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Thermo-optical corrections for accurate temperature determination by thermography in an industrial furnace

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Abstract

Petronor aims to monitor the surface temperature of the tubes inside a high temperature reforming furnace to avoid failures that could result in unplanned plant shutdowns. For this purpose, a thermographic camera has been installed in the furnace wall. However, the temperature readings obtained from the images provided by the camera include several spurious contributions and effects that produce a deviation in the value, so that various arrangements need to be performed. This work addresses the thermal and optical correction models that have been developed in order to obtain accurate temperature measurements.

1. Introduction

Temperature is probably the most critical parameter in petrochemical furnace operation, and an accurate measurement is essential to manage the overall performance of the plant. Due to the extreme conditions inside petrochemical furnaces, the use of thermocouples is not recommended and infrared (IR) thermographic cameras are postulated as excellent alternatives. This is because of their remote character that allows an in-situ temperature map without contact [1]. Nevertheless, quantitative temperature measurement by thermography is not simple, as there are several factors that reduce the reliability of the measurement obtained. Firstly, the emissivity of the target material at the working temperature, at the emission angle and at the measuring wavelength must be taken into account, as well as its evolution with time due to change in surface condition. Secondly, the radiation detected by the camera not only comes from the point of interest, but it is also the result of the emission and reflection of all other components of the furnace, including gases, being in this case highly contributing due to the high temperature of the operation. Therefore, due to the current absence of algorithms and/or procedures to supress these effects, thermo-optical corrections have been developed and applied in this industrial context to minimize the deviation and obtain accurate temperature readings. Besides, with the industrial application in mind, two methods with different operational and computational costs have been developed and the accuracy achieved with each one has been compared.

2. Methodology

The radiation images that serve as a source for temperature determination have been provided by Petronor and have been obtained by a LAND FTI-Eb borescope camera operating at 3.9 µm.

First of all, spectral (1.5 to 25 µm) and angular (0º to 90º) infrared emissivity measurements of the tube surface at temperatures between 500°C and 1000ºC have been carried out in the HAIRL emissometer [2], provided that the temperature of the object to be measured is known to be around 700ºC and the furnace wall at around 1000 ºC. Based on the experimental data, emissivity values have been fitted to a function that will be used in the work. Besides, the tubes are usually used until the age of 13 years, so, in order to know the error range in which the emissivity is going to lie due to the aging condition, measurements have been done also for both surfaces of tubes of 1 and 13 years-old.

Furthermore, a spectral study has also been made to see the influence the gases inside the furnace have on the camera measurements.

2.1. Blind corrections

In this case, a correction model has been developed considering the geometry of the furnace, wall temperature and emissivity function, with the aim to produce a fast and simple correction without further input.

First, to determine the furnace reflected radiation in the tubes, radiation coming directly from the walls has to be taken into account, for which two approaches with different computational costs have been considered: constant radiation coming from the walls, since the temperature of the walls is much higher than that of the tubes, and a more complex one taking into consideration it increases with height.

Once direct reflection is supressed, the emissivity function depending on temperature, angle, wavelength and age (surface condition) is applied and the radiance data from the camera is corrected. By doing this, the radiance of the target closest to the real value is obtained, and hence the temperature closest to the real value.

It is worth noting that the techniques mentioned above have been executed in seconds, using a laptop with 8 GB of RAM memory and a 2 core processor. For that reason, it can be said that the computational cost of this method is small.

2.2. Corrections based on ray-tracing

In order to get a more accurate idea on how reflected radiance affects, Ray Tracing simulations have been accomplished; these simulations allow us to consider all the scatterings suffered by the rays along the furnace that finally reach the camera. As a first step, a Computational Fluid Dynamics (CFD) model was developed in order to get a realistic 3D temperature map of the furnace [3]. Considering those temperatures and the emissivity functions of the materials involved, the paths of the rays are traced, taking into account the multiple reflections that happen inside the reforming furnace, until they reach the IR camera. That is, a simulated thermography can be obtained. This way an analysis of the effects that produce inaccuracies in the tubes temperature determination can be performed, and even separate effects can be considered, in order to balance the cost of the correction versus the accuracy required in the industrial context. Anyway, these simulations have a much higher computational cost.

3. Results and conclusions

To show the improvements achieved, the values provided by the camera are compared with those obtained after the corrections are applied. As an example, the value of the temperature measured by the camera at a particular point of a tube is 770º, and if Blind corrections are used, a value of 740º is got. On the other hand, by applying the corrections made with the method based on ray-racing, a temperature of 730ºC is obtained. As can be seen, better results are achieved with the second method, but its computational cost is much higher. This work sets a roadmap for the industry to choose a suitable correction algorithm depending on the desired accuracy.

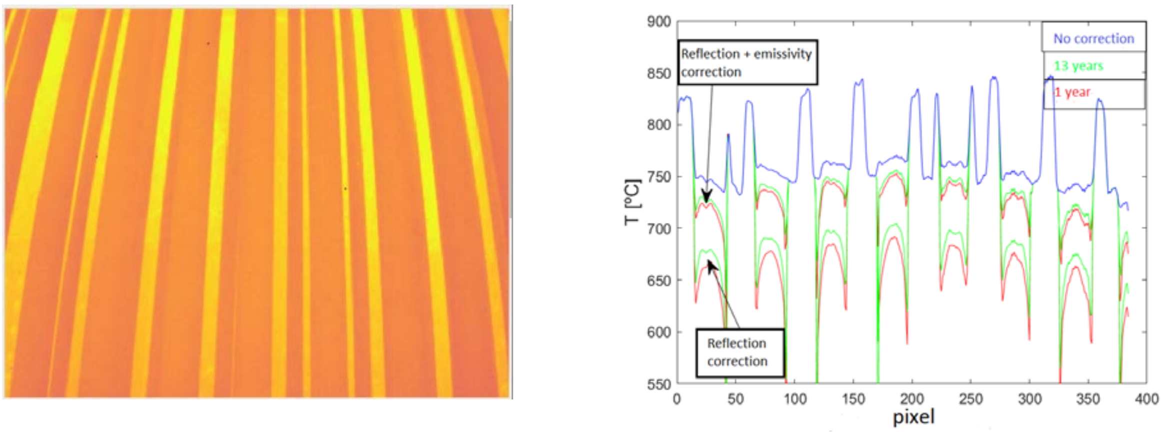

Fig. 1. *Left: Direct thermography of a Petronor furnace before correction; Right: temperature profile of a row of the image before (blue) and after partial and total corrections considering tubes 1 year (red) and 13 years-old (green).*

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