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Image Processing-based Quantitative Representation of Coal Porosity

Bing Li [1,2,3], Jiangang Ren[1,2,3], Zhimin Song[1,2,3,4*]

[1] College of Resource and Environment, Henan University of Institute, Zhengzhou 451191, China;

[2]Henan Engineering Laboratory of Comprehensive Treatment Technology for Environmental Geohazards in Coal Mine, Zhengzhou 451191, China;

[3]The Key Laboratory of Mine Geohazards and Environment Prevention, Zhengzhou 451191, China;

[4] Kaifeng University, Kaifeng 475004, China

Email: songzhimin1961@126.com

Abstract

As CFE-SEM fails to quantitatively represent coal porosity, we initiated a novel technique by using image sensing. First, an analysis was conducted on the grey level distribution of pixels of coal porosity images shot by CFE-SEM. According to the result, pore area signals are less bright and lower in pixel grey levels than signals elsewhere. Then, we converted original images into binary images in Matlab to calculate binary pixels. Image porosity is obtained by dividing the total number of pixels by binary pixels. The identity between image porosity computed by the proposed method and the one by liquid nitrogen adsorption technique is proved to be over 81%. In this way, this approach provides a new thought to coal porosity representation.

Keywords: image processing, coal, porosity.

1. INTRODUCTION

As the main room for gas accumulation, coal pores are formed complicatedly. Pore sizes fall into a wide range, from micropores to mesopores to macropores. Micropore is the predominant space to adsorb coal gases (Qi et al., 2012; Zha et al., 2017). Coal pores can be classified into connected pores as the major type and unconnected pores according to their connectedness (Meng et al., 2012; Wang et al., 2014).

Up to now, various fruitful methods have been applied to quantitative and qualitative research conducted on coal porosity, such as mercury intrusion porosimetry, liquid nitrogen adsorption, CT scanning, small-angle X-ray scattering, SEM, and TEM (Xia et al., 2016; Liu and Zhu, 2016; Mohapatra, 2016). According to the status of existing research techniques: mercury intrusion porosimetry and liquid nitrogen adsorption technique, known as the most widely used ones, are capable of detecting 0.01μm~10μm connected pores, but cannot seize unconnected pores; Despite the advantages of nondestructive inspection, quantitative analysis and precision, CT scanning is confined to macropore (>1um)examination (Gong et al., 2008; Gong and Li, 2010; Song et al., 2013); The present version of SEM is suitable to display and shoot surfaces and morphology of Nano-scale pores, but is proved useless for quantitative representation. With higher magnification and resolution than SEM, TEM is commonly used to analyze micropores and ultra micropores (at the limit value of 0.3~0.1nm), and can directly exhibit the structure of aromatic clusters in coal molecules (Zhang et al., 2011; Xu et al., 2016; Li et al., 2016).

The research objective is high rank coal in this paper. Image sensing in combination with CFE-SEM is used to gauge coal porosity. On the foundation of qualitative sample observation by CFE-SEM, we improved our studies on coal porosity properties by representing coal porosity quantitatively. This attempt aims to find a new way to represent coal porosity quantitatively based on image processing.

2.THE PRINCIPLE OF IMAGE PROCESSING

Coal is a type of porous medium with large micropore volume and substantially large specific surface area. To magnify these features, Menger sponge is a general choice to simulate coal porosity (Figure 1) (Zhang et al, 2016; Zhang and Erxin, 2015; Li et al, 2016). This example of fractals looks like a cubic frame, and simultaneously exhibits an infinite surface area and zero volume. Each face of the Menger sponge is a Sierpinski carpet. When shooting a SEM photograph through CFE-SEM, pore area signals are less bright than signals elsewhere because of different distances. Intuitively, pore area pixels are darker and lower in grey levels than pixels in solid parts. Allowing for this characteristic, based on previous studies, we proposed a pore area estimation method by checking points of local minimum in an image.

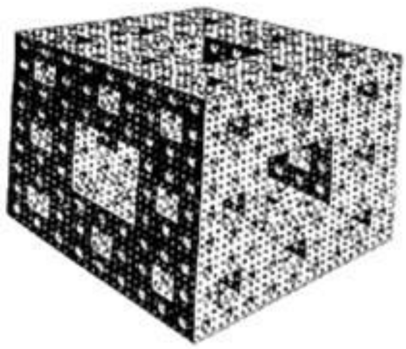


Figure 1. Menger sponge.

3.COMPUTING METHODS

We first analyzed the grey level distribution of images shot by CFE-SEM (Figure 2), and accordingly plotted a histogram as shown in Figure 3. This figure shows that grey levels basically fall into the interval of 60-140, with even distribution and small difference from each other. The histogram is a distribution with one clear peak, which means that the grey levels in pore area slightly differ from those in solid areas. Given this, we carried out threshold-based image partition to attain more satisfactory results than might not have been achieved with existing images using pore detection method. Figure 4 is the diagram of pore distribution based on thresholding dividing, for which thresholds are decided according to maximum margin criterion (determined by Otsu algorithm). In this specific result, the default value of threshold is 0.3922. The porosity is obtained as 55.6516%, deviating much from the actual and observed values.

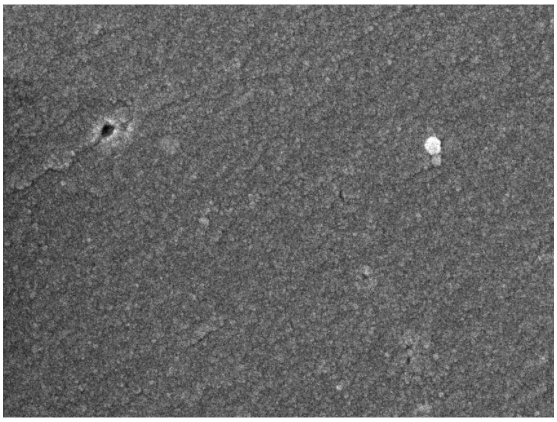


Figure 2. Electron microscope scanning figure of 1# coal (×50000).

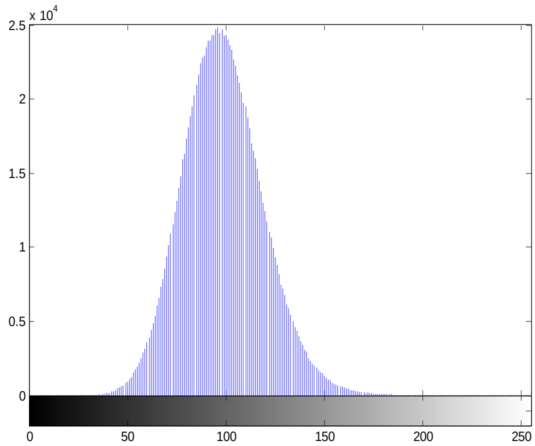


Figure 3. Ash histogram.

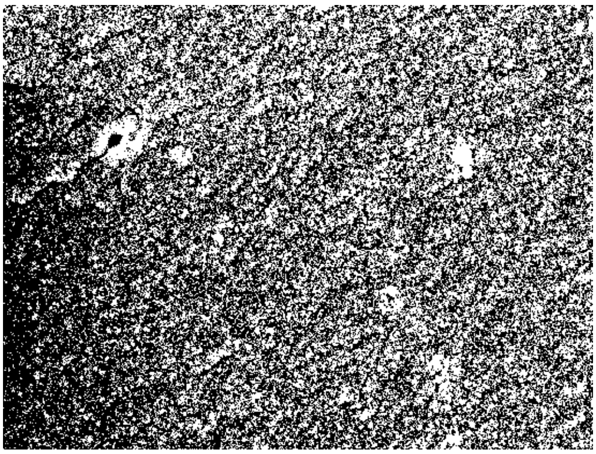


Figure 4. Pore distribution based on thresholding dividing.
(where black area is the pore area, white area is the solid area)

After referring to previous research experience, we proposed a pore area estimation method by inspecting points of local minimum in the image.

Here are several steps of this method:

(1) Each image pixel is assigned a pixel-centered neighbor (3×3 in this test);

(2)Find the minimum value in the neighbor and keep statistics;

(3) Judge whether the pixel value is equal to the minimum one; if it is, the pixel is a potential pore area point, and is assigned value 1; if not, the pixel is a pore-free point, and is assigned value 0.

(4) When all pixels are processed in the said way, we obtained the pore distribution diagram as shown in Figure 5. The porosity is computed to be 6.3031%.

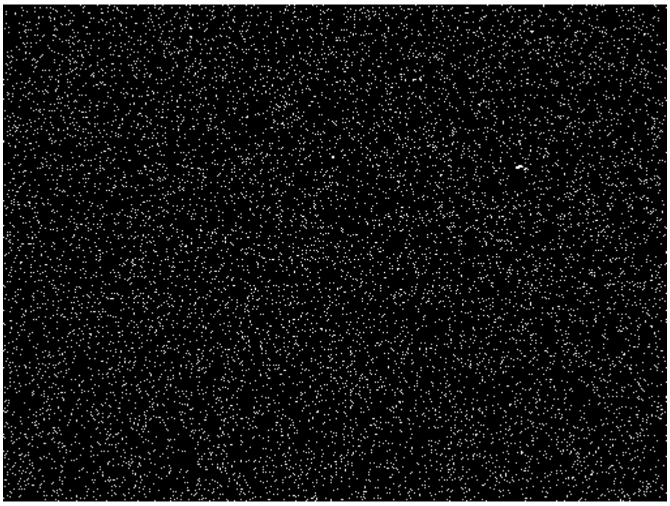


Figure 5. Pore distribution diagram obtained using local minimum pore distribution method
(where white parts are the gap)

(5) corrections made to pore distribution diagram

The test result is found to cover evenly distributed pore area points. However, pores of large size (outlined in red in Figure 6, for example) are missed. What is more, the test should not have detected obvious pore-free areas such as the one outlined in yellow in Figure 7. Therefore, on the said basis, slight corrections were made to the proposed algorithm. Referring to the image histogram, we set a relatively small threshold T_1, below which pixels are determined as porous; and a relatively large threshold T_2, above which pixels are determined as non-porous. In Figure 7, as T_1=40, pixels whose grey level is below 40 represent pore areas; as T_2=170, pixels whose grey level exceeds 170 represent solid areas. The porosity obtained using the modified algorithm is 6.3330%. Figure 7 is the diagram of pore distribution. As can be seen from Figure 7, areas of large pore sizes are detected and displayed at the same time when apparently non-porous areas are excluded.

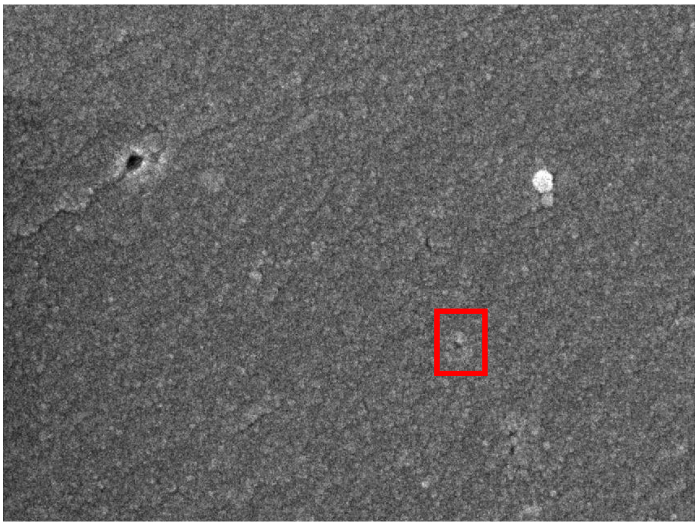


Figure 6. Original pore distribution.

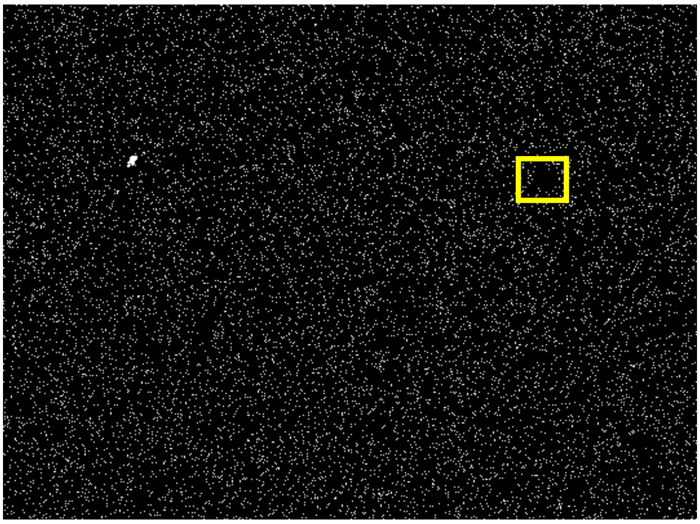
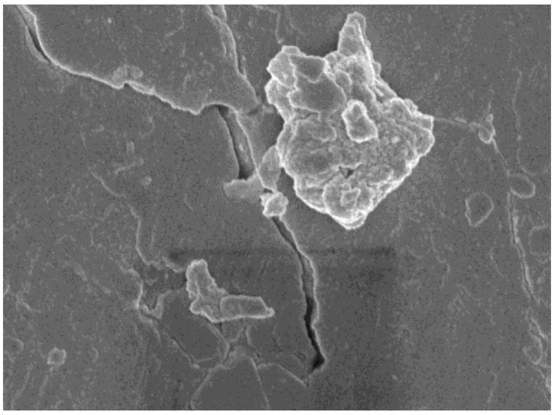
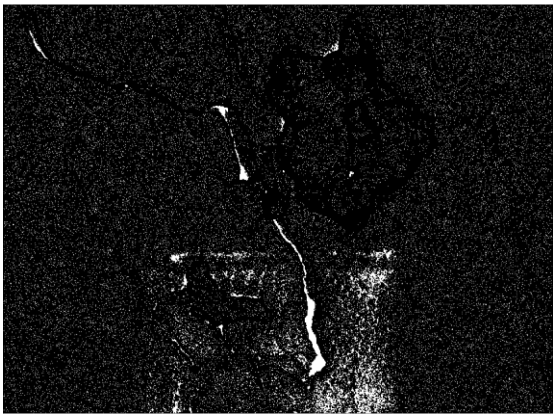


Figure 7. Corrected pore distribution

3. TEST RESULTS AND ANALYSIS

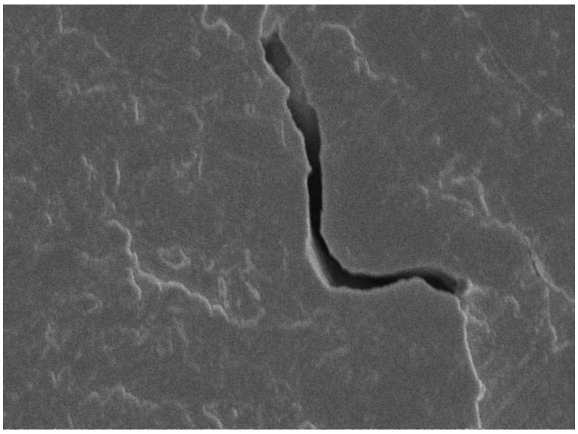
After observing the SEM photographs of coal samples, we found that SEM photographs of different coal specimens present similar regularity. To this end, we took 2# and 3# coal samples as examples to analyze the porosity of coal parallel and perpendicular to bedding direction, respectively (shown in Figure 8~Figure 11). The final result is:





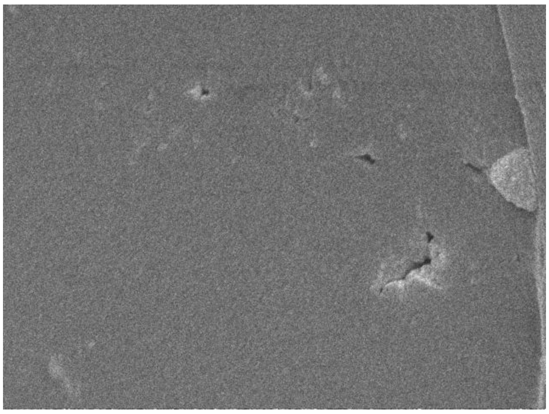
(a) Unprocessed image(×20000) (b) Processed image

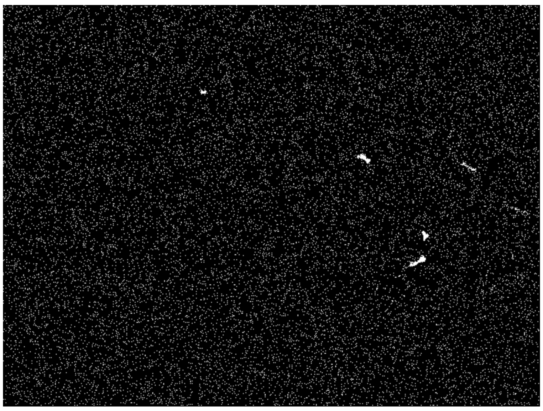
Figure 8.2# coal samples before and after binarization (Parallel to the bedding direction)



(a) Unprocessed image (×20000) (b) Processed image

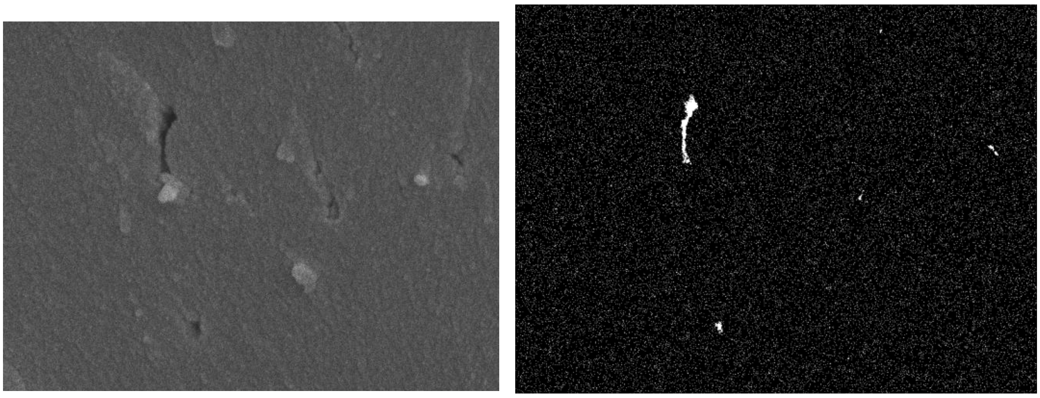
Figure 9.3# coal samples before and after binarization (Parallel to the bedding direction)





(a) Unprocessed image (×20000)(b) Processed image

Figure 10.2# coal samples before and after binarization (Vertical bedding direction)



(a) Unprocessed image (×50000) (b) Processed image

Figure 11.3 # coal samples before and after binarization (Vertical bedding direction)

According to Figure 8~Figure 11, SEM photos accurately capture micropores, mesopores and macropores. Table 1 shows the result of image processing based coal porosity. Porosity of coal parallel to bedding direction is much higher than the one perpendicular to bedding direction. The identity between image porosity computed by the proposed method and the one by liquid nitrogen adsorption technique is proved to be over 81%. These findings validate the feasibility of image processing based SEM photos to simultaneously observe parameters of pore morphology and pore distribution as well as represent coal porosity in the quantitative manner.

Table 1 Result of image processing based coal porosity

Sample No(#)	**Liquid nitrogen based porosity (%)**	**Image processing based porosity (%)**	**Similarity (%)**
2#	7.33	7.77	94.34
2#	7.33	8.11	90.38
3#	7.33	6.01	81.99
3#	7.33	6.49	88.54

4.CONCLUSION

The paper uses image processing in combination with SEM to quantitatively represent coal porosity, and achieve practical results. The identity between image porosity computed by the proposed method and the one by liquid nitrogen adsorption technique is proved to be over 81%. In this way, this approach provides a new thought to coal porosity representation.

5. ACKNOWLEDGMENTS

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