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Reduction of Irradiation Level for Personnel Working in a Steel Furnace Using NMG Method

Constantin Gheorghies[1, *], Simona Condurache-Bota[1], Geta Carac[1], Paula Cojocaru[2], Lucian Puiu Georgescu[1], Catalina Iticescu[1], Anotoaneta Ene[1]

[1]Chemistry, Physics and Environment Department, Dunarea de Jos University, Galati, Romania

[2]Politenico di Milano, Dip. Chimica, Milano, Italy

Email address:

cgheorg@ugal.ro (C. Gheorghies)

[*]Corresponding author

Abstract: The humidity of coke introduced into furnace used for preparation of cast-iron plays an important role in development of metallurgical processes. More that its importance results from the necessity to optimization of the energy consumption in the furnace. Therefore, the quick, precise, and in situ measurement of the humidity of coke is necessary and a decisive process in cast-iron preparation. In this aim, the nuclear moisture gauge (NMG) method is successfully used. Two main issues appear in this case. First of them concerns to the NMG calibration and second refers to get rigorous results. The last aspect is linked of the corrections have to be made for the density measurements of coke, during performing of a NMG measurements occurring into continuous flow. During humidity measurements it is necessary to take into consideration of the irradiation level of the workers performing calibration and moisture measurements implied by the NMG. The paper reveals and discusses the results concerning the use of the NMG technique without automatic density correction as compared to the NMG technique which users the automatic density corrections. The humidity of coke used in furnaces was monitored for several months by using both techniques and their results are compared. The linear dependence between the NMG indications and coke humidity is not influenced of the coke granulation. It is concluded that the NMG without automatic density correction gives as good results as the more complicated, much more expensive and, mainly, more radiation exposing of workers NMG method with automatic density correction.

Keywords: Coke, Moisture, Neutrons, Gamma Ray, Radioprotection

1. Introduction

The humidity of coke is an essential parameter when using it during the metallurgical processes. The humidity values of coke depend on its granulation and on its porosity. The classical chemical moisture analysis has proven to have inconsistency in sample selection and to be time-consuming as compared to the continuous flow processes occurring inside a furnace. Instead, the Neutron Moisture Gauge (NMG) method is fast and reliable for performing measurements of the humidity of coke right inside the furnaces where the coke is used [1-7]

The NMG method implies sending fast neutrons from a radioactive source (such as Am-Be having an activity of 11.1 GBq) to interact with a material containing hydrogen nuclei. Thus, the coke, containing water, it will contain hydrogen nuclei. The inelastic scatterings of the neutrons occur, which will decrease their energy [8, 9]. As a result, backscattered thermal neutrons will appear whose flux is detected and measured. The neutrons flux and, inherently, the magnitude of the electrical signal obtained from the detection unit will indicate the concentration of hydrogen atoms in the investigated volume. If the number of hydrogen nuclei within the analyzed sample varies only because of humidity

variations, then the detected signal from the backscattered neutrons will indicate the total volumetric humidity of the sample.

The NMG indicates the mass moisture, H_m, defined as the kilograms of water contained in 100 kg of material. Another parameter that can be used to express the humidity is the volume humidity H_v, meaning the volume of water, expressed in m^3 contained in $100\ m^3$ of material.

The NMG can be calibrated in units of mass humidity if the density of coke stays constant within the bunker or if the NMG device is equipped with a gamma ray source that "corrects" for the density variations. But, in this case, higher radiation exposure of workers and higher costs are implied [10]. Bulk density is an indicator of coke compaction. It is calculated as the dry weight of coke divided by its volume. This volume includes the volume of coke grains and the volume of pores among coke grains. Bulk density is typically expressed in g/cm^3.

Also, one has to take into consideration that the NMG indications are influenced by several parameters, such as: type of detector, wall material of the depth neutron probe, source-detector geometry, the thickness and nature of the material used as protection wall for the depth neutron probe and the volume of the material that must be investigated [4, 5, 7, 11, 12, 13]. Thus, considering the last parameter, an *influence sphere* must be defined, whose radius depends on the volumetric humidity H_v of the investigated material according to the following formula:

$$R = 69.62 \cdot \frac{1}{\sqrt[3]{H_V}}\ [\text{cm}] \qquad (1)$$

If the investigated volume is bigger than the "influence sphere", then its size will not influence the NMG indications [11, 12].

2. Experimental

The neutron-based moisture measurements are successfully used not only in the Iron and Steel Industry, but also in the Glass Industry, Cement and Ceramics Industry, Chemical Industry and also into the Coal Industry itself. It is a fast and reliable method, being able to be employed in continuous flow processes for feed-back control of the humidity of the implied materials. It can be easily attached on existing tanks, bunkers or even conveyor belts. Figure 1 presents a NMG device attached on the wall of a bunker, the round shape representing the influence sphere as compared to the size of the neutron-based device. In this figure the numbers stand for: 1 - scales bunker fed with coke (2) by a running belt 3; 4 – running belt which collects the material evacuated through the trap 5; 6 – NMG device, containing the neutron source, the thermal neutron detector, an amplifier and a recorder or an interface with a computer 7.
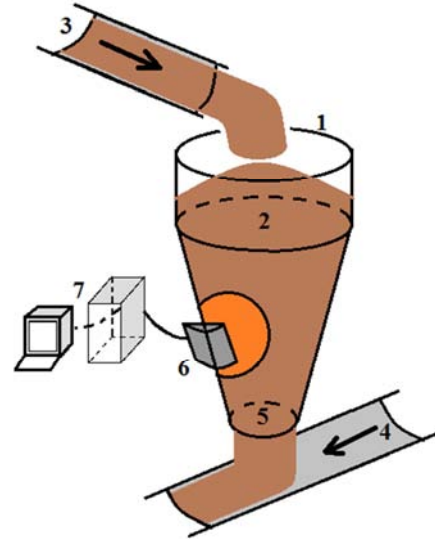

Figure 1. *NMG device attached to the bunker's wall to perform humidity measurements in continuous technological flow [13].*

Figures 2 and 3 present the block schemes of the two possible types of NMG devices: the first one, given in figure 2, does not provide for automatic density correction, while the second one, represented in figure 3 is equipped with automatic density correction device, implying the use of a gamma-ray source (Cs-137, having an activity of 1.11GBq, near the neutron source, as used for the 1st type of NMG. The NMG with automatic density correction is much more complicated and expensive and it submits the worker to a higher irradiation risk than the NMG without automatic density correction. In the first case the higher risk is given by presence a gamma ray source which contributes to growth of total level of radiation during manipulation of NMG probe due to various causes as: changing of protective metallic sheath, calibration, modification of measuring position etc.
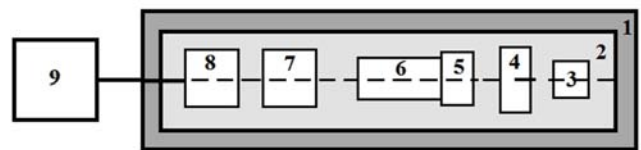

Figure 2. *Scheme of a NMG device without automatic density correction.*

(1 - protection case; 2 - neutron probe body; 3 – fast neutron source; 4 – protection screen; 5 - scintillating crystal; 6 - photomultiplier;7 - preamplifier; 8 - amplifier; 9 - humidity recorder)
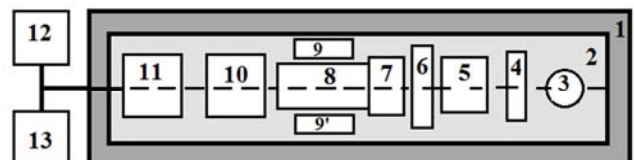

Figure 3. *Scheme of a NMG device with automatic density correction.*

(1 - protection case; 2 - neutron probe body; 3 – gamma ray source; 4 – protection screen; 5 – fast neutron source; 6 – screen; 7 - scintillating crystal; 8 - photomultiplier; 9 – gamma ray detector; 10 -preamplifier; 11 - amplifier; 12 - humidity recorder; 13 - density meter)

Until recently, the use of NMG implied the necessity of a preliminary laborious, expensive and rather dangerous calibration, called the gravimetric method. Such a technique is capable to evaluate the humidity by the use of a few coke samples, but it leads to modest calibration precision and does not allow for NMG measurements in continuous flow.

A fast and cheaper calibration method for the NMG is based on the preparation of some special calibration samples, made of cylindrical containers filled with dry sand, having in its middle a protection scabbard for the introduction of the depth neutron probe and several plastic tubes with various diameters, which are distributed in concentric circles inside the container. These tubes are filled with paraffin bars that can be inserted or taken out of the container. Thus, by changing the number of such bars inside the calibration cylinder, different indications of the NMG can be obtained and a calibration curve can be plotted [4].

3. Results and Discussions

In order to study the influence of the coke's granulation, G, on the NMG indications two sizes of coke were obtained from the technological flow by riddling and then it were introduced in the calibration bunker: 1) coke having $20\,mm \leq G \leq 40\,mm$ and 2) coke having $G \geq 60$ mm.
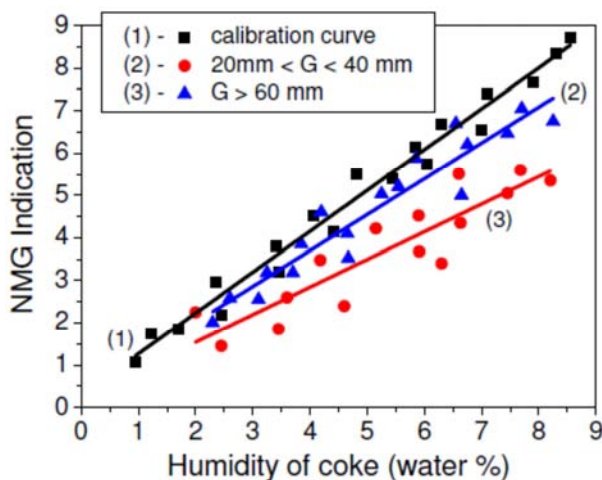

Figure 4. *NMG indications versus coke's moisture for different coke granulations.*

Figure 4 presents the plot of the NMG indications versus

coke's moisture determined by the gravimetric method both for the two categories of coke mentioned above and for the calibration curve.

It can be noticed that there is a linear dependence between the NMG indications (denoted by "y") and the humidity of coke (expressed as "x" variable, in percentage of water content in the analyzed sample):

$$y = a + b \cdot x \qquad (2)$$

Table 1 contains the data resulted from the linear fit of the plots in figure 4. It can be noticed from Table 1 that the linear fit parameters "a" and "b" are similar for the two types of coke granulations as compared to the calibration data.

The two types of NMG devices types - with and without automatic density correction - were tested and monitored simultaneously in the furnace for several months and the results are presented in Figure 5.
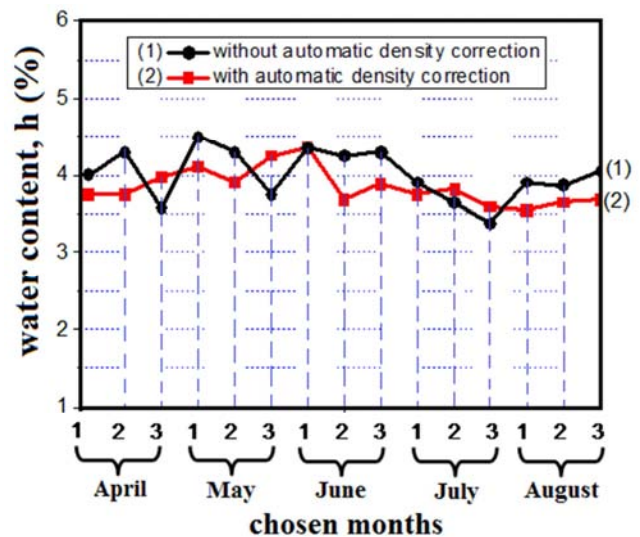

Figure 5. *Evolution of the average coke's moisture measured with the NMG method during 5 consecutive months.*

The granulation of the coke was also measured and monitored during the same time frame, leading to values around 36 mm for the average coke diameter. As compared to this value, when monitoring daily the coke's diameter during the whole month of July, values between 36.5 mm and 40 mm for were obtained.

Table 1. *Data from the linear fit of the NMG indications versus coke's humidity for the calibration curve and for the two types of analyzed coke granulations.*

Type of plot	Intercept, a	Slope, b	Standard error for the intercept, a	Standard error for the slope, b
Calibration curve	0.30047	0.96385	0.17986	0.03364
NMG=f(h) for $20\,mm \leq G \leq 40\,mm$	0.23823	0.65089	0.48246	0.0854
NMG=f(h) for $G \geq 60\,mm$	0.3159	0.84645	0.35976	0.0663

The main aspect which can be noticed from figure 5 is that there are insignificant differences between the results given by two types of NMGs. The water content, h, expressed in percent from the analyzed coke varies slightly between 3.35 % and 4.5 %, being somewhat smaller during August, which

was the hottest monitored month.

4. Conclusions

The NMG method allows for the determination of all

water molecules in virtually any type of material. The NMG performed without automatic density correction gives comparable results as the one with automatic density correction for measuring the humidity of coke during the continuous flow siderurgic processes. Thus, NMG without automatic density correction is more recommended, not only because of its simpler electronics, easy to do calibration and lower price, but mainly because the irradiation risk upon the steel workers is decreased and the radioprotection expenses are much diminished than for the NMG with automatic density correction.

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