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Petrochemical furnace precise temperature monitoring aided by thermographic data corrections

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Abstract

This work addresses the thermographic temperature monitoring in a high temperature industrial environment (800-1000 ºC). Specifically, Petronor Innovación aims to monitor the tube surface temperature of a reforming furnace to avoid failures that could result in unplanned plant shutdowns. The main drawback lies in the current absence of algorithms of sufficient precision to determine the temperature of a target body from infrared radiation readings by a camera. In fact, spurious contributions of infrared measurements, amplified in high temperature environments, are complex to suppress. In this research work, thermal and optical models are developed to generate precise algorithms for temperature correction in thermography and are implemented in a monitoring platform.

1. Introduction

The temperature control is one of the most critical parameters in a petrochemical furnace, since its precise value determines the global performance in a plant [1]. In the case of a reforming furnace, all heat transfer mechanisms (conduction, convection, radiation), together with the chemical reaction kinetics and the combustion process, have to be taken into account to determine the temperature distribution. Temperature *operando* measurement is essential to monitor the furnace properly and to avoid potential local failure points. Due to the aggressive environment and frequent failures, the use of thermocouples is not recommended and infrared (IR) thermographic cameras are postulated as excellent alternatives, because of their remote character that allows an *in-situ* temperature map without contact [2]. However, the camera calibration is complex and the main drawback lies within the current absence of algorithms of sufficient precision to determine the temperature from IR radiation readings by a camera. Among other factors, the direction of the emissivity at service temperature is required (which is usually unknown and extrapolated from room temperature indirect measurements) and the evolution of the involved surfaces has to be considered, because they can lead to very large errors. In addition, the radiation detected by the cameras comes not only from the emission of the viewed area, but also from incoming reflected and scattered radiation. This work introduces a thermo-optical model to generate precise algorithms for temperature correction in thermography for an actual high-temperature industrial furnace (800-1000 ºC).

2. Methodology

A methodology for precise temperature monitoring has been stablished. First, the radiance is recorded by the selected thermographic camera and registered in a monitoring platform (see Figure 1). Then, both thermal and optical influences are evaluated and spurious contributions are corrected from the measured data. Last, the precise temperature is obtained from corrected radiance values. Below, each step of the process is described.

2.1. Radiance Monitoring

Radiance monitoring of high temperature furnaces is constrained by strong physical limitations. Thick walls difficult the perspective from outside and peep-holes cannot be continuously open to the outdoor ambient. Thus, borescope cameras can be used as a solution to these problems because the camera's borescopic end is introduced through the wall. This method provides a good perspective of the inside elements. However, accurate temperature measurements requires filtering those radiation sources that do not correspond to the body temperature (e.g. atmosphere, reflections, dust scattering, etc.). Reflections can be estimated by rough approaches such as the background temperature or by modelling the furnace in 3D and applying light rendering techniques (ray-tracing, radiosity,...). Atmospheric effects are partially mitigated by the low spectral response of the flames and gases at the cameras operational wavelength. The equipment used in this work is a LAND FTI-Eb borescope camera operating at 3.9 µm.

2.2. Computational Fluid Dynamics (CFD)

Different approaches have previously been used to model, analyse and optimize reforming furnaces [3-5]. In this case, the reforming furnace has been modelled to obtain the skin temperature of the reforming tubes in steady working conditions. A commercial software for the Computational Fluid Dynamics modelling was used. Three main processes have been taken into account: combustion processes of the burners, heat transfer processes (radiation, conduction and convection), and, finally, the catalytic process that happens inside the reforming tubes. The resulting skin temperature of the tubes has been used as a reference to develop the correction procedure.

2.3. Optical corrections

To eliminate possible errors in the temperature calculation, an optical model that considers different optical phenomena has been implemented. This model focuses on three main features. First, it uses a ray-tracing method to observe the multiple reflections that happen inside the reforming furnace and its complex geometry. Second, emissivities from different furnace components have been measured at working temperatures and implemented in the model. Third, the angle dependence of the emissivity is introduced. This is especially important since materials will emit differently depending on the emission angle and IR camera detection will be influenced by it [6].

3. Results and conclusions

Thermal and optical corrections are implemented in a radiance lectures platform and then converted to temperature. Results are compared to usual temperatures provided by thermographic cameras, showing the improvement of the methodology in temperature measurement by passive thermography. The first temperature-dependent spectral emissivity measurements are performed in tube skins of a reforming furnace. The results show that the emissivity evolves with the temperature and that it decreases with the emitted angle. Besides, total hemispherical emissivity data, needed for the CFD model, is obtained. Corrections on the directional emissivity show that assigning the same emissivity value to different angles can lead to errors of up to 70 K. The work descripted in this paper showed Petronor a path to predict and correct for these influence to achieve a more accurate temperature measurement.

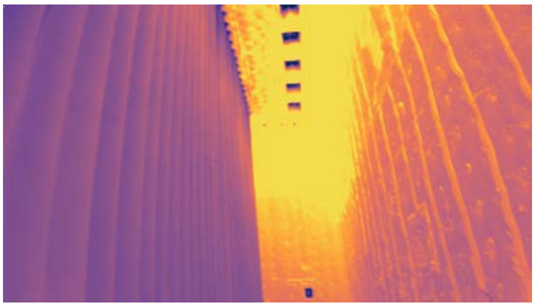

Fig. 1. *Measured infrared image of a Petronor reforming furnace before correction. (Courtesy Petronor)*

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