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Numerical investigation on post-combustion in a burner for heat treatment furnaces with a reducing gas atmosphere

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Abstract

Scale formation in reheating and heat treatment furnaces causes a significant metal loss on semi-finished metal products. The presented project is about the development of a burner that produces a low oxidizing / reducing atmosphere in the furnace with a thermal efficiency comparable to state-of-the-art recuperative burners. The concept combines direct fuel rich firing and indirect heating with radiant tubes in a recuperative burner. Unlike existing recuperative burners, the concept-burner is equipped with an open radiant tube (ORT) forming an annular gap between the burner and the tube, where the off-gas is post-combusted by the addition of secondary air. The heat of reaction is either transferred to the furnace by radiation of the ORT or recuperated to heat up the primary and secondary combustion air. In the presented numerical study, the impact of the primary equivalence ratio, the furnace temperature and the total equivalence ratio ϕ_{total} on the post-combustion process in the annular gap is evaluated. The total equivalence ratio has the most significant influence on post-combustion. The results for the variation of the total equivalence ratio ϕ_{total} show a faster post-combustion can be reached by using a lower total equivalence ratio of $\phi_{total} = 0.87$ instead of $\phi_{total} = 0.91$. Another parameter on post-combustion is the primary equivalence ratio $\phi_{primary}$. At $\phi_{primary} = 1.43$ the amount of H_2 and CO in the primary off-gas is higher, resulting in a slower post-combustion. At the same time the combustion at $\phi_{primary} = 1.11$ is delayed because of lower mixing rates and kinetics. A variation of the primary off-gas inlet temperature has a low impact on the post-combustion. Decreasing temperature from 1050 °C to 950 °C delays the reaction. The results show that there is a good correlation between the calculations and the measurements at the experimental setup. Therefore, the numerical model is capable to show the impacts of the different parameters on the post-combustion.

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Keywords: recuperative burner; fuel rich combustion; direct fired furnace; scale free reheating; post-combustion

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1. Introduction

Direct fired reheating furnaces are used to heat slabs or billets prior to the hot rolling or forging process. These furnaces are usually fired with natural gas and have to be operated with a high efficiency to ensure a profitable manufacturing process. The full combustion of the fuel is an essential step to get the maximum heat input into the furnace, which is usually realized by an operation with excess air [1]. The furnace atmosphere contains free oxygen, carbon dioxide and vapor, leading to an oxidation on the surface of the product [2,3]. Besides the atmosphere, temperature, time and the chemical composition of the workpiece have an important influence on the formation of scale in terms of quantity and composition [4,5,6,7]. Prior to the next production step the scale has to be removed from the surface, causing more effort and a loss of material up to 5 % [8].

A possibility to prevent scale formation is the usage of a protective gas atmosphere in the furnace. Usually these types of furnaces are equipped with radiant tubes or electrically heated. Typical atmospheres can be produced by oxidizing fuel gases and drying (exothermic / endothermic) or cracking of ammonia [9]. Another way to decrease the formation of scale is the rich combustion of natural gas [8,10,11,12]. It delivers atmospheres containing carbon monoxide (CO), carbon dioxide (CO_2), hydrogen (H_2), vapor ($H_2O_{(g)}$) and nitrogen (N_2) [13]. The flammable components like CO and H_2 result in an incomplete usage of the fuel energy content in the furnace. Furthermore, CO is a toxic gas and its emission is regulated by law [14]. In consequence, a post-combustion of the off-gas is necessary.

The aim of the presented research is the development of a burner that produces a low oxidizing / reducing atmosphere in the furnace with a thermal efficiency comparable to state-of-the-art recuperative burners. The concept combines direct fuel rich firing and indirect heating with radiant tubes in a recuperative burner, shown in Figure 1. The burner operates in flameless mode with a primary equivalence ratio $\phi_{primary} > 1$ allowing a uniform temperature distribution in the furnace and a low oxidizing / reducing atmosphere. Unlike existing recuperative burners, the concept-burner is equipped with an open radiant tube (ORT) forming an annular gap between the burner and the tube, where the off-gas is post-combusted by the addition of secondary air. The heat of reaction is either transferred to the furnace by radiation of the ORT or recuperated to heat up the primary and secondary combustion air.

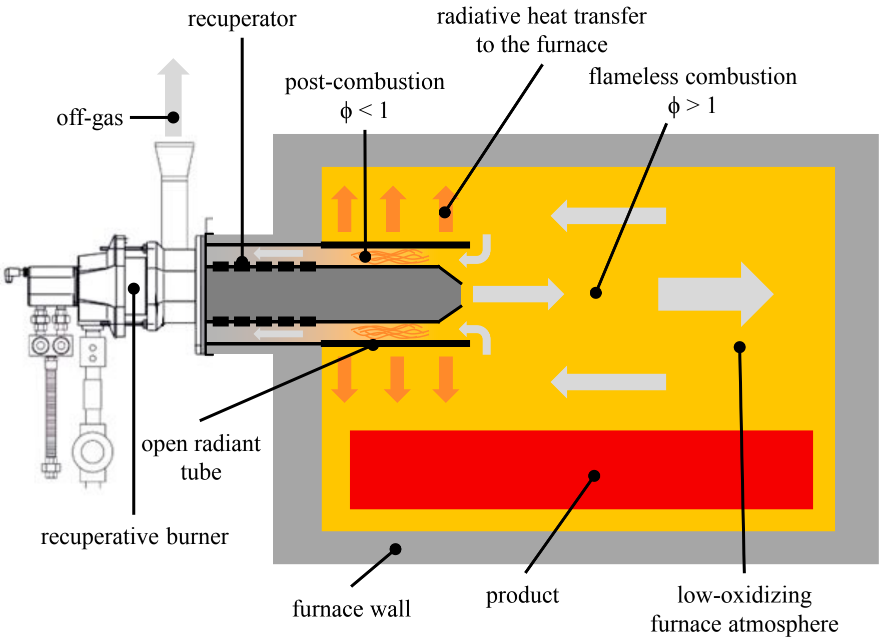

Figure 1: Concept of direct fuel rich firing and radiant tube heating