An neutron generator-based NIPGA system for on-site analysis

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Abstract Utilizing NIPGA, an experimental device for cement raw material analysis has been developed, with a 2.5 MeV D-D neutron generator, BGO detector and 2048 MCA. A linear regression was developed for calculating the data. A 6-month on-site application of the system showed that the CaO, SiO_2, Fe_2O_3 and Al_2O_3 analysis results agreed well with chemical analysis, within 0.40%, 0.40%, 0.50% and 0.50%, respectively.

Key words D-D neutron generator, Cement raw material, Detection, Development of device

Neutron-induced prompt gamma-ray analysis (NIPGA) for elemental contents of cement or coal is advantageous in terms of short analysis time and high accuracy[1–6]. Radioisotope neutron source and HPGe detector are often used in NIPGA, such as the neutron activation analyzer developed by the US Gamma-Metrics Co., with a ^{252}Cf neutron source. This is advantageous in stability of neutron flux and easy operation, but it is not convenient to store and transport the source, which decays in a half-life of 2.645 y. An HPGe detector costs more, though it has higher resolution. Its need of liquid nitrogen hinders on-site applications.

Studies have been carried out in China for alternate approaches in this regard[7–9]. A cement raw material analysis system has been developed at Radiation Technology Institute (RTI), Northeast Normal University, with a 2.5 MeV D-D neutron generator and a BGO γ-ray spectrometry system. A linear regression code is used for data analysis.

The 2.5 MeV neutrons react with the nuclides of interest in (n, γ) thermal neutron capture reactions. The γ-rays are detected by the BGO detector and analyzed in an MCA. Net area (N) of a γ-ray peak can be calculated by Eq.(1),

$$N = GN_L\Phi\sigma\varepsilon j\alpha t/A \quad (1)$$

where, G is the elemental content per unit volume, N_L is the Loschmidt constant, A is the atomic number of the element, Φ is the neutron flux, σ is cross section of the reaction, ε is the γ-ray detection efficiency, j is quantum yields of the γ-ray, and α is the isotopic abundance. And G and N can be related by Eq.(2),

$$G = pN + q \quad (2)$$

where, the coefficients of p and q can be determined experimentally. According to elemental analysis by Eqs.(1) and (2), CaO, SiO_2, Fe_2O_3 and Al_2O_3 contents of the cement raw materials can be obtained. Schematically, Fig.1 shows the analytical system consisted of the D-D neutron generator, neutron shield, γ-ray spectrometer, and sample container.

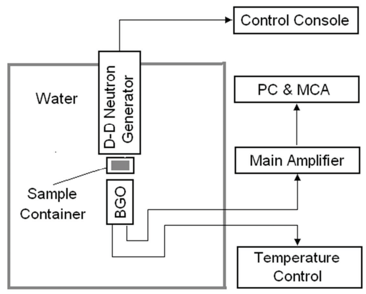

Fig. 1 A schematic diagram of the experimental device.

The neutron yield of D-D neutron generator is 5×10^6 n/s. The Φ76 mm×76 mm BGO detector, from Shanghai Institute of Ceramics, Chinese Academy of Sciences, is of high γ-ray detection efficiency, and inexpensive, without the need of neutron shielding, unlike an HPGe detector. But conversion efficiency of

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BGO scintillation is affected by temperature, causing drift of the γ-ray peaks, hence the need of a cooling system to control temperature at –4 ~ 4°C, so as to keep the peak positions in good stability. The MCA of 2048 channels was provided by Shanghai Institute of Applied Physics, Chinese Academy of Sciences.

The neutron shield is 30-cm thick water, which was determined in experiments to meet the radiation protection requirements but not disturb measurement of the samples. The sample container is made of polyethylene of 20 cm×20 cm×18 cm. The system also includes a control console and a sample conveyer.

A powder sample collected from cement raw materials is weighed with the container, and moved by a conveyer to the detection chamber, where it is bombarded by the neutrons for 900 s to obtain the γ spectrum. The software calculates the net peak area of each nuclide of interest and mass percentage of CaO, SiO_2, Fe_2O_3 and Al_2O_3.

Fig. 2 is a typical γ-ray spectrum of the sample. The spectrum height right to the dotted line is enlarged by 20, and the net peak areas for calculating different nuclides are given in Fig.1.

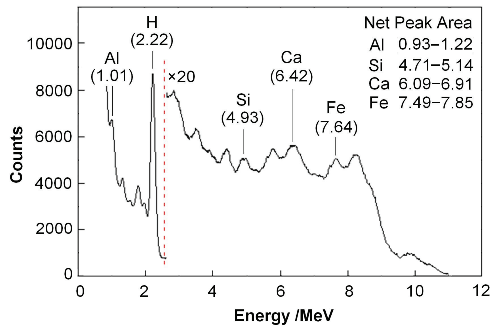

Fig.2 Gamma-ray spectrum of cement raw material.

Based on analysis of standard samples, a linear regression was established for calculating masses (in g) of CaO (m_{ca}), SiO_2(m_{si}), Fe_2O_3(m_{Fe}) and Al_2O_3 (m_{Al}) in the sample,

$$\begin{aligned} m_{ca} &= 22.6452A_{ca} - 7.3438 \\ m_{si} &= 40.4237A_{si} - 16.7896 \\ m_{Fe} &= 18.5619A_{Fe} - 4.6237 \\ m_{Al} &= 49.2465A_{Al} - 23.8254 \end{aligned} \quad (3)$$

where, A_{ca}, A_{si}, A_{Fe} and A_{Al} are net peak area of Ca, Si, Fe and Al, respectively. Table 1 shows the analytical results of the samples by the system, together with the results of chemical analysis. The data were averaged from ten measurements of each sample.

Table 1 Analytical results (in %) by the NIPGA system and chemical analysis. The data and SD were obtained from 10 measurements of each sample.

Oxides	This system	Chemical analysis	Deviations
CaO	39.52±0.24	39.72±0.17	–0.20
SiO_2	11.53±0.18	11.34±0.14	0.19
Fe_2O_3	2.82±0.15	2.59±0.16	0.23
Al_2O_3	3.24±0.11	3.41±0.15	–0.17

A 6-month on-site analysis of the raw materials with the system was performed at Xin Yu Cement Co., Ltd in Dehui. The system worked reliably and safely. Results of the on-site analyses of CaO, SiO_2, Fe_2O_3 and Al_2O_3 agreed well with chemical analysis, within 0.40%, 0.40%, 0.50% and 0.50%, respectively.

Before its industrial application, the NIPGA system shall be improved. First, the neutron tube shall have a longer service life, from about 3,000 h to over 6,000 h, which is a target at RTI in developing better neutron tubes. Second, stability of the D-D neutron generator shall be improved. A new circuit system to modulate high voltage and beam current of the neutron tube is under research. Finally, the neutron generator can be in better service with increased γ-ray detection efficiency.

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