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The application of thermal imaging in metals industry.

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Abstract

For many decades use of infrared equipment has been common practice at Hoogovens, both in process control and research. The development of modern thermal imagers gives new opportunities for the steel and aluminium industries. Thermal imaging has been used in applications for cokemaking, ironmaking and steelmaking, web handling, annealing and high pressure die casting of aluminium.
This paper presents some results of these industrial measurements.

Nomenclature

U	voltage output from detector (V)
k	pyrometer constant (V^{-1})
ε	emissivity of object ( )
r	reflectivity of object ( )
c_2	Planck's second constant ($1.4388*10^{-2}$ mK)
λ	effective wavelength of pyrometer (m)
T	temperature of object (K)

1. Introduction

Koninklijke Hoogovens is an international group of companies which produces an annual volume of over 6.000.000 tonnes of steel and approximately 400.000 tonnes of aluminium, most of which it supplies to its customers in the form of rolled and extruded products.

At Hoogovens Research & Development, the use of thermal imagers has increased during the last years in treating temperature and heat transfer problems. In this paper we present some theoretical backgrounds of temperature measurement by means of infrared radiation and some results of temperature measurements performed with a thermal imager.

2. General considerations and theory

Like all other infrared measurements, the practical application of thermal imagers is influenced by several environmental factors, notably the emissivity of the object of interest and the angle of incidence between the camera and the object.

2.1. The influence of changes of emissivity.

The influence of the change of emissivity of an object on the error of the temperature indication of a pyrometer or thermal imager can be derived from Wien's law, which approximates Planck's law if the quantity $c_2/\lambda T$ is sufficiently high:

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$$U = k.\varepsilon.\exp(-c_2 / \lambda.T) \tag{1}$$

$$\ln\left(\frac{U}{k.\varepsilon}\right) = -c_2 / \lambda.T \tag{2}$$

$$T = \frac{-c_2}{\lambda.\ln\left(\frac{U}{k.\varepsilon}\right)} \tag{3}$$

$$\frac{dT}{d\varepsilon} = \frac{-\lambda.T^2}{c_2.\varepsilon} \tag{4}$$

$$\Delta T = \frac{-\lambda.T^2}{c_2.\varepsilon}.\Delta\varepsilon \tag{5}$$

The error in temperature measurement depends on the relative change of emissivity, the absolute temperature of the object and the wavelength.

Temperature measurements of aluminium objects are more sensitive to fluctuations of emissivity than of oxidized steel ($\Delta T_{aluminium} / \Delta T_{steel,oxidized} = 4$, same wavelength and temperature and $\varepsilon_{aluminium} = 0.2$ and $\varepsilon_{steel,oxidized} = 0.8$). This makes the use of thermal imagers (and other pyrometers) on low emissivity surfaces such as aluminium very critical.
Equation (5) also indicates that the lowest possible wavelength should preferably be choosen.
The results of equation (5) can be used to estimate the errors in measurements *(figure 1).*

2.2. The angle of incidence.

It is known that the emissivity or the reflectivity of a surface is not constant for all values of the angle of incidence. The reflectivity for unoxidized steel and for pure aluminium for two wavelengths has been calculated for different angles of incidence with the refractive index n and the extinction coefficient κ in the Fresnel formulas for a smooth surface [1] [2].
For opaque materials:

$$\varepsilon = 1 - r \tag{6}$$

The calculated reflectivity data, converted into emissivity values according to (6) are presented in *figure 2.* This figure shows that beyond an angle of approximately 60 ° the emissivity changes substantially. According to equation (5) this is a potential source for errors in temperature measurement.

3. High pressure die casting of aluminium

In high pressure die casting of aluminium, the die surface temperature is a very important parameter to control the product quality and production rate. The rapid heating and cooling cycles during the process may cause thermal cracks in the die, resulting in prints on the

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product. The first aim of the project was to establish the heat balance of the die. To relate surface temperatures to other process parameters like cooling type, on-line temperature measurements of the die surface were performed with a thermal imager, mounted on the caster and continuously taking images from the moment that the die opened until the moment of closing, including removing the product and the spraying sequence of the surface. The thermal imager was protected against radiation during these measurements by insulation blankets. The lens cap of the thermal imager was adapted by adding an air purge to prevent the lens from contamination with dust and oil-water emulsion. *Figure 3* is a typical example of die surface temperatures after removing the product.

Because of the relief of the surface, those parts for which the angle between the camera and the surface exceeds 45 °, cannot generate reliable temperature data, as described in part 2.2. The measurements showed good correlation between the different types of cooling and the die surface temperature. In *figure 4* the temperatures at the same positions as in *figure 3* are shown for three types of cooling. The cooling types mentioned here refer to cooling by means of liquid filled tubes, placed a couple of centimeters behind the die surface.
These measurements have been used as input for the calculation of the heat balance.

4. Temperature distributions on outside of casting ladles.

A casting ladle is a vessel containing approximately 300 tonnes of liquid steel. The steel flows through the taphole into the tundish and the mould. This flow induces extra wear of the refractory around the taphole. Hot spots at the outside of casting ladles are an indication of wear of the refractory, so they must be detected. A measurement was carried out on the bottom of a casting ladle while it was heated at the ladle furnace *(figure 5)*. The taphole is clearly seen on the right side, while the isotherms are concentric with respect to the taphole. This is an indication of extra wear of the refractory around the taphole. This kind of information is useful for planning maintenance schedules and revamp intervals of the refractory.

5. Coke surface temperatures in the quenching car

The temperature of the coke in a coking plant is usually measured by means of a pyrometer pointing at the center line of the quenching car. This temperature is used for controlling the coking chamber. This measurement system does not show how the temperature distribution differs over the whole quenching car. A measurement with a thermal imager provides temperature information of the whole surface of the quenching car. For a practical experiment, the quenching car was devided into five sections over its width and with a thermal imager these sections were scanned to give an indication of the temperature distribution. This experiment was executed for a total of eleven batches.
Figure 6 shows an example of this temperature distribution. The five sections are labelled 1 to 5 and the average temperatures in the five sections are given on the right side of *figure 6*. They show that there is a substantial difference in the average temperature values per section.
The average values per section for the eleven batches have been indicated in *figure 7*, together with the average value of the spotpyrometer. It shows that all five sections follow the trend of the spotpyrometer, but the temperature is not randomly distributed over the quenching car. This is clearly indicated in colour *figure A* , where the same data as in figure 7 is plotted. Section 1 and section 2 indicate low temperatures, whereas section 4 and section 5 indicate high temperatures.
This information is used for conclusions about the spotpyrometer measurement system and about the way the coke falls from the coking chamber into the quenching car.

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6. Conclusions

In conclusion we can say that thermal imaging adds a new dimension to temperature measurement in heavy industry both for research and production purposes.
It is found that care should be taken of measurements on surfaces with changing emissivity and on surfaces with a lot of relief.

REFERENCES

[1] NUTTER (G.D.). - Radiation thermometry-The measurement problem. Richmond (J.C.) and DeWitt (D.P.) ed., Applications of radiation thermometry, ASTM publication 895, 1984, p. 9-14.

[2] WEAVER (J.H.) and FREDERIKSE (H.P.R.). - Optical properties of metals and semiconductors. LIDE (D.R.) ed., Handbook of Chemistry and Physics, 77th edition, 1996, p. 12.126-12.132.

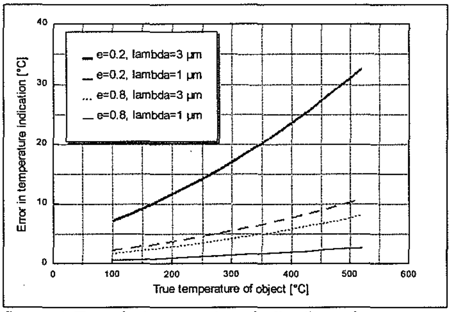

figure 1.Error in temperature indication when $\Delta\varepsilon = +0.05$ for high and low emissivity surfaces and two wavelengths.

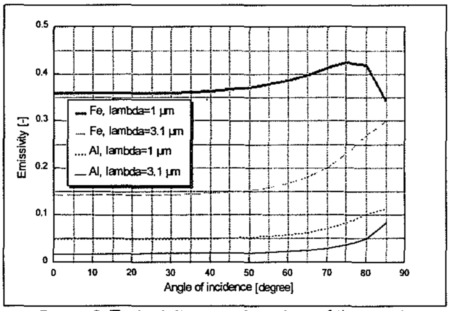

figure 2.Emissivity as a function of the angle of incidence for iron and aluminium.

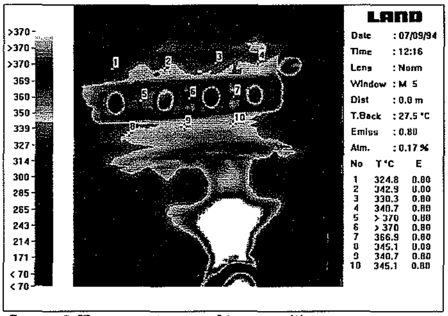

figure 3:Temperatures of ten positions on the die surface.

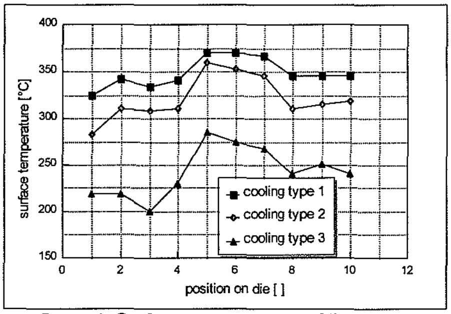

figure 4. Surface temperatures of the die for several cooling types.

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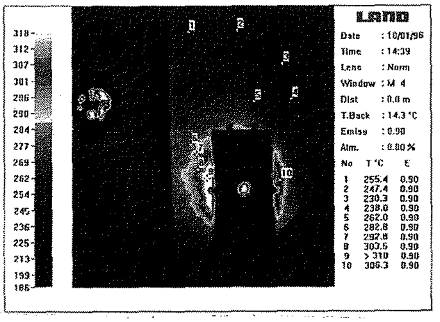

figure 5. Temperatures of the bottom of a casting ladle.

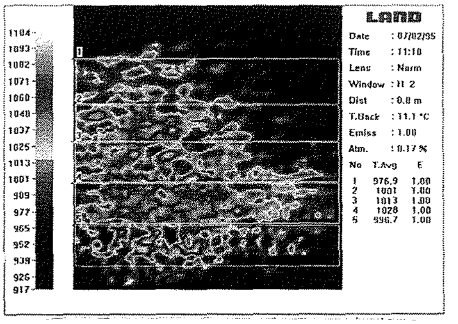

figure 6. Coke surface temperatures in the quenching car and averages per section.

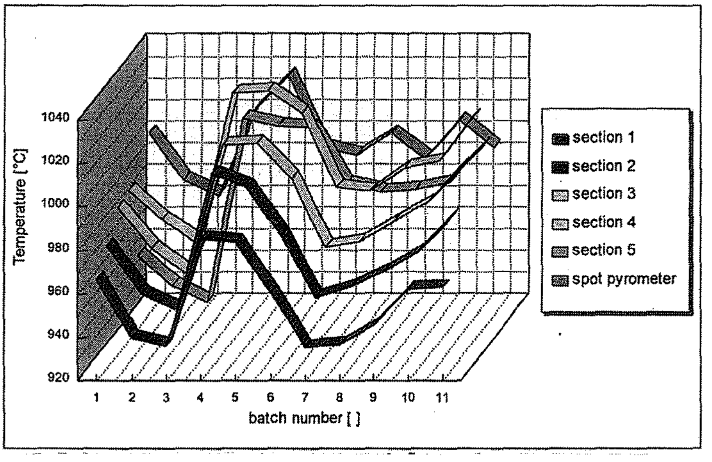

figure 7. Average coke surface temperatures in five sections of the quenching car and spotpyrometer temperature for a total of eleven batches.

Colour figure A

figure A: Average coke surface temperatures in five sections of the quenching car and spotpyrometer temperature for a total of eleven batches.