QIRT 2012

http://dx.doi.org/10.21611/qirt.2012.297

11th International Conference on
Quantitative InfraRed Thermography

Multispectral system for measuring the radiation parameters of steel slag during the discharge of steelworks furnace

by B. Więcek*, K. Pacholski**, T. Świątczak*, W. Wittchen***, M. Borecki***

** Institute of Electronics, Technical University of Lodz, Poland, wiecek@p.lodz.pl*
*** Institute of Electrical Systems Engineering, Technical University of Lodz, Poland, kpacholski@p.lodz.pl*
**** Institute for Ferrous Metallurgy, K. Miarki Street 12-14, 44-100 Gliwice, Poland, wwittchen@imz.pl*

Abstract

This paper presents recently developed a multispectral system for measuring and calculation the chosen radiation parameters of the steel slag for the investigation of FeO content. The system contains 2 infrared (IR) and 2 visual (CCD) cameras. IR cameras capture images in MWIR and LWIR spectral ranges. The visual broad band optical system acquires the images in NIR and visual (RGB) subbands. The short band pass optical filters are used in visual spectral range. CCD RGB camera is used to select the proper wavelength bands in the visual range. The main objective of the research is to define different thermal and optical parameters of the steel slag stream for further image classification and FeO content estimation.

1. Introduction

The chemical content of the steel slag is very important technological parameter during steel production [1-12]. The concentration of FeO together with the basicity of the stag is the basic figure which allows estimating the steel and slag quality. Typically, the content of FeO is now measured off-line by chemical and spectrophotometric analysis. It requires the very stable and repetitive measurement conditions and it is time consuming procedure using the complex mathematical and chemical modelling [5-7]. Recently, the IR thermography has been introduced in steel mills. It is now used to estimate the moment of slag appearance which gives an automatic signal to stop discharging the vat [4-12]. It is relatively simply, as the emissivity of steel and slag differs significantly.

Now, there is a hope the extend the thermography applications in steel production to on-line estimation of FeO content in the steel slag by analysing the visual and infrared images during the pouring out the vat [1-3]. The results of first investigations confirm the possibility of using the multispectral system operating in visual and infrared spectrum starting from 0,5 μm up to 14 μm [3].

2. System configuration

The multispectral and multicamera system has been developed in order to measure and estimate the content of FeO in steel slag. It consists of MWIR, LWIR, NIR and CCD-RGB camera – table 1 and fig. 1. All cameras are connected to the computer using fast USB and Internet links. The cameras are operating in parallel, but recording of the images is asynchronous. After registering the images, the off-line synchronisation is performed. It is done by actual time setting in all computers one day before the measurement session. The appropriate measuring distance was chosen as the compromise between the spatial resolution and safety due to the very high level of IR radiation intensity in the steel mill, and is between 40-70 m from the furnace – fig. 1.

Table 1. Cameras used in the proposed multispectral system

Camera	**Wavelength (μm)**	**Detector**	**Resolution**	**Optics f (mm)/FOV(°)**	**Frame rate frames/s**
MWIR	3-5	InSb cooled	640x512,/14 bits	50/14	25
LWIR	7-14	aSi, bolometer, uncooled	640x480/14 bits	38/24	15
NIR	0.7-1	uncooled with narrow IR filter	640x480/12 bits	50/4	25
CCD-RGB	visible	still image camera	4928x3264/24 bits	55-300/28.5-5.3	4

3. Measuring methodology

As it has been already presented [1-3], the pouring out the steel from the vat ends with the slag. Because the emissivity of the slag is significantly greater then the emissivity of the steel [3], the apparent (radiation) temperature rapidly increases during the final stage of pouring out the metal. The standard procedure for measuring the temperature was worked out in this research. We record the sequence of IR and visual images before the end of discharging the vat, starting when the metal is still pouring out, before the temperature rise. Then by analysing the images, we separate 15 frames before and after the transition between the steel and the slag as it is presented in fig. 2. The parameters are typically calculated as the mean value for all 15 frames.

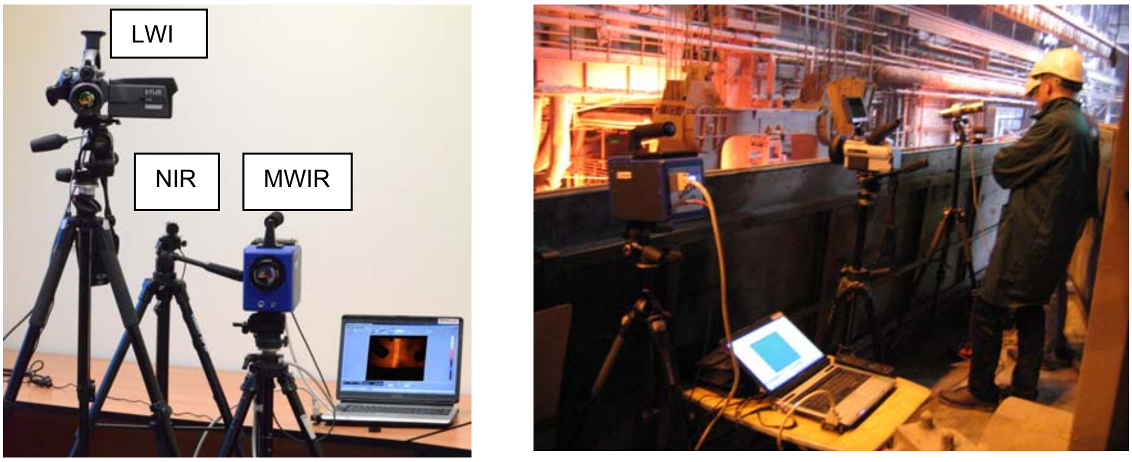


Fig. 1. *(a) Multispectral system developed for steel slag analysis*

Special software is prepared for image capturing from each camera. After image acquisition, an automatic feature extractor is implemented. The software operates in real-time because the slag is only present within the last few seconds of the discharge. The triggering of images' capturing is controlled manually by the experienced operator when the steel is still pouring out. The appropriate frames are selected for calculating the images' parameters as shown in fig. 2.

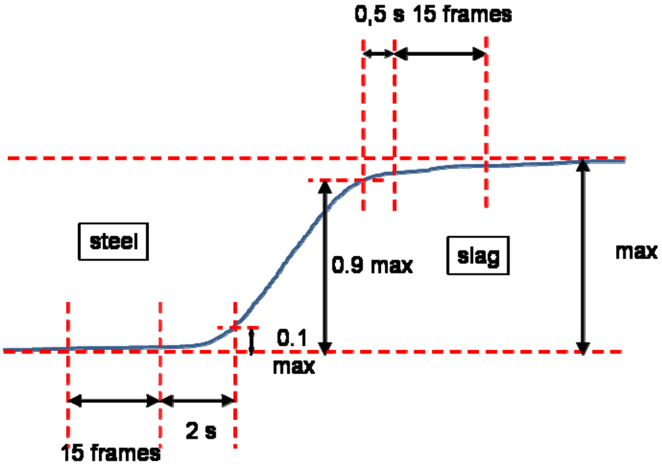
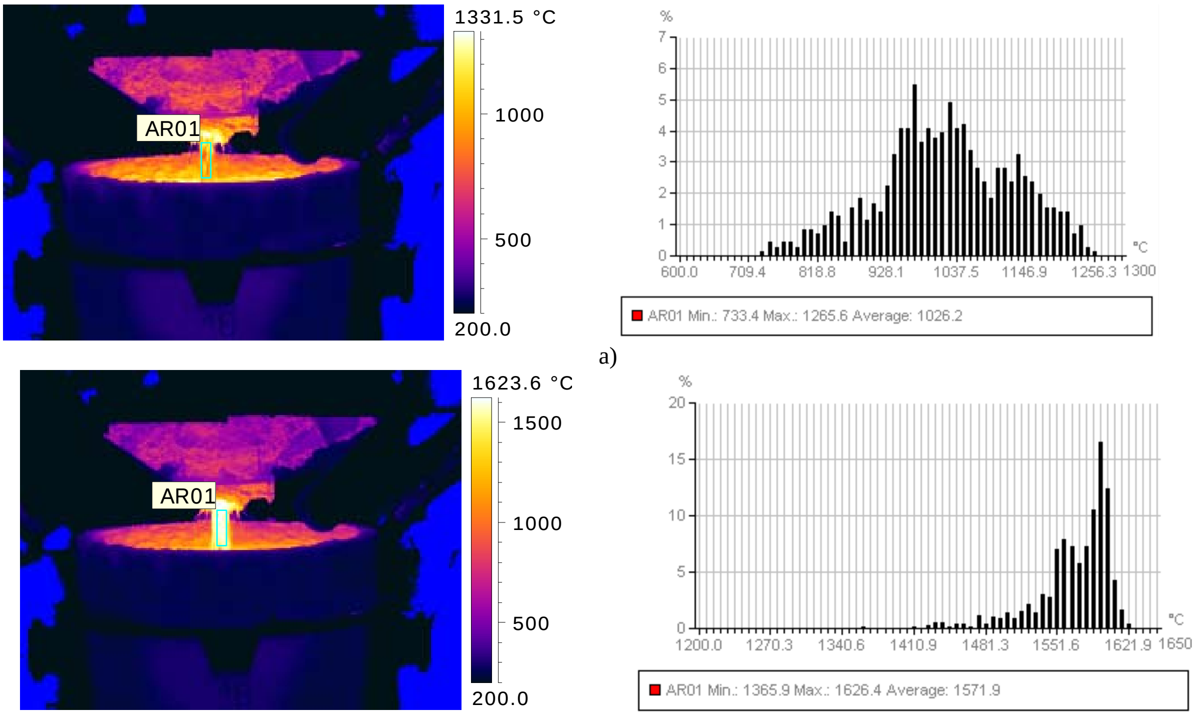


Fig. 2. *Temperature rise as a result of transition between the steel and slag during the pouring out the content of the vat*

4. Preliminary results

An appropriate rectangle-shape region of interest is defined covering the main part of the stream during pouring out the steel and the slag – fig. 3-5. Next, the histogram and other parameters (features) are calculated. Among many of proposed image features, the emissivity, mean value, standard deviation, min and max temperature, as well as the temperature gradient along the steel slag stream are calculated for different spectral bands. We assumed a hypothesis that these parameters correlate with iron (II) oxide (FeO) content in the slag. A neural network is implemented for estimating the iron oxide content in the steel slag. The classification results will be presented in the next papers.

During the preliminary measurements we noticed the high difference of the values of some parameters for steel and slag. Besides of the mean temperature and emissivity that are different for steel and slag, the temperature decay along the stream significantly varies. Low varying temperature characterizes the slag (table 2, fig. 4), for the steel the fluctuation of temperature is much higher. The similar conclusion can be drawn while calculating the standard deviation of for temperature in the region of interest as presented in table 2. One con notice, that in table 2, all values of temperature are apparent temperatures (we call them radiation temperatures), and they were obtained using the default value of emissivity ε=0,95.



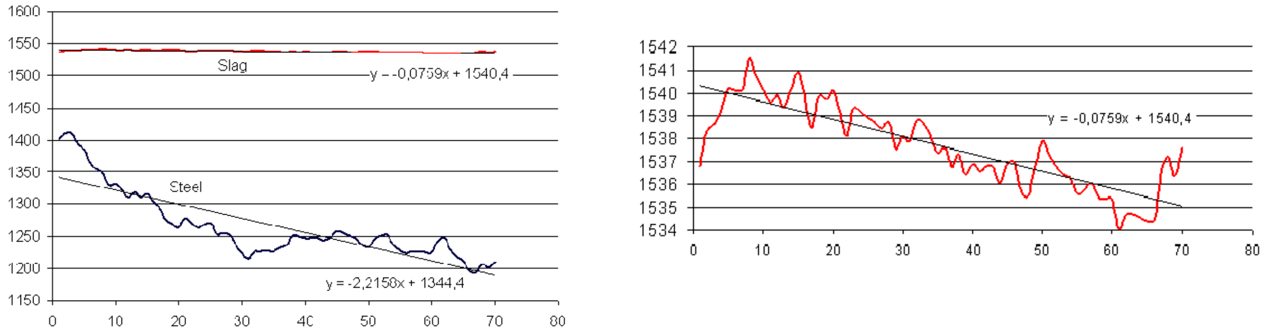
a)

b)

Fig. 3. *IR images and histograms for steel (a) and slag (b), obtained by LWIR (7-14 μm) uncooled, microbolometer camera, reference temperature obtained by contact measurement T=1662 °C*

Table 2. Exemplary values of chosen parameters for MWIR and LWIR thermal images, reference temperature obtained by contact measurement T=1662 °C

Parameter	**Steel**	**Slag**	**Steel**	**Slag**
	LWIR, 7-14 μm,		**MWIR, 3-5 μm**	
Emissivity	0.38 – 0.50	0.86 – 0.88	0.4 – 0.6	0.7 – 0.8
Max. radiation temp.	1265.6 °C	1626.4 °C	1409.0 °C	1541.5 °C
Min. radiation temp.	733.4 °C	1365.9 °C	1193.0 °C	1534.0 °C
Max-min radiation temp.	532.2 °C	260.5 °C	216 °C	7.5 °C
Mean radiation temp.	1026.2 °C	1571.9 °C	1265.7 °C	1537.6 °C
Standard deviation	106.7 °C	37.3 °C	53.3 °C	1.8 °C
Temp. trend	-2.1 °C/pix	-1.1 °C/pix	-2.22 °C/pix	-0.076 °C/pix



a)

b)

Fig. 4. *Temperature trends for MWIR thermal images, a) both for steel and slag, b) for slag only (detailed view)*

Histograms for steel and slag are very different. In particular, the width, shape and position of the histograms are different. It denotes that we could use the well-known first order statistical parameters to distinguish steel and slag precisely [2]. The final goal of the research is to distinguish not only the steel and slag, but the slag with different content of FeO. This challenging task is performed by multivariate statistical analysis using large set of image features obtained in different subbands of the optical and IR spectrum [2].

In fig. 5 one can see the RBG components of the slag CCD image. The blue part has relatively low intensity, and it has no practical application. Two other bands (RG) seem to be very useful for feature extraction. The histograms (fig. 5) are not symmetrical and not overlapping. This facts can be used for quantitative differing the chemical content of the slag.

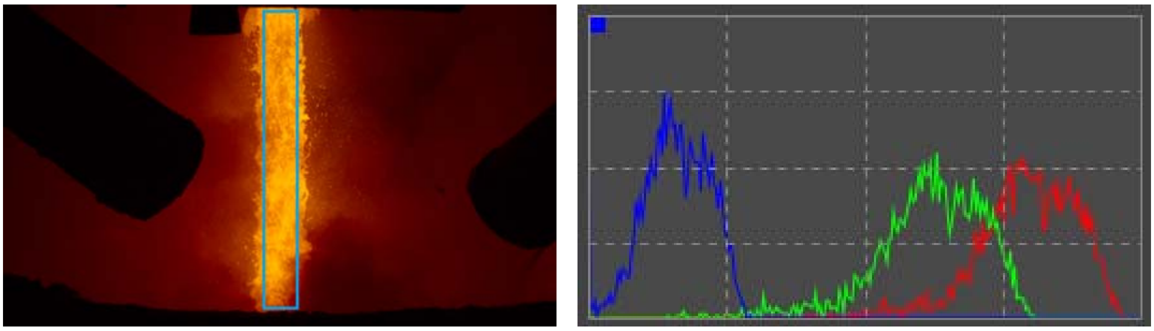


Fig. 5. *Visual image and RGB component histograms for a chosen region of interest for the slag*

5. Conclusion

In this paper we have presented the multispectral system dedicated for analyzing the chemical content of steel slag. The preliminary results are shown for IR medium and long wavelength spectrum ranges, as well as for visual subband which is divided into narrow RGB wavelength regions. In this phase of the research we confirmed that multispectral image feature analysis can easily be used for separating the steel and slag. The main research goal is to estimate the FeO content in the steel slag and it will be next step. Having the multispectral system ready for using in steel mill, we need to perform many measurements in order to confirm its useness statistically. The first attempt has been already done, however to have the statistically valid practical tool one needs to have at least 50 measurements of the slag with different content of FeO. This challenging task has to be done soon with the close cooperation with the steel making factory. We believe that using learning system (neural network) performing multivariate statistical classification, we will be able to estimate the content of FeO in the steel slag.

REFERENCES

[1] Więcek B., Świątczak T., Olbrycht R., Wittchen W., Borecki M., Badanie emisyjności żużla stalowniczego w zakresie podczerwieni MWIR i LWIR, Pomiary Automatyka Kontrola, 2009, No.11, pp. 914 – 917, (in Polish).
[2] M. Wiecek M., Strakowski R, Więcek B., Olbrycht R., Świątczak T., Wittchen W. Borecki M., Estimation of steel slag parameters using thermal imaging and neural networks classification, 10th International Conference on Quantitative InfraRed Thermography, QIRT2010, Quebec, Laval University, 2010 – Canada.
[3] Pacholski K., Więcek B., Wittchen W., Borecki M., Wyznaczanie parametrów promiennych żużla stalowniczego do oceny jego właściwości metalurgicznych, Pomiary Automatyka Kontrola, 2011, No. 10, pp. 1245 – 1248, (in Polish).
[4] IR remote slag identification at tap, Steel Times, 1999, vol. 227, No. 11, pp. 415.
[5] Zahorszki F., Specht V., Schlackenerkennung auf Infrarotbasis mit einem Schlackedektions-system, Stahl u. Eisen, 1999, vol.119, No. 11, pp. 61-63.
[6] Zachorszki F., Specht V., Slag detection by means of infrared technology, MPT Internacional, No.1, 2002, 46-47.
[7] Goldstein D.A., Sharan A., Stofanak J.A., Infrared Imaging for BOF Slag Detection, Iron a. Stelmaker, 2000,vol.27, No. 7, 2000, pp. 31-38.
[8] Enker B., Paster A., Schwelberg J.: New slag stopping system for oxygen converter steelmaking, MPT International, No. 3, 2001, pp. 40-45.
[9] Rau H., Ropenacki I., Thermographische Schlackenerkennung in der Anwendung, Stahl und Eisen, No. 11, 2001, pp. 53-56.
[10] Rau H., Ropenacki I., Application of thermographic slag detection, MPT International, No. 1, 2002, pp. 52-55.
[11] Bors M., Ortelt P., A new infrared – camera method of gate – unit control during converter tapping, Steel Times Internacional, No. 3, 2002, pp. 19-20.
[12] Bors M., Ortelt P., IRIS, un nouveau systeme de controle de l' obturateur du tru de coule des convertisseurs, La Reuve de Metallurgie-CIT, Janvier, 2002, s. 41-48.