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# Online simulation model of the slab-reheating process in a pusher-type furnace

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**Abstract**

This paper presents an online simulation model of the slab-reheating process in a pusher-type furnace in Acroni d.o.o. in Slovenia. The simulation model is connected to the information system of a hot-processing plant that provides online measuring and charging data of the furnace. The simulation model considers the exact geometry of the furnace enclosure, including the geometry of the slabs inside the furnace. A view-factor matrix of the furnace enclosure was determined using the Monte Carlo method. The heat exchange between the furnace gas, the furnace wall and the slab's surface is calculated using a three-temperature model. The heat conduction in the slabs is calculated using the 3D finite-difference method. The model was validated using measurements from trailing thermocouples positioned in the test slabs during the reheating process in the furnace.

A graphical user interface (GUI) was developed to ensure a user-friendly presentation of the simulation-model results.


*Keywords:* On-line simulation; Reheating furnace; Slab heating; Mathematical model

## 1. Introduction

A computer-controlled hot-rolling process for steel slabs requires high-quality reheated slabs in terms of time, temperature, thermal profile and furnace atmosphere. Each steel slab has to be reheated at a suitable temperature for hot-rolling with the prescribed temperature difference inside the slab. Temperature differences during the whole reheating process should not cause the maximum-allowed thermal stress inside the slab to be exceeded.

The slabs are reheated in the gas-fired pusher-type furnace (Fig. 1). The furnace has six control zones: the upper and lower preheating zones, the upper and lower heating zones, and the left and right soaking zones. The material flow through the furnace is discontinuous, with the movement happening in push steps. At each push step the pushing machine pushes all the slabs until the slab at the exit drops out from the furnace. The length of the pushing step depends on the width of the discharged slab. The number of slabs inside the furnace can vary and depends on the width of the individual slabs.

There are many influences that can affect the reheating process. The time intervals between pushing steps can vary, and delay conditions in the material flow are often present. There are two kinds of delay: scheduled delays, e.g., mill roll changes, meal breaks, etc., or unscheduled delays, e.g., mill breakdowns, etc. Another influence on the reheating process comes from slabs of different dimensions and the different steel grades, which have to be reheated to different discharge temperatures. All these influences significantly affect the reheating process and mean that almost every slab has a different reheating history.

Knowledge of the temperature field of slabs during the reheating process is very important for successful furnace control. The temperature fields of the slabs are non-measurable values during the production process. Computer simulation is sometimes the most reasonable way to

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**Nomenclature**

| | |
|---|---|
| $a$ | heat-transfer coefficient ($\mathrm{W\,m^{-2}\,K^{-1}}$) |
| $A$ | surface area ($\mathrm{m^2}$) |
| $c$ | specific heat (J/kg K) |
| $d$ | furnace-wall/floor-layer thickness (m) |
| $F$ | view-factor |
| $\boldsymbol{F}$ | view-factor matrix |
| $I$ | number of surfaces in a furnace enclosure including slab surfaces |
| $\boldsymbol{I}$ | identity matrix |
| $K$ | number of the furnace-wall/floor-layers |
| $L$ | length (m) |
| $M$ | number of the furnace-floor surfaces |
| $N$ | number |
| $q$ | heat flux ($\mathrm{W\,m^{-2}}$) |
| $Q$ | element of heat-flux vector |
| $\boldsymbol{Q}$ | heat-flux vector |
| $S$ | width of the water pipe |
| $T$ | temperature (K) |

*Greek letters*

| | |
|---|---|
| $\alpha$ | absorptivity factor |
| $\varepsilon$ | emissivity factor |
| $\phi$ | water flow ($\mathrm{m^3/s}$) |
| $\lambda$ | heat conduction ($\mathrm{W\,m^{-1}\,K^{-1}}$) |
| $\pi$ | number PI |
| $\rho$ | density ($\mathrm{kg/m^3}$) |
| $\sigma$ | Stefan–Boltzmann constant, $\sigma = 5.671 \times 10^{-8}\,\mathrm{W\,m^{-2}\,K^{-4}}$ |

*Subscripts*

| | |
|---|---|
| abs | absorption |
| air | air |
| cond | conduction |
| conv | convection |
| floor | furnace floor |
| g | furnace gas |
| $H_2O$ | water |
| $i$ | index of surface in furnace enclosure |
| in | input |
| $j$ | index of surface in furnace enclosure |
| $k$ | index of layers of furnace wall/floor |
| $m$ | index of furnace-floor surface |
| $n$ | index of furnace-floor surface |
| out | output |
| p | pipe |
| rad | radiation |
| s | slab |
| total | total |
| w | furnace wall |
| $\rightarrow, \Rightarrow$ | outgoing |
| $\leftarrow, \Leftarrow$ | incoming |
| $\Longleftrightarrow$ | balance |

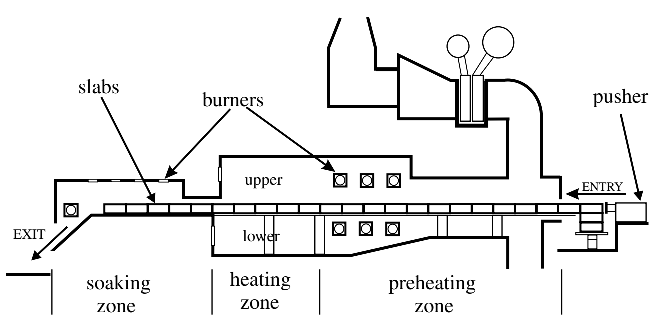


Fig. 1. Pusher-type furnace.

determine such values. The state of the art is one- and two-dimensional online calculations of the stock temperature [1–5]. However, the computational power of today's personal computers means that increasingly complex simulations can be performed in real-time. Thus, complex simulation models can be implemented in the monitoring and control systems of industrial processes, and the first attempts have been made to calculate the stock temperature in three dimensions online [6–8].

An online supervision system based on a three-dimensional simulation model of a steel-slab reheating process in a pusher-type furnace has been developed. The calculations in the model are based on a mathematical model that includes the main physical phenomena appearing during the reheating process in a natural-gas-fired pusher-type furnace: thermal radiation is the main heat-transfer mechanism, and the geometry of the furnace enclosure has an important role in the heat transfer of the thermal radiation. The furnace enclosure consists of the furnace geometry together with the geometry of the charged slabs inside the furnace.

One of the chief mathematical complexities in treating the radiative heat transfer between surfaces is accounting for the geometrical relations involved in how the surfaces view each other. For the whole furnace enclosure they are expressed with a view-factor matrix form. In order to determine the matrix, a separate simulation model based on the Monte Carlo method was developed [9]. This model allows a view-factor determination for a general furnace enclosure consisting of rectangular surfaces, including multiple reflections. In the presented approach the view-factor matrix for a particular furnace enclosure, including the slabs and skid pipes, is calculated only once (the typical calculation time on a Pentium4 PC is three days). The view-factor matrix is read into the online simulation model of