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Numerical Approach for the Implementation of the Interaction of Pyrolysis Gases and Combustion Products in an Aluminium-Melting Furnace

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Abstract

Aluminium is a key material in modern society and serves the needs because of the unique properties of the metal and its alloys. Scientific evidence and rational economic theories have repeatedly demonstrated that recycling is the most critical and efficient pathway to sustainable human development. Aluminium products like Used Beverage Cans or Containers (UBCs) has been alloyed with other elements to fulfil consumer requirements and contain organic material due to paint and lacquer coatings on the body. The melting and pre-treatment of scrap has an emphasized role in the recycling chain of contaminated aluminium products. The relationship between the amount of contamination, pre-treatment and melting procedure and dross formation attains crucial attention in order to enhance the energy efficiency in existing furnaces. Therefore, understanding the melting and pre-treatment processes includes statistical surveys and systemic modelling. In the present work, numerical simulations were carried out using the commercial software FLUENT for generating a helpful tool in evaluating operational conditions. The main perspective is to analyze the relevant operational conditions inside an aluminium-melting furnace employing oxygen-fuel burner, which is capable to run in the flameless combustion mode. To cope with the challenge of simulating flameless combustion (highly diluted chemical conversion) proved detailed chemistry mechanisms are involved. Further crucial aspect is to evaluate additional in house written codes for the evaporation and gas release due to contaminated input material. Within the scope of the project P5 of the AMAP (Advanced Metals And Processes) research cluster in Aachen a virtual remelting furnace is set up as a CFD (Computational Fluid Dynamics) simulation for evaluating the terms of combustion, pyrolysis/ thermolysis, interaction of combustion products and pyrolysis gases and other crucial phenomena.

Keywords: Combustion, Flameless combustion, CFD simulation, Chemical schemes, Industrial furnaces, Aluminium recycling

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1. Introduction

The global demand for aluminium is increasing year by year (+7.8 % or 1.8 Mio tonnes in 2010 compared with the previous year [1]). The production of aluminium is linked to excessive use of valuable energy; especially the production of primary aluminium is energy-intensive. Only 5 % of the energy to produce primary aluminium (14.239 kWh/t [2]) is required for remelting and refining of aluminium scrap [1]. Political and economic orientation to the recycling economy requires the advancement of the remelting process, since more and more contaminated scraps arrive in this cycle. The majority of secondary aluminium is used in automotive sector, followed by machine construction, buildings and packaging industry [1]. Aluminium scrap like baled UBCs contain in general substantial amount of paint, plastic and liquids like water. Increased level of organic content reduces metal recovery and therefore the metal yield. With the view to ensuring efficiency and the conservation of resources, promoting the use of these organic contaminations as valuable energy source is desirable. While some furnaces address this potential (twin chamber furnaces), the status quo is still the reverberatory one chamber furnace equipped with gas burners. The latest generation of burners is designed to reduce exhaust gas emissions. Low NOx emission burners, like FLOX burners, reflect the stage of the art of aluminium melting. The crucial difference of the flameless combustion principle is the mixing of air and fuel firstly with reaction products via a strong recirculation, resulting in a nonluminous “flame”. The absence of temperature peaks (spatial and temporal) is the major benefit of this type of combustion, which leads to a nearly uniform combustion throughout the entire furnace gas volume [3]. The reactive flow has a major impact on the heat transfer to the load. Thereby it is mostly dominated by gas combustion due to the heating burners in the furnace and pyrolysis/ thermolysis reaction caused by organic contamination of the charge. Numerical modelling has become an essential tool in industrial processes for evaluating and optimization of industrial processes. The prediction of the emissions pollutants, temperature and velocity pattern support the understanding of the combustion and melting process. Even in cases of more complex procedure like FLOX (Flameless Combustion) numerical calculations supply reliable values. The attempt to develop a CFD model for achieving higher metal recovery and less environmental impact postulates capturing the whole complexity. Chemical reaction mechanisms, high temperature effects, burned-off reactions and the shifting scrap properties like the contamination are some of the parts of this complex system. As mentioned, the characteristics of the flameless combustion differ strongly from the conventional methods of burning. Numerical predictions that have proven in standard furnaces are not working well in predicting flameless conditions. Developing models, which can deal with the flameless specifics, are imperative, due to the potential for more widespread implementation of these efficiency-increasing techniques.

Several experiments within scope of AMAP were carried out in order to gain property data of input material, as well as exhaust gas composition and output material in dependency of boundary conditions, pre-treatment and combustion modes. Fluent database of materials extended with the obtained data and numerical model is validated by the measurement results.

2. Investigated Furnace and Burner

The laboratory scale reverberatory furnace (figure 1) with total capacity of 120 kg load of aluminium and is not intended to be a scale model of an industrial furnace, rather it is a testing model to evaluate i. A. the interaction between combustion atmosphere and the charge material and the dross produced during melting of certain scrap. It is equipped with one oxygen-gas burner, shown in figure 2. In case of fuel/air combustion, a tube-in-tube arrangement is available. Natural gas is injected in the inner and air in the outer tube. Permitting fuel/oxygen combustion the outer tubes on the both side of the tube-in-tube configuration are used to inject pure oxygen. While the Oxy-gas burner is of interest the following description, consider only this burner. It has three different combustion modes: standard mode, semi-flameless mode and flameless mode. The firing rate of the burner is 40 kW.