Model of an Electric Arc Furnace Oxy-Fuel Burner for dynamic simulations and optimisation purposes.

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Abstract: Optimisation and dynamic studies of Electric Arc Furnaces have long relied on empirical models to describe the behaviour of the oxy-fuel burner during the melting stages of a batch. These models are very weak for optimisation purposes as they fail to describe the effect that variations on both the scrap density and the flow rate of the fuel have on the heat exchanges between the oxy-fuel flames and the solid scrap. In this work, we propose a novel first principles model that tackles those weaknesses and therefore, can be used in dynamic optimisation approaches that aim at improving the efficiency or the economics of the EAF. The well known empirical approximation by Bergman et al., (1990) is used for validation purposes and an average error lower to 3% is obtained over the whole batch time.

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1. INTRODUCTION

Modern Electric Arc Furnaces (EAFs) for steel production are equipped with oxygen lances, coal injectors, oxy-fuel burners, and electromagnetic stirring systems to optimise its energy performance and to reduce operative costs. The application of these technologies has proven to be successful as during the last decades, the energy consumption of the EAF has been reduced by over 45%, passing from 630 kWh/Ton during the early days of the technology to the actual average of 350 kWh/Ton. (Pfeifer et al., 2002).

On the contrary to oxygen lances and coal injectors, which are normally used during the refining process after the smelting stages, the Oxy-fuel burners can be used any time for different purposes (Rathaba et al., 2004). Despite its versatility, a widespread practice in the industry is to use them only during the beginning of the melting stage. This industrial practice finds its justification on the findings of Bergman et al., (1990), who calculated the instantaneous efficiency of the burner based on the temperature of the flue gases of an EAF. This work suggests that the maximum efficiency of the burner is 70%, and it occurs at the beginning of the melting stage. As the batch progresses, the efficiency of the burner drops until it reaches a value of 20% by the moment in which 90% of the total solid mass has been molten.

Oxy-fuel burners introduce into the shell of the EAF flows of natural gas and pure oxygen that mix and combust, creating flames that can reach temperatures of up to 3200 K (Yigit et al., 2014), (Alam et al., 2010). Heat transfer from the flames of the burner to the metal occurs mainly by convection and radiation of combustion products (Jones et al., 1998). In the literature, most of the industrial studies have focused on calculating the overall EAF energy efficiency improvements when burners are used (Kirschc et al., 2009) (Toulouevski et al., 2013), but detailed insight into the process is still missing. In fact, most of the EAF dynamic models in the literature – at the knowledge of the authors – have employed the Bergman efficiency curve to account for the dynamic effect of the burners into the melting process (Logar et al., 2012), (Optiz et al., 2016), (Fathi et al., 2017), or have just assumed a perfect heat exchange between the burners and the melt (Rathaba et al., 2004), (Bekker et al., 1999). On the other hand, McGregor et al. (2005) used online measurements of the temperature and composition of the off-gas of a real EAF to estimate the heat transfer coefficients from the gaseous atmosphere to the solid metal. Later, McGregor et al. (2007), employed a simplified version of their model into a dynamic optimisation framework to obtain the dynamic electrical, gas, oxygen and coal inputs that minimised the cost of operation of an EAF. The importance of identifying the efficiency of the burner was stressed by Rathaba et al. (2004) in his modelling work of an EAF burner, but its calculation was not attempted.

In this paper, a first principles model that builds on the results obtained from CFD models will be introduced (Yigit et al., 2014), (Alam et al., 2010). The model of the burner can estimate the energy transfer from the oxy-flame to the scrap for variable scrap densities as well as for variable flow rates of fuel. The empirical approximation of Bergman et al. (1990) will be used as a benchmark for the comparison and validation of the results regarding the efficiency of the burner.

2. DESCRIPTION OF OXY-FUEL BURNER MODEL

The oxy-fuel burner model is part of a larger EAF model that describes the dynamics of the melting process of scrap in an