

# Energy X-ray fluorescence and its application in iron ore

Xiaofeng Ji

School of metallurgy and ecological engineering, University of science and technology Beijing,  
Beijing 100083, China

## Abstract

**This paper mainly introduces the application of X-ray fluorescence(XRF) in iron ore, the basic principle of X-ray fluorescence spectrometry, the sample preparation method and analysis method of EDXRF in iron ore analysis, as well as the application development and future prospect of EDXRF in iron ore.**

## Keywords

XRF; EDXRF; Iron ore.

## 1. Introduction

With the rapid development of iron and steel industry and the rapid development of research and application of iron ore, there is an urgent need for an analytical method that can accurately and quickly determine various elements in rare earth products. X-ray fluorescence spectrometry (XRF) has the characteristics of simple spectral line, less interference and good stability. It has become an important means of rare earth element analysis. EDXRF is widely used in all aspects because of its short analysis time and low cost.

## 2. Application of EDXRF in iron ore

With the development of science and technology, especially the rapid progress of data processing technology, all kinds of analytical instruments are moving towards intelligence, miniaturization and portability. As an important raw material of iron and steel industry, iron ore plays an important role in the national economy. The world is rich in iron ore resources, but the global distribution is uneven. The identified rich iron ore resources are mainly concentrated in Australia, Brazil, India, Guinea, South Africa and other countries. Although China's iron ore output continues to grow, most of them have low grade and few rich ores, which can not meet the demand of China's iron and steel production. Therefore, China attaches great importance to the exploration, import and intensive and economical utilization of high-grade iron ore resources. With the continuous development of modern steel-making industry, the requirements of blast furnace ironmaking on raw materials are also increasing. Blast furnace ironmaking not only has certain requirements on the grade of ironmaking raw materials(TFe), but also has high requirements on elements such as Ca, Si, Al, Mg, S and P. Therefore, how to accurately measure the content of various elements in sinter has become one of the factors to improve the quality of sinter. Traditional iron ore analysis usually adopts wet analysis, which has long analysis cycle, cumbersome operation and high cost. With the development of X-ray fluorescence spectrum analyzer and detection technology, XRF has been widely used in the detection of iron ore with its fast, effective, accurate and highly automated multi-element analysis method.<sup>[1-3]</sup> In recent years, the application of EDXRF instrument in multi-element analysis of iron ore has started. Good results have been obtained by using powder tablet to determine multi-elements including iron in iron ore. This result is of great significance. EDXRF is faster, more economical and more convenient than WDXRF. It may be a good start for rapid on-site analysis of iron ore.<sup>[4,5]</sup>

### 3. Basic principle of XRF spectral analysis

The detection principle of X-ray fluorescence spectrometry is that the absorption of X-ray intensity of the tested sample changes with the properties and content of the tested components in the sample, which is used as the basic basis for qualitative or quantitative analysis. The nucleus and the electrons moving at high speed outside the nucleus together constitute the stable phase state of the atom. The extra nuclear electrons of different elements run on their own fixed orbits with their own unique energy. When the primary X-ray with sufficient incident energy irradiates the sample to be tested, the electrons in the k-layer, L-layer and other inner layers of the atom obtain sufficient energy, so as to break free from the bondage of the previous orbit and release, so the electron shell generates a corresponding electron vacancy, and the electrons on the high-energy electron shell will transition to fill the electron vacancy. The energy of different electron shells of an atom is different, and the energy of the electron shell farther away from the atomic nucleus is also greater. After the electron transition, the energy is released in the form of X-ray fluorescence, which is equal to the energy difference between the electron shells. The schematic diagram of X-ray fluorescence generation is shown in Fig1.

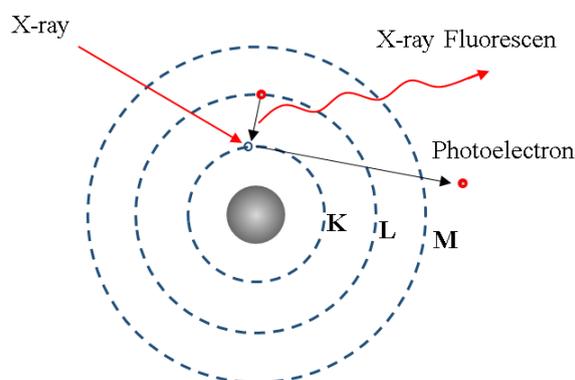


Fig1. Schematic diagram of X-ray fluorescence generation

The intensity of X-ray fluorescence of different elements is not only closely related to the energy and intensity of the excitation source, that is, the intensity of X-ray fluorescence increases with the increase of X-ray tube voltage, but also related to the content of the element in the measured sample. This is the theoretical basis for quantitative calculation of elements, so as to establish the quantitative relationship model between XRF spectral intensity and element content. Quantitative analysis is a method to establish a mathematical model based on statistical data, and use the mathematical model to calculate the indexes and values of the analysis object.

### 4. Principles of qualitative and quantitative analysis

In 1913, the famous British physicist mosele studied the properties of characteristic X-ray fluorescence emitted by different elements on the basis of his experimental results, and determined the relationship between characteristic X-ray fluorescence frequency and atomic number of elements, that is, characteristic X-ray frequency of each element( $\nu$ ) It has a specific relationship with its atomic number( $Z$ ), as shown in formula(1). This is the famous "Moseley's law", which shows that the characteristic X-ray spectrum of elements in XRF spectral analysis can be used as a kind of fingerprint identification information.<sup>[6]</sup>

$$\sqrt{\nu} = Q(Z - \sigma) \quad (1)$$

Where  $\nu$  is the frequency of characteristic X-ray fluorescence,  $\nu=1/\lambda$ ,  $Q$  is a constant,  $Z$  is the number of charges,  $\sigma$  Is the shielding constant,  $(z-\sigma)$  is the concept of effective charge number.

Each element has its own series of characteristic X-ray fluorescence spectra, such as  $K_{\alpha}$ 、 $K_{\beta}$  or  $L_{\alpha}$ 、 $L_{\beta}$ 、 $L_{\gamma}$ , etc. The relative positions of K-series and L-Series spectral lines are qualitatively analyzed. At the same time, the relative content of the element can also be calculated according to the fluorescence intensity of the element characteristic peak. The irradiation rate intensity of the element characteristic spectral line in the sample will increase with the increase of the content. The relative content of the element( $I_i$ ) can be obtained by calculating the irradiation rate intensity( $I_i$ ) of the characteristic spectral line in the component( $\omega_i$ ), formula(2) is as follows:

$$I_i = \frac{K_i I_{i0}}{\mu_0 + \mu_x} \cdot \omega_i \quad (2)$$

Using XRF for quantitative analysis, sample preparation and data processing will directly affect the accuracy and accuracy of element quantitative analysis. Particle size effect and mineral effect are two important aspects of matrix influence in XRF analysis. Appropriate sample preparation method can improve the accuracy of element quantitative analysis. For iron ore, the common sample preparation methods include melting sample preparation method and powder tablet preparation method.

#### 4.1. Melting sample preparation method

The sample is melted and diluted by melting method, and the glass sample is prepared, which can effectively eliminate the influence of mineral and particle effect in fluorescence analysis, reduce the influence of matrix, and greatly improve the accuracy of fluorescence analysis.<sup>[7,8]</sup> Gao Xinhua et al.<sup>[9]</sup> used mixed flux melting to prepare samples, proposed for the first time to use Co as the internal standard of TFe and the empirical coefficient method to correct the matrix effect, and analyzed the primary and secondary elements in a variety of iron ores. The analysis results show that the method used is reliable, but the relative standard deviation of TFe element is still large. In 2000, Liang Pengshan et al.<sup>[10]</sup> used a single reagent  $\text{Li}_2\text{B}_4\text{O}_7$  to melt the sample with the same dilution ratio, but improved the adding method of Co powder. The original direct adding method was changed to melting the flux and high-purity cobalt oxide powder in the ratio of 10:1, then crushing it into uniform powder, and then adding it, which solved the problem of poor reproducibility of the sample. Using ARL9400 single channel scanning instrument, The feasibility of correcting matrix effect by Co internal standard and empirical coefficient method is verified again, and satisfactory results are obtained. Wang Dequan<sup>[11]</sup> used a single reagent  $\text{Li}_2\text{B}_4\text{O}_7$  to melt the sample, the dilution ratio was 1:10, and the Fe element selected RHC line as the internal standard and the empirical coefficient to correct the matrix effect. The method experiment of iron concentrate powder was carried out on panaco PW4400 instrument, which also achieved satisfactory results and met the requirements of daily analysis of metallurgical enterprises.

#### 4.2. Powder compression sample preparation method

For many years, the analysis of elements in geological materials has been based on powder tablet preparation.<sup>[12-15]</sup> In 1990, Xu Chengmin et al.<sup>[16,17]</sup> first discussed a new method for the determination of primary and secondary elements of imported iron ore by using powder tablet preparation and XRF. Through the reproducibility test of the fusion sample preparation and powder compression sample preparation of Hamersley iron ore samples with different particle sizes, it is found that the non-uniformity of fusion still exists, while the standard deviation of the 200 mesh sample compression sample preparation is similar to that of the fusion preparation. the same. Therefore, it can be considered that samples above 200 mesh can meet the precision requirements of chemical analysis and testing. In 2017, Qi Yun<sup>[18]</sup> and others conducted the sample particle size test again. After tablet preparation, the main element TFe was used as an example for XRF measurement. After chemical method verification, after the sample particle size was less than 0.074mm (200 mesh), the results were stable and stable.

close to the sample comparison results. In this study, the influence of the absorption enhancement effect between elements was eliminated by the method of matrix correction. Once the method is established, the sample pretreatment is simple, the analysis period is short, and multiple elements are determined simultaneously, which is especially suitable for iron and steel enterprises that require a large number of samples to analyze and fast analysis speed. Shi Lihua<sup>[19]</sup> and others discussed the application of X-ray fluorescence spectrometry in the analysis of iron ore in my country, and the determination process and matrix calibration of the powder tablet method, the selection of the type of flux in the melting method, the amount of flux added and the internal standard elements. selection is discussed. In 2014, Min Hong<sup>[20]</sup> conducted a comprehensive analysis and elaboration on the current detection methods of TFe content in iron ore, including chemical analysis method, instrumental analysis method and microtitration method, and analyzed the determination of TFe content in iron ore. The development and improvement of the commonly used instrumental analysis method and X-ray fluorescence spectrometry provides a reference and basis for the further development and improvement of the new method for the detection of TFe content in iron ore. This shows that for the simultaneous analysis of multi-elements of iron ore, the application research of powder tableting method also has a good application prospect.

## 5. Processing of data

The initial X-ray fluorescence quantitative analysis mainly used experimental calibration methods, mainly including internal standard method, external standard method, incremental method, scattering line standard method, direct measurement of mass attenuation coefficient, etc. However, with the continuous progress of industrial technology and the expanding measurement requirements, these methods can no longer meet the needs of scientific and technological development. And because of the emergence and popularization of computer technology, it also provides a good foundation and conditions for the processing of experimental data and the study of matrix correction mathematical models. Among them, the more important methods are Beattie-Brissey equation, Lachance-Traill equation, Lucas-Tooth equation, Claisse-Quintin equation, de Jongh equation and Rasberry-Heinrich equation.<sup>[21-23]</sup> In recent years, a variety of algorithms have been developed for the analysis of energy spectrum, such as genetic algorithm, neural network, wavelet analysis, Kalman filter, Mento Carlo simulation, intelligent expert system, etc., which have been used in fluorescence spectrum analysis.<sup>[24-26]</sup>

### 5.1. Filtering

Due to the inherent statistical fluctuations in rays and detectors, and the influence of electronic noise, the spectral data obtained by the instrument has a lot of noise. In severe cases, weak peaks may be lost, false peaks or peak net area errors during peak searching. Therefore, the spectral line smoothing method must be used to remove or suppress these noises, and it is required that the smoothed spectral lines retain various features in the spectral lines before smoothing as much as possible, and the shape and area of the peaks should not change too much. The most direct method is the moving average method, which replaces the count value of the channel with the average value of the channels on both sides of a channel. This method, although simple, can sometimes lead to waveform distortion. Savitsky-Golay polynomial filter is another classic denoising algorithm, based on the idea of polynomial fitting, its biggest advantage is that it can maintain the characteristic signal of the original signal, such as the maximum and minimum values. Azami<sup>[27]</sup> processed the fitting data and experimental data respectively with these two methods, and found that there is no phenomenon of spectral peak drift after denoising. Although the moving average method is simple and fast, the smoothing effect is not as good as that of the Savitsky-Golay filter. Using the Savitsky and Golay polynomial

least squares method for spectral line smoothing requires appropriate selection of the number of points on both sides of the processing point and the degree of polynomial, which requires high data processing experience, and too many smoothing times will affect the original spectrum. Using wavelet transform theory to smooth the spectral lines can achieve better results. The wavelet transform projects the signal into different frequency subspaces, and uses the threshold and other forms to process the wavelet coefficients to filter out the high-frequency component coefficients, and then restore the signal. A smooth curve can be obtained. Xue Xiangming et al.<sup>[28]</sup> used wavelet transform to decompose the signal when analyzing the copper-zinc alloy Cu401 sample, and used soft threshold to process high-frequency coefficients. After reconstruction, noise can be effectively removed, and the smoothing effect is better than the five-point moving average method, especially in weak peaks. It can better reflect its advantages. Liang et al.<sup>[29,30]</sup> compared the denoising of the wavelet transform method and the Fourier transform denoising in terms of energy ratio, standard deviation and smoothness, and proved the superiority of the wavelet transform method.

## 5.2. Background deduction

Due to the interaction between X-rays and matter, such as coherent scattering, incoherent scattering, Compton scattering, etc., the all-energy peaks of characteristic X-rays are superimposed on a certain background, and it is necessary to obtain the accurate net peak area of the all-energy peaks of the measured elements. The background must be deducted. Zhang et al.<sup>[31]</sup> proposed a background subtraction method based on the combination of Fourier transform and SNIP, which makes the FWHM independent, can automatically subtract the background and keep weak peaks, and successfully applied the method to X-ray tube as the excitation source energy spectrum processing. Omer et al.<sup>[32]</sup> used the SNIP algorithm to deduct the background, and believed that when the value of the clipping window is between FWHM and FWTM, the deduction of the background is the most effective and can improve the resolution by 50%. The actual spectrum can be seen as a higher frequency all-energy peak superimposed on a lower frequency background. The background obtained by the wavelet transform method is closer to the actual background than that obtained by the curve fitting method, especially for binary systems and Multivariate system, the wavelet transform method is more accurate. Hu et al.<sup>[33]</sup> used the complex wavelet designed by Daubechies to remove the background of the simulated spectrum and the actual spectrum, and proved that its effect is better than that of the real wavelet. Kessler<sup>[34]</sup> proposed a method using multidimensional wavelet filters to achieve accurate spectral resolution and quantitative analysis without using pure background samples. Fang Yong et al.<sup>[35]</sup> combined the wavelet transform method with the peak clipping method to analyze the elements such as Cu and Ni in the standard sample of zinc cupronickel(GBW020104) and nickel-copper standard sample, and compared with the Top-Hat filter method. The bottom is more consistent with the original spectral line.

## 5.3. Decomposition and peak finding

In the process of qualitative analysis, due to the complexity of EDXRF spectrum, including the influence of background and overlapping peaks, the elements contained in the sample can only be determined by accurately finding the position of all peaks in the spectral line and through the correspondence between the channel address and the energy. The most direct method is the quadratic differentiation method, and the first-second derivative of the spectral line is filtered by the Savitsky and Golay filters, and the peak position is obtained according to the method of finding the maximum value. Another method convolves the original spectral line with a filter that approximates the peak shape to highlight the peak, which can accurately find the peak position and effectively suppress the background. This type of filter commonly used zero-area filter, top-hat filter is a typical representative. However, this method has strict requirements on the matching of the central window and side window width of the filter with

the original spectrum. Improper value selection will reduce the ability of peak seeking and background subtraction. Wavelet analysis has the characteristics of multi-scale analysis and can accurately reflect the mutation signal in the spectrum. The wavelet discrete approximation of a certain decomposition scale can reflect the local characteristics of the spectrum, and can perform time-frequency localized analysis on overlapping signals. Based on this, the use of wavelet transform methods for peak finding is particularly advantageous. Luo Jian-ming<sup>[36]</sup> successfully used wavelet transform to decompose overlapping peaks and analyzed Mn and Fe elements in six standard samples of GSD-5, GSD-10, GSD-11, GSD-12, GSD-14 and GSD-1a. The results showed that The peak area and actual content of the two elements maintained a linear relationship. Wang Ying et al.<sup>[37]</sup> used the second-order spline wavelet convolution peak splitting method to convolve the second-order spline wavelet with the signal, and processed the simulated signal and the experimental signal, which could achieve the separation of overlapping peaks, and proved theoretically. The peak position remains unchanged after convolution and the ratio of peak widths can be calculated.

#### 5.4. Extraction of fluorescence intensity

The element content in the sample has a linear relationship with the corresponding count of the corresponding characteristic peak. In EDXRF analysis, the fluorescence intensity can be obtained by calculating the peak area, and then the element content can be obtained. With the development of computing technology, the function fitting method is usually adopted. The function fitting method is to describe the spectral peak with a characteristic function, find out the characteristic parameters of the function through the least squares fitting, and then integrate the characteristic function in the left and right boundary interval of the spectral peak, and then obtain the spectral peak area. . The fitting algorithm is often based on the Marquardt-Levenberg(M-L) algorithm, which is accurate and fast when the selected model is complete. However, the ML method cannot accurately fit all peaks, so Brunetti et al.<sup>[38,39]</sup> proposed a peak fitting algorithm based on genetic factors to analyze soil samples(IAEA Soil-7) and thin glass membrane standard samples(Elements such as Si, K, Ti, and Fe in NBS SRM 183 XRF standard), the results are more accurate than the ML algorithm. After that, a fast and fine-grained genetic algorithm is used to fit the spectrum, which overcomes the problem that the convergence speed is slower than that of the M-L algorithm.

## 6. Summary

After continuous practice and research by analysts, XRF method can simultaneously analyze multiple elements in samples, and has become one of the most important analytical methods for iron ore analysis. Among them, the EDXRF analysis technology of powder pressing and sample preparation has the advantages of environmental protection, low cost, rapidity and accuracy in the analysis of iron ore samples. And in energy spectrum processing, wavelet algorithm, neural network and artificial intelligence algorithm have been applied more and more with their superiority, which is a hot direction of EDXRF algorithm research, and will definitely make a breakthrough in spectral processing technology. sexual progress. With the growth of society's demand for the environment, EDXRF technology will certainly have a broader development prospect.

## References

- [1] GUO Fang, LI Xiao-jie, CHEN Zhi-yong. Spectroscopy and Spectral Analysis, 1999, 19(3): 437.
- [2] ZHOU Su -lian, CAI Yong-hai, HUANG Zhao-min. Spectroscopy and Spectral Analysis. 2001, 21(4): 572.
- [3] LIU Fei-ming, GAO Fu-jia, GAO Xin -hua. Spectroscopy and Spectral Analysis, 1996, 16(6): 107.

- [4] HU Bo, Wu Xiao-mei, et al. Development and application of X-ray fluorescence spectrometer[J]. Nuclear Electronics and Detection Technology, 2015, 35(7): 695-701.
- [5] LIN Han-Bing, KANG Yong-le, et al. Detection of harmful substances by X-ray fluorescence spectroscopy[J]. Physical Experiment, 2017, 37(03): 1-5.
- [6] WEN Zi-qiang. Research and application of single standard modified FP method in energy dispersive XRF analysis[D]. Chengdu: Chengdu University of Technology, 2015.
- [7] DU Jian-min, WANG Zhao-li, ZHENG Jian-dao, et al. Effective path of enhancing X-ray fluorescence analytical accuracy to iron ore[J]. Henan Metallurgy, 2010, 18(6): 26-27.
- [8] LUO Xue-hui, ZHANG Yong, AI Xiao-jun, et al. Progress on determination of TFe and other elements in iron ores by fused glass-wavelength dispersive X-ray fluorescence spectrometry[J]. Chinese Journal of Inorganic Analytical Chemistry, 2011, 1(3): 23-26.
- [9] GAO Xin-hua, GAO Shu-zhen, ZHUN Yi-jun et al. Empirical coefficient correction of matrix effect in X-ray fluorescence spectrometry of iron ore[J]. Metallurgical Analysis, 1982, 2(2): 20-23.
- [10] LIANG Peng-shan, TIAN min. Determination of analytical elements in iron ore by X-ray fluorescence spectrometry[J]. Journal of Zhejiang Metallurgy, 2000(4): 26-29.
- [11] WANG De-quan, ZHANG Ping-jian, GE Hai-ying, et al. Measurement on primary and secondary element of iron fine powder using method of XRF melting glass plate[J]. Science Technology and Engineering, 2006, 18(6): 2955-2957.
- [12] CHEN Yuan-pan, SUN Ping-hui, WU Zhi-hong. Comparison of several sample preparation methods for the determination of low trace elements in iron ore and rock by X-ray fluorescence spectrometry[J]. Mineral Resources and geology, 1985(3): 110-114
- [13] ZHANG Lian-xiang, FU Bin. Advances in X-ray fluorescence spectrometry[J]. Chinese Journal of Inorganic Analytical Chemistry, 2013, 3(3): 1-7.
- [14] MA Lei. Study on detection technology of total iron content in iron ore[J]. Chemical Industry Management, 2013(8): 190-190.
- [15] DONG Yan-min. Study on the analytical method for the determination of multiple elements in iron ore by X-ray fluorescence[J]. Chemical Industry Management, 2019(5): 85-86.
- [16] XU Cheng-min, LIU Bang-jie. Determination of major and minor elements in hamersley iron ore by X-ray fluorescence spectrometric method[J]. Chinese Journal of Spectroscopy Laboratory, 1998, 15(2): 79-82.
- [17] XU Cheng-min, Ren Li-ping, JIANG Hai-ning, et al. Determination of major and minor elements in imported iron ore by X-ray fluorescence spectrometry powder tablet method[J]. Modern Commodity Inspection Science and Technique, 1998, 8(6): 11-13.
- [18] XIAN Yun, JIA Li-na. Analysis of iron ore component using XRF with powder pressured sample method[J]. No-ferrous Mining and Metallurgy, 2017, 33(4): 52-56.
- [19] SHI Li-hua, YUAN Chang-sheng. Study on Determination of multi elements in iron ore by X-ray fluorescence [J]. Technological Innovation and Application, 2013(6): 13.
- [20] MIN Hong, REN Li-ping, QIN Ye-qiong, et al. Research progress of total iron analysis in iron ore[J]. Metallurgical Analysis, 2014, 34(4) :21-26.
- [21] Criss J W, Birks L S. Calculation Methods for Fluorescent X-ray Spectrometry-Empirical Coefficients vs Fundamengtal parameters [J]. Analysis Chemical, 1968, 40: 1080-1083.
- [22] Klimasara A J. A Mathematical Comparison of the Lachance-Trail Matrix Correction Procedure with Statistical Multiple Linear Regression Analysis in XRF Applications [J]. Advance in X-ray Analysis, 1993, 36: 1-4.
- [23] Mantler M. Software for XRF [J]. Advance in X-ray Analysis, 1994, 37: 13-16.
- [24] JI Ang. Development of X-ray fluorescence spectrometry in 30 years[J]. Rock and Mineral Analysis, 2012, 31(3): 383-398.
- [25] ZHANG Kai-chun, WU Li-ping, YAO Jun, et al. Study of recognition of production areas for ceramic fragments by X-fluorescence spectrum combined with artificial neural network[J]. Nuclear Techniques, 2006, 29(11): 854-858.

- [26] JI Ang, ZHUO Shang-jun, LI Guo-hui. Energy dispersive X-ray fluorescence spectrometry[M]. Beijing: Science Press, 2011: 119-135.
- [27] Azami H, Mohammadi K, Bozorgtabar B. An improved signal segmentation using moving average and savitzky-golay filter[J]. Journal of Signal and Information Processing, 2012, 3(1): 39-44.
- [28] XUE Xiang-ming, FANG Fang, WANG Min, et al. Research of X-ray fluorescence spectrum lines smooth and background subtraction based on wavelet theory[J]. Nuclear Electronics & Detection Technology, 2012, 32(11): 1320-1323.
- [29] Liang M, Weizhi H, Zhitao X. Study on denoising based on the wavelet transform[J]. Semiconductor Photonics and Technology, 2010, 16(1): 29-34.
- [30] Zheng S L, Gui Y F, Chen X Q. The study of smoothness and similarity for denoising signal based on wavelet transform[J]. Advanced Materials Research, 2013, 655: 984-988.
- [31] Zhang Q, Ge L, Gu Y, et al. Background estimation based on fourier transform in the energy-dispersive X-ray fluorescence analysis[J]. X-ray Spectrometry, 2012, 41(2): 75-79.
- [32] Omer M, Negm H, Kinjo R, et al. Analysis of SNIP algorithm for background estimation in spectra measured with labr3: Ce detectors[A]: Yao T. Zero-carbon energy kyoto 2012[C]. Kyoto: Springer Japan DA, 2013: 245-252.
- [33] Hu Y, Zhou J, Tang J, et al. The application of complex wavelet transform to spectral signals background deduction[J]. Chromatographia, 2013, 76(11-12): 687-696.
- [34] Kessler B. Method and apparatus for wavelet based elemental spectrum analysis[P]. United States: 8412468, 2013.
- [35] FANG Yong, ZENG Li-bo, LEI Jun-feng, et al. A new method of background subtraction for energy dispersive X-ray spectra[J]. Journal of Instrument Analysis, 2001, 20(3): 23-27.
- [36] LUO Jian-ming. The study of spectrum resolving of EDXRF based on the wavelet theory[D]. Chengdu: Chengdu University of Technology, 2007.
- [37] WANG Ying, MO Jin-huan, CHEN Xiao-yan. Overlapped signal resolving by convolution of second-order spline wavelet[J]. Science in China(Series B), 2003, 33(4): 296-305.
- [38] Brunetti A, Golosio B. Fit of EDXRF spectra with a genetic algorithm[J]. X-ray Spectrometry, 2001, 30(1): 32-36.
- [39] Brunetti A. A fast fine-grained genetic algorithm for spectrum fitting: an application to X-ray spectra[J]. Computer Physics Communications, 2013, 184(3): 573-578.