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Advanced monitoring of the fouling process on water walls

Matthias Reiche*, Sebastian Grahl, Michael Beckmann

Chair of Energy Process Engineering, Dresden University of Technology, George-Bähr Str. 3b, 01062 Dresden, Germany

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ABSTRACT

During the combustion of fossil fuels in a steam generator, slagging and fouling of the combustion chamber occurs which hinders the heat transfer, declines the steam generator performance and promotes corrosion of the water-tube walls. Due to the deposition and its noticeable impact on the operation of the steam generator, there is a need to clean the heat exchanger surfaces during operation. A demand-actuated cleaning requires information about deposits on water walls regarding their thicknesses, structures and strengths. Previously we have described a concept that characterizes the material properties of deposits on water-tube walls analyzing the unsteady temperature field within the deposit (Grahl and Beckmann, 2013). In this paper the applicability of the concept is discussed and was tested in a steam generator of a waste incineration plant. The concept was found to be sufficiently accurate regarding thickness changes due to fouling as well as cleaning processes.

1. Introduction

The operation of fossil-fired steam generators comes with one main issue, which is the formation of deposits on heat exchanger surfaces by fly fuel ash, especially on the water-tube walls as well as on the superheaters and re-heaters. Deposits influence strongly the heat transfer between flue gas and water-steam cycle and thus the performance of the steam generator. Furthermore, these ash deposits even may promote corrosion of the heat exchanger surfaces through their chemical composition [2,3].

Depending on the thermal properties and thickness of the deposit the heat transfer is hindered. Numerous theoretical and experimental studies were focused on the thermal properties of ash deposits. Wall et al. [4] assumes in their review that the thermal conductivity drops with growing thickness of a particulate deposit. On the other hand the temperature of the deposit surface increases continuously. Through reaching high temperatures within the deposit, sintering and fusion of the particles occur. As a consequence, the change in deposit structure results in an increase of the thermal conductivity. Anderson et al. [5] observed in their experiments that the deposit structure does have a significant effect on the thermal conductivity which is considerable higher for solid-porous deposits compared to particulate deposits. Wain et al. [6] found in their experiments a strong dependence between thermal conductivity and deposit porosity. Rezaei et al. [7] recently investigated the thermal conductivity of bag filter ash samples and synthetic ash samples with a laboratory apparatus. Rezaei et al. concluded from their experiments that the chemical composition does have a minor effect on the thermal conductivity below sintering temperature. But the chemical composition seems to influence significantly deposit sintering and changes of the deposit structure, respectively. Grahl et al. [8] categorized deposits into different types on the basis of the apparent relationship between deposit structure, deposit strength and thermal conductivity. The main categories are: loose deposits with low or medium binding (low thermal conductivity), hard deposits with strong binding (average thermal conductivity), highly sintered deposits or slag (high thermal conductivity).

Grahl and Beckmann [1] presented theoretically a method which can detect deposits on water-tube walls and characterize their material properties. As outlined before this method may help to characterize the deposits on the water tube wall regarding their structure as well as strength and consequently leads to an optimized cleaning of the heat exchanger surfaces through better adjusted properties of the water cannon system. Important properties of a water cannon system may be its residence time and the water pressure. However, to the best of our knowledge, a scientific, experimental investigation regarding the applicability of the approach described in [1] has never been done. The

* Corresponding author.
E-mail address: matthias.reiche@tu-dresden.de (M. Reiche).

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Nomenclature

Latin letters

a	thermal diffusivity, m^2/s
b	thermal effusivity, $J\,m^{-2}\,K^{-1}\,s^{-0.5}$
c	specific heat capacity, J/kg/K
n,N	natural number, dimensionless
q	heat flux density, W/m^2
$\hat{q}$	amplitude of heat flux density oscillation, W/m^2
t	point in time, s
x	local coordinate, m

Greek letters

Δ	difference, dimensionless
δ	thickness, m
ϑ	temperature, °C
$\hat{\vartheta}$	amplitude of temperature oscillation, °C
λ	thermal conductivity, W/m/K
ξ	phase shift, dimensionless
ω	angular frequency, s^{-1}
ϖ	deposition parameter, $s^{1/2}$
ρ	deposition density, kg/m^3
τ	time interval, s

main objective of this study is the investigation of this approach in a steam generator of a waste incineration plant.

In Section 2 of this paper the approach of [1], hereafter called deposit sensor, is briefly reviewed and the signal processing using wavelets is discussed. In the following section, the first field campaign of the sensor system in a steam generator of a waste incineration plant is presented. Afterwards the results of the sensor systems are discussed as well as compared with other methods investigating deposition and the effectiveness of cleaning procedures on a water-tube wall. In the last section the findings are summarized and the further development of the deposit sensor is outlined.

2. The deposit sensor

Due to the nature of combustion of solid fuels like coal and blends of coal with biomass, the temperature of the flue gas fluctuates rather than it is absolutely constant. These flue gas temperature fluctuations can be measured in the entire combustion chamber and even at the outer surface of the combustion chamber wall. Through a comparison of the temperature fluctuations in the combustion chamber with the fluctuations at the outer combustion chamber wall over time, two phenomena can be recognized: A time shift and damping of the temperature fluctuations at the outer surface of the combustion wall occur compared to those in the combustion chamber. Since the thermal diffusivity of a deposit is very low in comparison to the steel of the water wall, the presence of a deposit influences mainly the two mentioned phenomena as the temperature changes have to pass the deposit. The deposit sensor analyzes time shift and damping of the signals in order to detect and characterize deposits on water tube walls without influencing their shape and structure ("in-situ"). The basic concept of the deposit sensor is shown in Fig. 1. Currently the deposit sensor works on water tube walls with refractory tiles.

The deposit sensor uses an infrared camera in order to measure temperature changes on the deposit surface, a heat flux sensor [9], consisting of a pair of thermocouples at the outer surface of the water wall, and a thermocouple in the refractory tile in order to obtain the time displaced and damped signal. Instead of using an infrared camera and investigating the deposit over a certain area of the water wall, a pyrometer can be used to capture the temperature changes at a single point. Analyzing only temporal signal changes of an optical temperature measurement instrument comes with one important advantage: The emissivity of the deposit and the transmissivity of the flue gas don't

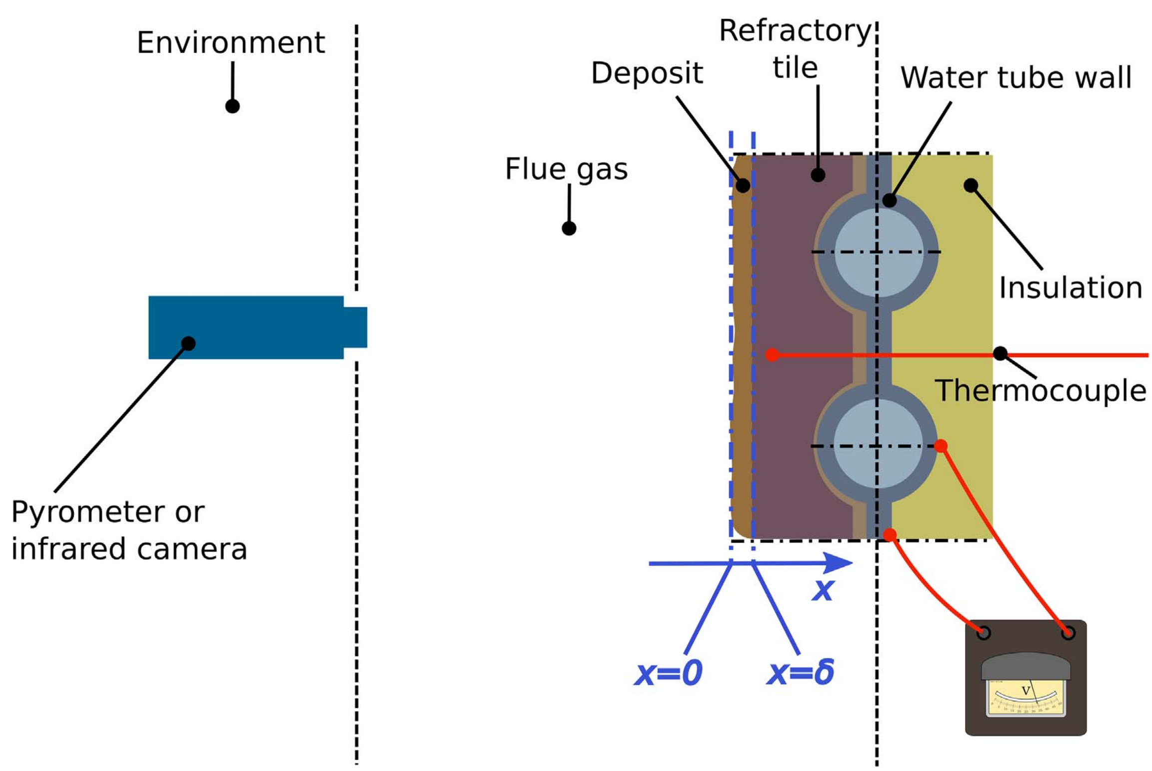

Fig. 1. Measuring concept of the deposit sensor.