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Thermally induced stresses on radiant heating tubes including the effect of fluid–structure interaction

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HIGHLIGHTS

- Temperature and stress distribution on a radiant heating tube are examined numerically.
- The numerical model is validated with experimental results.
- The stress calculations conducted are based on elastic material parameters.
- Critical areas of the component can be identified also with elastic material parameters.
- Mainly responsible for the stresses occurring are temperature differences on the tube.

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ABSTRACT

High temperatures as well as local temperature peaks and their gradients within the individual components of industrial furnaces are a challenge for the durability of the furnace. In order to optimize furnace component design and thereby increase the life expectancy of each component being considered, the exact determination of local temperature distributions is indispensable. This necessitates a coupled examination of fluid flow and thermal processes, including the calculation of the resulting stresses for the considered component. In order to introduce the so-called fluid–structure interaction (FSI) in the field of plant engineering and industrial furnace engineering, a radiant heating tube was selected for calculations concerning temperature and stress distribution, since radiant heating tubes are especially subject to considerable thermal and mechanical loading.

1. Introduction

Industrial furnaces are thermoprocessing facilities, which are – especially for high-performance facilities – often equipped with gas burners.

For direct firing of an industrial furnace the material is in direct contact with the combustion gases. This leads to scaling on the product surface, and can also lead to a chemical change on the surface. To avoid these effects, the combustion gas and process gas atmosphere can be separated by means of radiant heating tubes. Here, the heat transfer between the combustion gas and the process gas takes place indirectly. Radiant tubes are for example used in furnaces for hot-dip galvanizing, strip flotation furnaces for the recrystallization annealing of copper strips, or in furnaces for the heat treatment of aluminum.

The heat transfer in fuel fired radiant heating tubes results from internal and external heat transfer and thermal conduction in the material of the radiant heating tube. The heat transfer on the inner side of the tube results from the flame propagation and convection in the tube. In a diathermic furnace atmosphere, for example nitrogen (N_2) or hydrogen (H_2), the heat transfer on the outer surface of the radiant heating tube depends on the convective heat transfer of the radiant tube's surface to the furnace atmosphere and the radiation exchange with the furnace walls. These act as auxiliary heating surfaces, which in turn redistribute part of the heat received from the radiant tubes to the furnace atmosphere by convection (Fig. 1).

Depending on their field of application, industrial furnaces are exposed to different thermal loading. For example, facilities for aluminum heat treatment are operated in a temperature range of 150 to 600 °C, steel heat treatment facilities require temperatures above 1000 °C, and in the ceramic industry temperatures of 1300 °C are not uncommon.

These different furnace temperatures result in considerable demands on the deployed materials, since corrosion resistance and mechanical strength properties decrease drastically with increasing temperatures [2].

Furnace radiant heating tubes are a good example for the thermal loading conditions to which furnace components are subjected. This is confirmed by numerous failure analyses in literature concerning heating tubes [3–8].

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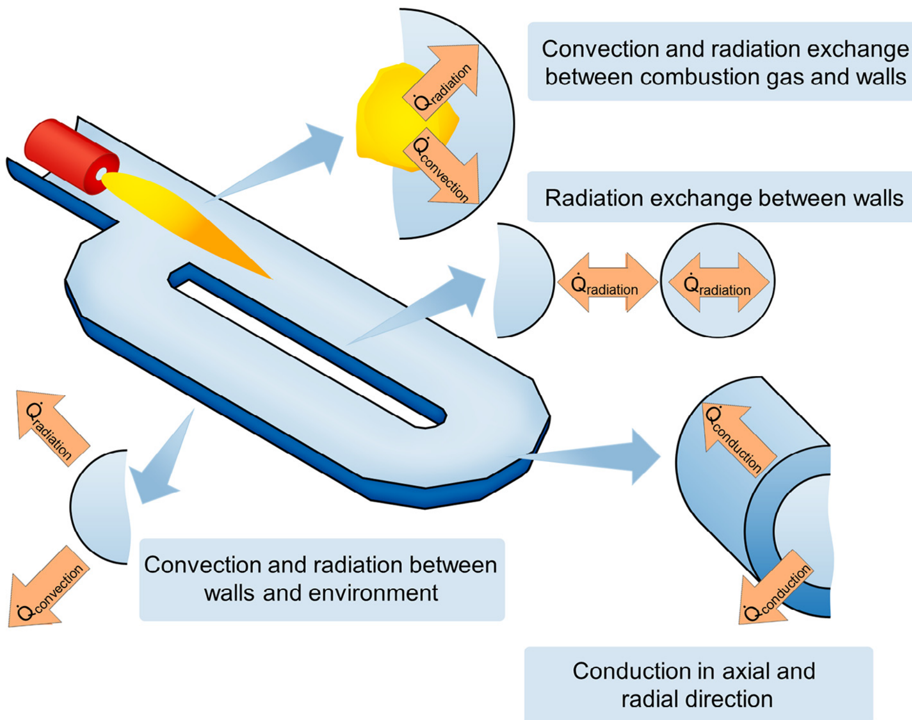

Fig. 1. Heat transfer mechanisms on a p-shaped radiant heating tube (acc. to [1]).

In addition to the high process temperatures, the high local temperature gradients in the components of the furnace result in significant stresses in the materials used.

A better understanding of the fluid flow and heat transfer in an industrial furnace can be achieved with the assistance of computational fluid dynamics (CFD). For example, Hornig et al. calculate the temperature distribution on the surface of radiant heating tubes in a strip flotation furnace for recrystallization annealing of copper at a temperature of approx. 750 °C (Fig. 2) [9].

In this case for the simulation a constant heat flux is assumed as a boundary condition at the surface of the tubes. Thus the areas of different temperatures characterize areas of different heat transfer conditions on the outer surface.

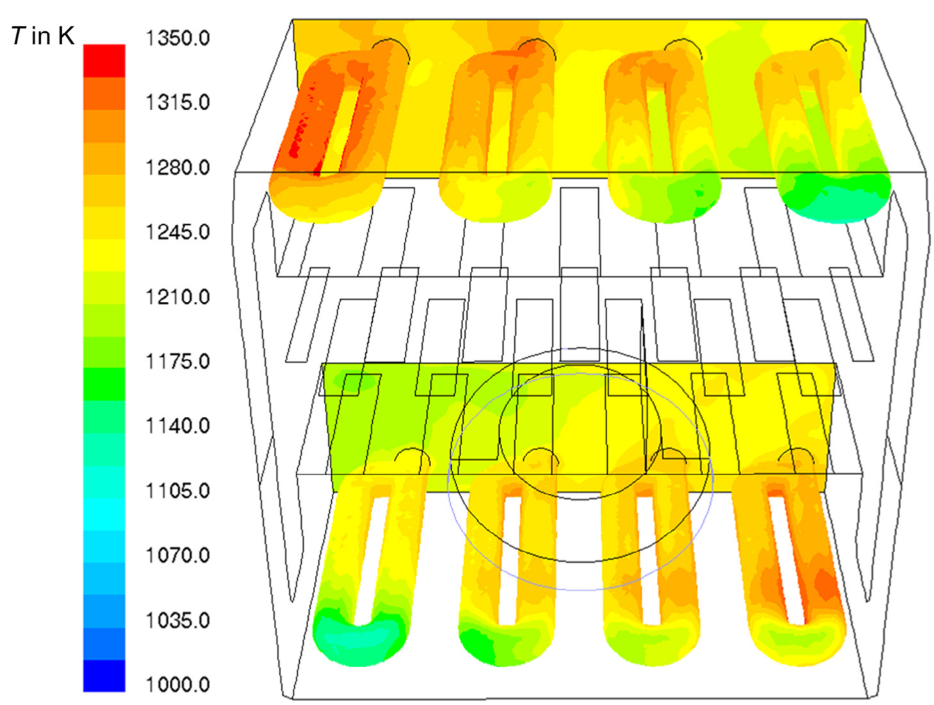

Fig. 2. Surface temperatures on p-shaped radiant heating tubes [9].