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Radiant tubes lifetime prediction in steel processing lines using fluid–structure interaction modelling

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Abstract

One of the limiting factors for processing steel lines performances is the radiant tubes damage. This damage results from a combination of many parameters such as operating conditions (combustion performances, depending on burner design and control, furnace control, fuel quality and stability…) and radiant tube design (material selection, geometry, and manufacturing). Current operating conditions lead to upper temperature limit for radiant tubes, which are then exposed to several mechanisms, such as hot corrosion, creep, and thermal fatigue that ultimately may result to their failure. To improve equipment lifetime subject to severe thermal stresses it is essential to know precisely the radiant tube temperature distribution. The common approach to evaluate radiant tube lifetime is usually limited to thermal stresses calculations on the hypothesis of linear elastic behavior, based on calculated or measured temperature distribution. However, at high temperature, creep behavior implies large deformations that could change the fluid flow inside the radiant tube. A coupled analysis of fluid dynamics and thermomechanical behavior could lead to a more precise evaluation of thermal operating conditions and lifetime for radiant tubes. Thus, a development has been carried out by Fives to increase lifetime of W-shape NiCr cast radiant tube operating at temperatures up to 1000 °C. Combustion and heat transfer inside the tube are simulated using Computational Fluid Dynamics with RANS approach, for fuels including Natural Gas, Coke Oven Gas and residuals Mixed Gases from the steel production. Creep behavior is simulated using a Nonlinear Structural model with Norton's creep law model, using parameters from the literature. The deformation resulting from creep combined with material selection, tube design and tube supports contributes to evaluate radiant tube lifetime. Our results are satisfactory compared with radiant tubes surface temperatures and observed deformation after several years of operation, obtained in Fives test center and during industrial operation.

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Keywords: Fluid-Structure-Interaction; Radiant tube lifetime; AdvanTek® WRT Burner; Creep Model.

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1. Introduction

In steel processing lines, indirect heating of products in protective atmosphere is carried out with radiant tubes equipped with gas-fired burners (Fig. 1). The markets needs are productivity, flexibility, high annealing temperature for new steel grades, and environment friendly technical equipment with in particular low NOx emission, low maintenance costs, and energy savings. Radiant tubes (Fig. 2) are designed to heat metal strips up to 2 m width, common shapes includes U, I, P, double P and W shapes [1]. One of the limiting factors for processing lines performances is the radiant tubes damage. This potential damage results from a combination of many parameters such as operating conditions (combustion performances, depending on burner design and control, furnace control, fuel quality and stability…) and design (material selection, geometry, manufacturing…). In current operating conditions, radiant tubes are exposed to severe thermal loading:

- High temperature up to material temperature limit,
- Heterogeneous thermal field resulting from combustion,
- Thermal cycles resulting from furnace control for various production and burner control.

These stresses account for the observed damage on radiant tubes resulting from coupled phenomena such as creep, thermal fatigue, and corrosion. The temperature increase needed to reach expected metallurgical performances for new advanced high-strength steels grades is limited by the mechanical strength of metallic material used for radiant tube. To improve the lifetime of equipment subject to severe thermal stresses, it is essential to know precisely the radiant tube temperature distribution. This temperature field depends on the heat transfer inside the tube resulting from the combustion, and the heat transfer outside the tube, with the strip, the numerous other tubes and the walls. Radiant tube temperature distribution can be obtained by different means:

- On-site measurement [2], keeping in mind that up to 380 radiant tubes may be present in a single steel processing line, with different temperature profiles depending on the location. In some lines, one or several radiant tubes may be instrumented with thermocouples to estimate the temperature cartography, but not all of them.
- Laboratory tests [3], they have the advantage to be extensive, qualifying the radiant tubes with associated burners and heat exchangers, allowing to develop and investigate innovative equipment, with low pollutant emission such as NOx [4], [5]. Nevertheless the representativeness of these tests in regard to real condition is not always convincing, especially in terms of atmosphere, boundary conditions (wall, tubes…), duration and transient behavior [6], [7].
- Computational Fluid Dynamics (CFD), with combustion modelling [8], [9], [10], [11], [12], [13], this technique has the advantage of allowing a better understanding of the flow inside the radiant tube, where measurement are not easy to perform. However, it implies a good knowledge of the material physical characteristics, including for example emissivity at different temperatures and wavelengths. In addition, adequate boundary limits, fuel composition, and kinetic model are needed.

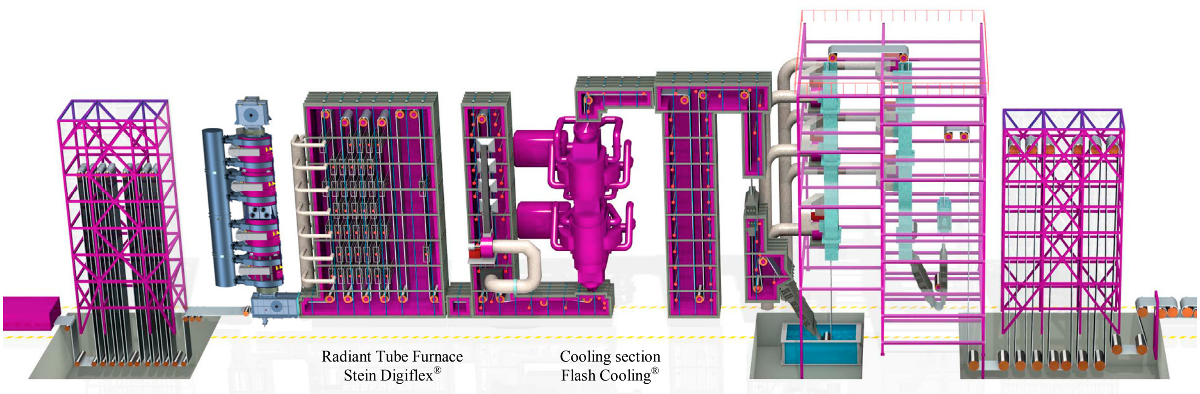

Fig. 1. Schematic view of a galvanizing furnace (metal strip goes from the left to the right side).