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Infrared thermographic inspection of operating smokestacks

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Abstract

The general principles of the IR thermographic inspection of operating smokestacks are presented. The features of surface temperature distributions are illustrated for metallic, brick and concrete smokestacks. Typical IR thermograms are presented. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Infrared thermography; Diagnostics; Smokestack; Data interpretation

1. Introduction

The use of infrared thermography in predictive maintenance and condition monitoring is well known and requires no comments. There was fragmentary information on the inspection of operating smokestacks in the past, mainly in the USA and Russia with the corresponding experience being collected in the book by Drozdov and Sukharev [1]. However, in the last decade, the number of research studies in this area was rather poor. In Russia, the period of 'perestroika' has been accompanied by a general decline in high-tech activity. However, recently, the interest to IR thermographic diagnostics of smokestacks has grown due to a more rigid policy toward the careful inspection of potentially-dangerous industrial installations. Recently, the United Power Networks of Russia, Inc. (RAO "ES Rossii"), the major producer of electrical power in the country, allowed the use of IR thermography in monitoring smokestack conditions along with a traditional visual inspection.

The number of smokestacks in Russia that belong to large- and middle-size industrial enterprises and power production companies is innumerable. Most smokestacks were built in the 1960–1970s and have by now exceeded their lifetime because of a low quality of building in the former USSR and changed work conditions (many enterprises switched from coal to gas or black oil). Some smokestack collapses have been reported in Russia although official statistics are scarcely available.

Recently, the federal law that requires an urgent inspection of all dangerous industrial installations all over the country was accepted. This has excited the interest of potential clients of IR thermography as a fast non-contact diagnostics tool. In Tomsk Polytechnic University, IR thermographic diagnostics of smokestacks started in 1998 by using a Thermovision-570 IR camera. By now, the number of inspected smokestacks has exceeded 40. Our initial experience in this area was presented at the Thermosense-XXIII meeting in 2001 [2].

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A collection of documents on the inspection of smokestacks was issued by the Russian Ministry of Energy. Most of them deal with surface defects that could be detected visually and verified by taking some probes (of concrete, gas etc.). Measurements of smokestack heels are also obligatory through a period of exploitation.

The role of IR thermography is believed to be in the detection of subsurface defects that are typically missed during visual inspections, namely: (1) deterioration of thermal insulation, and (2) air in-leaks (air out-leaks appear only on the very top of smokestacks where the internal gas pressure could exceed an atmospheric pressure).

2. Modeling and inversion

At the first glimpse, smokestack seems to have a rather simple design. They typically include 3 or 4 layers: an outer shell made of brick or reinforced concrete, a thermal insulator (mineral wool or air gap), a refractory and sometimes a brick support wall. Destructive processes could appear in any layer but the condition of the shell that bears a main load is crucial for keeping a smokestack alive. A dew point should appear on the internal surface of a smokestack to provide the collection of moisture on the smokestack bottom. The use of gas instead of coal can move this point into the insulating gap thus moistening the mineral wool and initiating corrosion processes. The same situation will happen in the case of the deterioration of smokestack thermal insulation. Air in-leaks could also change the thermal regime of smokestacks accelerating condensation and corrosion.

Initially, we tried to use the ThermoCalc-2D and ThermoCalc-3D computer programs to calculate 2D and 3D temperature distributions. However, we have found that practitioners are also content using simple 1D stationary models of heat conduction in a multi-layer wall [2]. These models are valid for large subsurface defects that are of interest in practice allowing to calculate expected temperature signals over typical defects, such as refractory destruction, mineral wool moistening or destruction etc. As for air in-leaks, the relationship between the temperature drop and the leak rate is less obvious than the phenomena related to variations in wall thermal resistance. However, we have proposed a simple formula that allows calculating air in-leak rate if the surface temperature gradient is measured and if the gas pressure inside the smokestack is known [2].

The main problem we have met has been related to the interpretation of quantitative data in terms of defect parameters, i.e. data inversion. The difficulties in data treatment are typical for diagnostic problems with several not well-controlled parameters. The simple 1D models seem to be not very convenient in interpreting temperature measurement results. The main sources of errors have been the following: (1) unstable and inaccurately measured values of the outer wall heat exchange coefficient, (2) the fuzzy definition of the ambient temperature and the "smokestack temperature memory" that disturbs a stationary temperature distribution, (3) a poor knowledge of a real temperature of the gas flowing through a smokestack (gas temperature is typically measured at the furnace outlet and its accurate values within a smokestack are not known). Thus, the above-mentioned data inversion problems are analogous to those that appear in IR thermographic diagnostics of buildings.

However, by combining 1D model predictions and our practical experience, we have found that, independently of inspection conditions, dangerous defects in thermal insulation create temperature elevations of about 3–4 °C, while serious air in-leaks correspond to temperature drops up to 7–10 °C. For many types of smokestacks, these absolute values are not much affected by the ambient temperature and the gas temperature because their typical difference is about 200–250 °C. On the outer wall, it is equivalent to few centigrade of the temperature variation.

The examples of the described two kinds of defects are presented in Fig. 1 along with the values of the related temperature signals.

3. Typical IR thermograms

A smokestack is typically surveyed from 5 to 7 observation points thus providing 40–60 IR im-

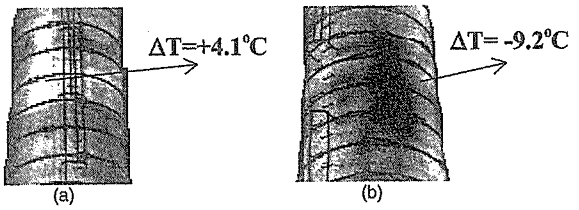

Fig. 1. IR thermograms of (a) thermal insulation degradation and (b) air in-leak.

ages. These images are used in computer data treatment to compose what we have called "panoramic thermograms" shown in Fig. 2.

Metallic smokestacks are not typical in the power production industry but they can be frequently met at petrochemical plants. The 40 m metallic smokestack shown in Fig. 2a is internally insulated along half of its height. The additional narrow insulation on the very bottom of the smokestack (nearly not seen in the image) ensures the surface temperature close to ambient. Then, the vast but thin internal refractory keeps the surface temperature about 170 °C. The destruction of the upper edge of the refractory is well seen. The part of the smokestack free of insulation has a temperature about 210 °C. Notice that the highest temperature occurs where the hot gas leaves the area of thin refraction (Fig. 2a).

Brick smokestacks are typically from 40 to 60 m high. The smokestack shown in Fig. 2b has a large number of cracks where air in-leaks occur to create the areas of decreased temperature. Oblique and horizontal cracks are the most dangerous for smokestack load-carrying ability.

The interpretation of the thermograms that adhere to concrete smokestacks is the most difficult. Such smokestacks can be up to 430 m high, although their typical height is from 120 to 180 m. Panoramic thermograms of concrete smokestacks reveal the particular circular areas that correspond to the so-called 'tear collection' rows where a special internal brickwork is made to ensure the collection of the condensate. There is no mineral wool in these areas, therefore the thermal resistance of

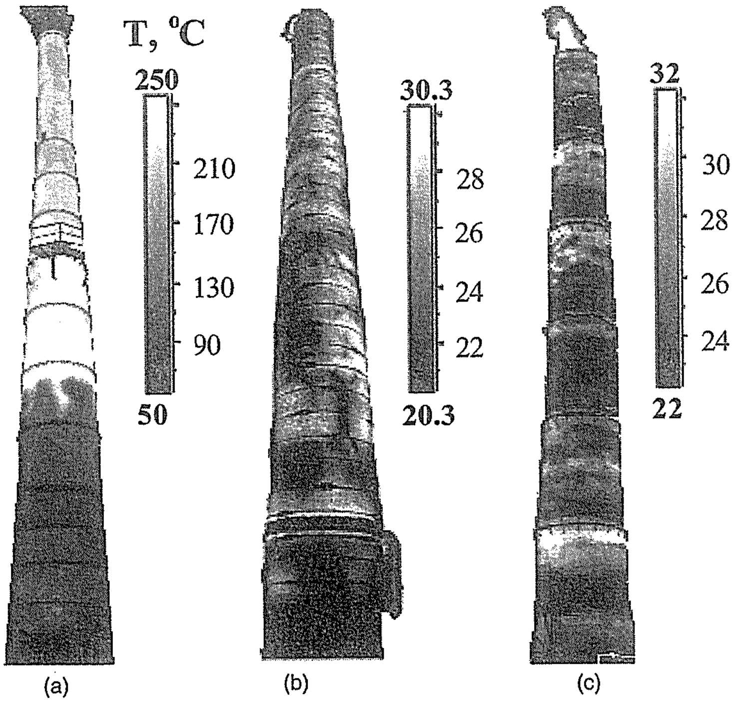

Fig. 2. Typical smokestack IR panoramic thermogrms: (a) metallic smokestack with internal refraction, (b) brick smokestack and (c) reinforced concrete smokestack.

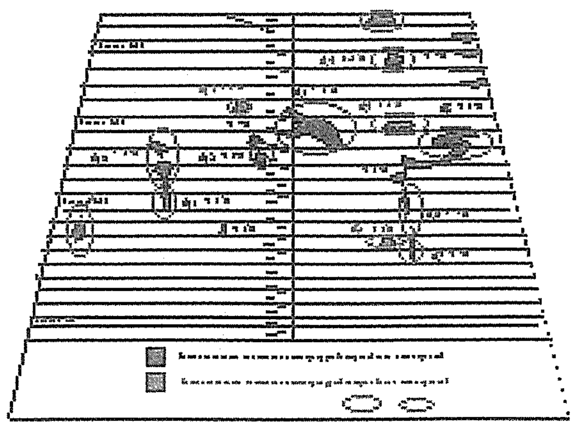

Fig. 3. Defect map of the reinforced concrete smokestack.

tear-collection rows is lower than that of the main shell. The concretion of mineral wool mats leads to the appearance of large warm areas over the external surface of a smokestack. However, the most frequent defects in concrete smokestacks are conditioned by a poor quality of concreting (large pores, stone inclusions etc.). Such defects typically look like stripped cold areas (Fig. 2c).

4. Defect map

The frequent goal of smokestack inspections is determining the size of a planned repair. According to smokestack inspection requirements, the building companies that perform repairs must have the defect maps reflecting the defects to be repaired. A defect map represents the evolvement drawing of the smokestack surface where all dangerous defects are depicted. It is important that, unlike common defect maps made by the results of visual inspections, the IR thermographic diagnostics allows mapping subsurface defects. An example of the smokestack defect map where the above-mentioned defect signal criteria have been used is presented in Fig. 3. The shaded areas correspond either to the degradation of thermal insulation, or are related to air in-leaks.

5. Conclusion

IR thermographic inspection of operating smokestacks experiences a new wave of interest at least in Russia where many industrial smokestacks have exceeded their lifetime expectation. The analysis of surface temperature distributions allows obtaining the useful information on hidden smokestack imperfections. Even from the academic point of view, this kind of diagnostics is interesting since it provides a target ground for verifying the ideas in solving inverse heat conduction problems. In practice, some simple absolute temperature thresholds allow composing defect maps preferred by practitioners.

References

[1] V. Drozdov, V. Sukharev, Thermography in building, Stroyizdat Publ, Moscow, 1987 (238 pp).

[2] V. Vavilov, V. Demin, V. Shiryaev, Inspecting smokestacks by IR thermographic smokestacks and heat conduction modeling, in: Proceedings SPIE "Thermosense-XXIII", Orlando, USA, vol. 4360, 2001, pp. 324–332.