped with a cooling box system is simulated using CFD software. A SIMPLE algorithm using the second order discretization method and a DO model of the radiative heat transfer are utilized for simulation of the furnace. The simulation results are validated with the help of thermograph pictures taken from the experimental model. The comparison indicates good accuracy of the proposed model in predicting the experimental results. To identify the reasons for reduced working life of cooling box systems, a number of parameters are studied including the performance of the water cooling box and also the temperature distribution which causes thermal stress. The results of the numerical simulation demonstrate that a poor cooling system in the front panel of the cooling box can degrade its useful life considerably. Meanwhile, a small volume of the cooling water through the devised route and designed arrangement of the cooling box are among the factors which can lead to early failure of this equipment. Taking into account the numerical results and identifying the reasons for the reduced life of the cooling box, a new cooling system for the blower is designed, constructed and tested inside the furnace under real working conditions. The experimental results from one year operation of the furnace show an increased life for the equipment, going from 1500–1775 to 2500 melts. The new model is further developed using the CFD software and the practical results are compared with the new experimental data.

1. Introduction

The electrical arc Furnace (EAF) is the common technology used in industry to make steel (see Fig. 1) [1,2]. Providing energy for an EAF and enhancing the efficiency are significant concerns for industrial sustainability [3,1]. Chirattananon et al. [4] describe a mathematical model to minimize energy operation for an EAF. In addition, Sakamoto et al. [5] have estimated the energy consumption in EAF by using statistical process.

Electricity is the main source of energy to melt iron. However, due to the high cost of electricity, burners and oxygen/carbon blowers have been used in furnaces [6,7]. Over recent years, the use of oxygen in EAF steelmaking has grown considerably. In this method, the oxygen is injected over the molten bath by an oxygen lance for converting the molten iron into steel and enhancing the efficiency of EAF melting. Because of the melting process and electrical arc inside the furnace, the range of temperature inside the furnace can reach up to 1400–1600 K. Hence, water circulating cooling panels are used around the burners and oxygen injector

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Nomenclature

a	absorption coefficient
C_p	specific heat at constant pressure (J/kgK)
I	radiation intensity (W/sr)
k	thermal conductivity (W/mK)
n	refractive index
P	pressure (Pa)
q	heat transfer rate (W)
r	location vector
s	direction vector
s′	scattering direction vector
T	local temperature (K)
U	average velocity (m/s)

Greek symbols

$a_{\varepsilon,i}$	emissivity weighting factor for *i*
μ	viscosity (m^2/s^3)
ε_w	total wall hemispherical emissivity
σ	Stefan-Boltzmann constant ($\sigma = 5.67 \times 10^{-8}$ W/m^2 K^4)
σ_s	scattering coefficient
ρ	density (kg/m^3)
Φ	phase function
Ω'	solid angle (degree)

Subscripts

In	inlet
out	outlet
s	solid
f	fluid
w	wall

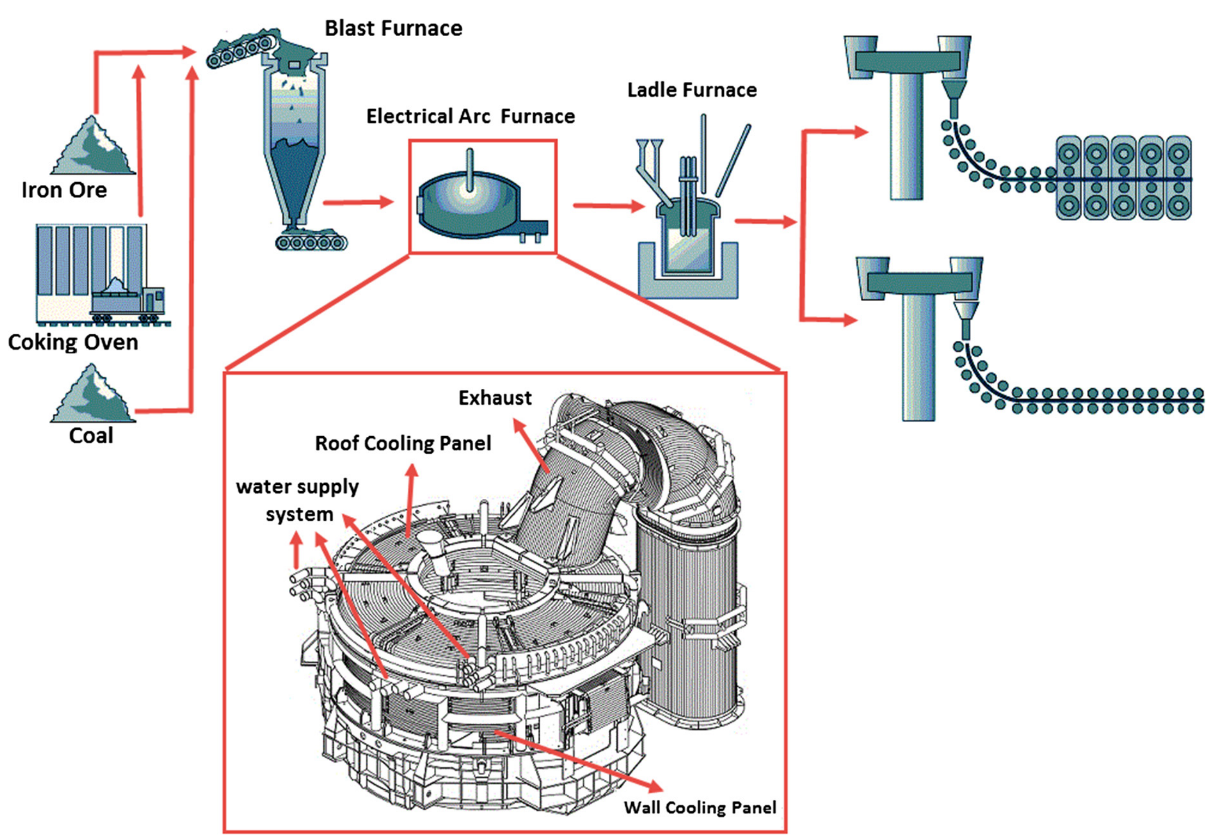

Fig. 1. Steel making flow chart.

to protect the instruments at this temperature. This frequent cooling and heating as well as high temperature inside the furnace result in thermal stress, thermal fatigue and finally cracking on the surface of the cooling system. The life time of the instruments mainly depends on water flow path in cooling system. Enhancing the lifetimes oxygen injectors can decrease the time of the melting process and the cost of steel production for the entire plant. The need for switching or repairing the oxygen injector is another consequence of inappropriate cooling system which causes many pauses in the melt period of an electrical arc furnace, decreases in the production capacity of the plant and finally, significant financial losses over the long period. In spite of the increasing importance of the EAF in the steel-making industry, few studies have been carried out on increasing the lifetime of the oxygen injector.

The main target of this study is to analyze numerically and experimentally the thermal behavior of the oxygen injector cooling system of the electrical arc furnace during the furnace charging process. It is shown that a full-scale CFD modeling is the useful approach for evaluating the fluid flow and heat transfer characteristics of the various cooling systems [8–11].

Thermal radiation is considered as the main heat transfer mechanism in a furnace [12,13]. Several studies have addressed radiative heat transfer in the EAF using a numerical CFD approach. For