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Simulation of a round steel charge heating by a pulsatory disturbed flue gas stream using the fluent software

Monika Górska*

Czestochowa University of Technology, Faculty of Production Engineering and Materials Technology, Częstochowa 19 Armii Krajowej Av., 42-200 Częstochowa, Poland

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Abstract

The paper presents a numerical modelling of a round steel charge heating by a pulsatory disturbed flue gas stream. The problem, which was decided to be modelled using modern tools for numerical solutions, is the performance of calculations of the surface temperature distribution on a cross-section of a tube 64 mm in outside diameter and with the wall 10 mm thick. Boundary conditions calculated on the basis of data obtained from experimental studies were used for computational purposes. The geometrical shape caused that at different points on the cylinder circumference the heat exchange was proceeding at various intensities, which resulted in a diversified temperature distribution on the cross-section. The knowledge of the impact of the introduced pulsatory disturbances and of the location of boundary-layer separation point in a significant way can shorten the process of low-temperature heating and by appropriate scheme of the round charge rotation can ensure a uniform distribution of the temperature field on its circumference.

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Keywords: convective heat transfer; numerical modeling; cilcular cylinder; pulsatory disturbances; flue gases;

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1. Introduction

The process of heat exchange at temperatures 150÷723°C is based mainly on the convection, where the flue gas radiation in any range is negligibly small. The utilisation of so low temperatures (low in terms of all metallurgical processes) takes place during the final heat treatment of a steel charge, previously subject to the martensitic quenching. Quenched machine parts or other structural elements are prone to brittle fractures, sometimes even under

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* Corresponding author. Tel.: +04 860-668-9086.
E-mail address: monika.gorska77@wp.pl

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small loads. The tempering is sometimes used also after the normalising, if the hardness is too high and the plastic properties low [1, 2]. The tempering is carried out in low-temperature furnaces, where the convection has the main contribution to the heat exchange. Therefore a good circulation in the chamber must be ensured to obtain a good exchange of heat between the charge and the flue gas or inert gases. Such furnaces should be equipped with a system of burners, enabling a quick outflow of the mixture and hence an intensive mixing of the flue gas, or with an installed system of fans or mixers.

The heating of a round charge, which is a complicated process, differs slightly from heating of a flat charge. The geometrical shape causes that at different points on the cylinder circumference the heat exchange proceeds at various intensities, which results in a diversified temperature distribution on the cross-section. The technological requirements to be met by the heated charge before the plastic working, e.g. the production of seamless tubes, assume slight temperature deviations on the cylinder cross-section. The neglecting of this phenomenon may result in the origination of internal material defects, which on the technological line based on quenching and heat treatment can cause the formation of a diversified structure or cracks. A thorough learning of phenomena accompanying the cylinder heating in a stream of hot flue gas will allow minimising the temperature unevenness on the cross-section, eliminating thus the occurrence of internal stresses leading to the material defects [2, 3].

Walking-beam furnaces with a transverse arrangement are among the main types of heating equipment, in which tubes heat treatment is performed. The tubes transport in the furnace is carried out by the movement of walking beams, shifting the charge by one step. By the adjustment of the walking beams movement it is possible to force a rotation of tubes by a specific angle during the next shift. The knowledge of principles of streams forming and of distribution of vortices, which originate during the flow around a cylinder by the flue gas stream, will allow running the heating properly [4].

2. Equations Used to Solve the Problem

The computational model used in the computational algorithm of the Fluent software is based on the k-ε model expanded to the RNG version, which is used in flow calculations and has a very good agreement of the results with the data obtained from experiments. The kinetic energy k of the turbulence and also the dissipation of kinetic energy ε were calculated on the basis of the following transport equations [5, 6]:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}\left(\frac{1}{\mathrm{Pr}_k}\mu_{ef}\frac{\partial k}{\partial x_j}\right)+G_k+G_b-\rho\varepsilon-Y_M+S_k \tag{1}$$

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial x_i}(\rho\varepsilon u_i)=\frac{\partial}{\partial x_j}\left(\frac{1}{\mathrm{Pr}_\varepsilon}\mu_{ef}\frac{\partial\varepsilon}{\partial x_j}\right)+C_{1\varepsilon}\frac{\varepsilon}{k}(G_k+C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}-R_\varepsilon+S_\varepsilon \tag{2}$$

where $\boldsymbol{G_k}$ stands for the generation of kinetic energy of the turbulence. In addition, contrary to the standard k-ε model, the $\boldsymbol{R_\varepsilon}$ term was added to the equation in the RNG version, assuming the form of:

$$R_\varepsilon=\frac{C_\mu\cdot\rho\cdot\eta^3\left(1-\frac{\eta}{\eta_0}\right)}{1+\beta\eta^3}\cdot\frac{\varepsilon^2}{k} \tag{3}$$

To a large extent this allows reducing unnaturally excessive increase in the turbulence energy in the area of high fluctuations of the velocity field. The fact that for $\eta > \eta_0$ the $\boldsymbol{R_\varepsilon}$ term assumes negative values is a significant advantage, increasing at the same time the level of turbulence kinetic energy dissipation, followed by the decrease of the turbulence kinetic energy.

Constant values are:

$$C_{1\varepsilon}=1{,}42;\quad C_{2\varepsilon}=1{,}68;\quad C_\mu=0{,}0845;\quad \eta\equiv\frac{S\cdot k}{\varepsilon};\quad \eta_0=4{,}38;\quad \beta=0{,}012$$

where *S* is the tensor of deformation velocity and may be given by the following formula: