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A study on Fast Predicting the Washability Curve of Coal

Zhang Ze-lin, Yang Jian-guo, Wang Yu-ling, Xia Wen-Cheng, Ling Xiang-yang

China University of Mining & Technology, Key Laboratory of Coal Processing and
Efficient Utilization, Ministry of Education
Xuzhou,221008, China
zhangzelin3180@163.com

Abstract

A pure new MATLAB-based image recognition system was developed to compute the coal particle picture of same grain class through the digital image processing method, 13 image feature parameters was selected to be most representative image characteristic parameters. Take the above parameters as the input of RBF neural network, the density level of coal particles could be estimated , combined with the real ash content of each density level, the washability curve could be drawed. Experement show,the absolute error of the total ash is 2.375% ,which is Slightly big in the China standards of coal preparation (GB/T477 -1998); the related coefficients of each indicator in both actual and predicted float-and-sink material are all close to 1, while the curves of λ, β, θ and δ are very similar and the deviation of ξ curve is relatively large.
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*Keywords:*Digital coal preparation; image analysis; neural network; washability curve

1. Introduction

In the mineral processing field, many processes should be analyzed and judged mainly by visual information, such as use the microscope to observe and utilize the image to analyze the physical dimension, shape, color, dissociation degree, intergrowth, mineral type and content of mineral particles. Use the "computer vision" replace human vision, enhance the application of digital image technology in mineral processing, and apply the latest contemporary technological achievements of digital images to promote the development of mineral processing technology, all of which have a very important guiding significance on the coal preparation industry.[1]

Coal is the main part of China's energy and in quite a long time China's coal-dominated energy structure will not change. In nearly 30 years, the coal will continue to dominate the leading position in the production and consumption of primary energy sources. However, in the use of coal, there still exists low efficiency of energy and environmental pollution as well as other issues, so the only way to resolve this contradiction is to develop clean coal technology. Coal washing and processing is the preferred solution recognized internationally to realize the coal efficient and clean use and it is still one of the main content to develop clean coal technology.

The so-called washability means the complexity of selecting products from raw materials according to the required quality indicator. The washability curve is drawn in accordance with the results of the float-and-sink test, which is used to reflect all the density level or any density distribution of coals and it is the necessary mean to understand the washability, evaluate, predict, and optimize the effect of gravity separation of raw coal. Besides, it can provide correct way for the coal washing and processing as well as effective way of supervision and management, so it has a pivotal position in the coal washing and processing industry. The float-and-sink experiment should not only cost a lot of manpower and resources, but also take a long time. For this, the coal preparation plant commonly conducts the comprehensive test once a month. In the daily production, they sometimes carry out a quick float every one hour to guide the production. For the quick float has an hour lag, so it cannot opportunely guide the production. Besides, operators mainly operate by experience, which has large blindness and cannot automatic control accordingly. Therefore, how to rapidly predict the washability curve of raw coal has become an urgent issue. In 1996, Maixi Lu started to study the relationship between coal ash and it's float-and-sink composition and also establishes the model to predict the float-and-sink composition of the raw coal [2]; In 1998, Jing Liu and Maixi Lu predict the the washability of the raw coal through the total ash content [3]; in 1999, Zhenchong Wang & Maixi Lu developed a set of online system to predict coal washability curve based on the relativity between ash and density of the raw coal from some given coal preparation plants. However, this system only limited to the specific coal quality and density range and cannot achieve the industrialization [4]. This paper uses the digital image processing method to extract the

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surface information of coal particles in each density level, and then utilizes neural network to predict washability curve. This method doesn't limit to coal quality and density range, so it can achieve the purpose of automatic control and guiding production quickly.

2. Coal quality characters of experimental coal

The coal used in this study is the coal particle with grain size of 13mm-25mm in the Taixi Coal Preparation Plant of China. When conducting the screen analysis on the raw coal of Taixi, we also carry out the lithotype proximate analysis on the raw coal in various density levels.

Table 1. according to its genesis, lithotypes of coal distinguished from chemical nature and rock property and its visual characteristics

Composition of coal	visual characteristics
vitrain	bright，black，generally very brittle and often with cracks
glance coal	Semi-bright，black，thin layer
dull coal	dim，black or gray-black，hard，rough surface
fusit	silk gloss，black，nemaline，soft，very friable

After the float-and-sink analysis on the experimental coal, we divide it into 10 density levels: 1.325-1.35、1.35-2.375、1.375-1.40、1.40-1.45、1.45-1.50、1.50-1.60、1.60-1.70、1.70-1.80、1.80-1.90 and >1.90。Through the observation on the various components of float-and-sink experiment, it can be seen that the vitrain is mainly concentrated in the density level of 1.35 ~ 1.40 Kg / L; dull coal is mainly concentrated in the density level of 1.40 ~ 1.50 Kg / L; fusain is mainly concentrated in the density level of 1.40 ~ 1.60 Kg / L; mineral-rich coal is mainly concentrated in the density level of 1.60 ~ 1.80 Kg / L; ash minerals (gangue) are mainly concentrated in the density level of +1.80 Kg / L.

By Table 1 and the macro-components of densities, which can be seen that there exist large differences for experimental coal in 13mm-25mm and various density levels, besides various macro-compositions are also different in visual characteristics, so using the image analysis method can predict the density level of coal particles in the same grain sizes.

3. Identification system of coal particle image

Use self-developed MATLAB-based image recognition system of coal particles to extract the characteristic parameters of the coal particle image, whose functions are as follows:

1) Image Acquisition: it can be used to easily intercept and load images.

2) Image preprocessing: conduct the gray-scale processing on the coal particle image, contrast enhancement, threshold binaryzation, dilation and erosion preprocessing; use the principle of color segmentation to identify and separate the coal particle image, and calculate cross-sectional area of the coal particles.

3) Image analysis and operation: extract 29 characteristic parameters of coal images - in the color images, extract the first-order, second-order and third-order (ie mean, standard deviation and gradient) of color component、hue、saturation and value by two reference systems---RGB and HSV; obtain the first, second and third-order moment of gray scale from the gray image, the contrast, correlation, energy, homogeneity, entropy, coarseness, Tamura-contrast and directionality of texture parameters.

4) Data storage and processing: save the feature parameters of coal particle image into Excel tables, and then conduct filter the characteristic parameters and re-storage through the analysis of statistics and graphs.

5) RBF neural network prediction: regarding the feature parameters of filtered image as input, the average density level of the coal particles as the training objective, we can train the network to predict the density level of coal particle, and then combined with the real ash content of various density levels to predict the washability curve .

4. Predicting the washability curve

After filter the characteristic parameters, the most representative image feature parameters of 13mm-25mm coal particles in the Taixi Coal Preparation Plant are the first-order of grayscale, second-order of grayscale, third-order of grayscale, first-order of hue, second-order of hue, third-order of hue, second-order of saturation, third-order of saturation, contrast, energy, homogeneity, entropy and directionality.

Randomly select 10 groups of coal particles in 13mm-25mm from the raw coal in Taixi Coal Preparation Plant. Select at random 15 coal particles from each group, that is, each density level, extract the filtered characteristic parameters of coal particles, and then regard the normalized average value of characteristic parameter of each coal particle in each density level (as shown in Table 2) as the input of RBF neural network, which can effectively reduce the error caused by the difference in the coal surface.

Table 2. the normalized average value of characteristic parameter in each density level

parameter \ density	1.325-1.35	1.35-1.375	1.375-1.40	1.40-1.45	1.45-1.50	1.50-1.60	1.60-1.70	1.70-1.80	1.80-1.90	>1.90
G first –order	0.978	0.912	0.907	1.000	0.484	0.111	0.762	0.000	0.583	0.474
G second-order	0.967	1.000	0.650	0.534	0.729	0.382	0.281	0.000	0.363	0.436
G third-order	0.000	0.628	0.940	1.000	0.203	0.575	0.899	0.539	0.932	0.837
V first -order	0.348	0.159	0.522	0.768	0.000	0.188	0.406	0.942	1.000	0.072
V second-order	0.793	0.000	0.163	0.087	0.326	0.598	0.554	1.000	0.326	0.359
V third-order	1.000	0.031	0.000	0.108	0.672	0.851	0.872	0.933	0.118	0.738
S second -order	0.542	1.000	0.000	0.458	0.375	0.458	0.375	0.417	0.250	0.333
S third -order	1.000	0.537	0.220	0.317	0.780	0.951	0.878	0.902	0.000	0.756
contrast	1.000	0.887	0.189	0.528	0.113	0.453	0.000	0.245	0.113	0.019
entropy	0.000	0.381	1.000	0.552	0.686	0.552	0.790	0.914	0.895	0.581
energy	0.000	0.714	1.000	0.524	0.810	0.333	0.524	0.095	0.429	0.571
homogeneity	0.445	0.828	0.453	0.133	0.875	1.000	0.000	0.469	0.469	0.680
directionality	1.000	0.000	0.302	0.257	0.849	0.798	0.099	0.850	0.800	0.434

In Table 2, regard the normalized characteristic average value as the input of RBF neural network and the average density of each density level as the training objective, and then enter the characteristic parameters of 40 coal particles in different grain sizes to conduct prediction.

Assume the coal grains physical volume V of the same size is constant，the ash content A of coal particles in each density level is constant, the density level is i, the number of coal particles in each density level is ji, the productive rate γi of Ith density level is:

$$\gamma_{\mathrm{i}}=\frac{\mathrm{V}\ (\sum_{\mathrm{j=1}}^{\mathrm{j}_i}\overline{\rho}_{ij})}{\mathrm{V}\ (\sum_{i=1}^{10}\sum_{j=1}^{j_i}\overline{\rho}_{ij})}=\frac{(\sum_{\mathrm{j=1}}^{\mathrm{j}_i}\overline{\rho}_{ij})}{(\sum_{i=1}^{10}\sum_{j=1}^{j_i}\overline{\rho}_{ij})}$$

Related coefficient, also known as the Pittler product-moment related coefficient, indicates that the statistical analysis indicators of the intensity of the correlativity between two phenomenon. Related coefficient of the sample is shown as r, the greater the value of | r | is, the smaller the error Q will be, and also the higher the linear correlation degree of variable X, Y will be; when the value of | r | is closer to 0, Q is greater, and the linear correlation degree between variables X, Y is lower. N is the data dimension of variable X, Y.

$$r=\frac{\sum XY-\frac{\sum X\sum Y}{N}}{\sqrt{(\sum X^2-\frac{(\sum X)^2}{N})(\sum Y^2-\frac{(\sum Y)^2}{N})}}$$

Table 3. Actual and predicted washability curve data

Curve Classify	Characteristic ash curve λ		Cumulative floats curve β		Cumulative sinks curve θ		Densimetric curve δ		δ+/-0.1 curve ε	
	Ash content%	Productive rate%	Ash content%	Productive rate%	Ash content%	Ash content%	Productive rate%	Ash content%	Productive rate%	Ash content%
Actual	1.769	4.227	1.769	8.455	20.633	0.000	1.35	91.545	1.30	74.058
	3.345	12.787	2.567	17.119	22.375	8.455	1.38	82.881	1.40	55.623
	5.351	21.531	3.514	25.942	24.364	17.119	1.40	74.058	1.50	71.712
	6.239	30.472	4.219	35.001	26.630	25.942	1.45	64.999	1.60	79.658
	12.435	39.689	5.955	44.377	29.471	35.001	1.50	55.623	1.70	78.387
	14.448	49.304	7.498	54.231	32.343	44.377	1.60	45.769	1.80	77.115
	22.545	59.475	9.937	64.719	36.195	54.231	1.70	35.281	1.90	75.844
	24.597	70.282	12.087	75.844	40.253	64.719	1.80	24.156		
	28.665	81.724	14.313	87.604	47.464	75.844	1.90	12.396		
	65.299	93.802	20.633	100	65.299	87.604				

Predicted	1.769	5.208	1.769	10.417	23.008	0.000	1.35	89.583	1.30	83.178
	3.345	13.619	2.369	16.822	25.478	10.417	1.38	83.178	1.40	65.007
	5.351	16.822	2.369	16.822	27.182	16.822	1.40	83.178	1.50	69.689
	6.239	21.286	3.711	25.751	27.182	16.822	1.45	74.249	1.60	67.183
	12.435	30.372	6.015	34.993	29.701	25.751	1.50	65.007	1.70	71.099
	14.448	41.063	8.187	47.133	32.156	34.993	1.60	52.867	1.80	83.082
	22.545	57.471	12.566	67.810	36.222	47.133	1.70	32.190	1.90	76.033
	24.597	71.922	13.867	76.033	45.007	67.810	1.80	23.967		
	28.665	80.380	15.385	84.727	52.010	76.033	1.90	15.273		
	65.299	92.364	23.008	100	65.299	84.727				
Related coefficient r		0.990	0.994	0.989	0.990	0.986		0.983		0.427

According to the national standards of coal preparation in China--GB / T 477-1998 [5], when the ash content is larger or equal to 20%, the absolute error of the filtered gross sample ash content and weighted average of ash content of each grain size can not exceed 2%. It can be seen from Table 3, when the ash content A > 20%, the absolute error between actual ash content and predicted ash content is 2.375%, although bigger in nation standard, have already neared to very. In addition to the low correlation coefficient of the productive rate in each density level of ε curve, the correlation coefficient of the actual and predicted washability curve data is close to 1, indicating that they have a high degree similarity.

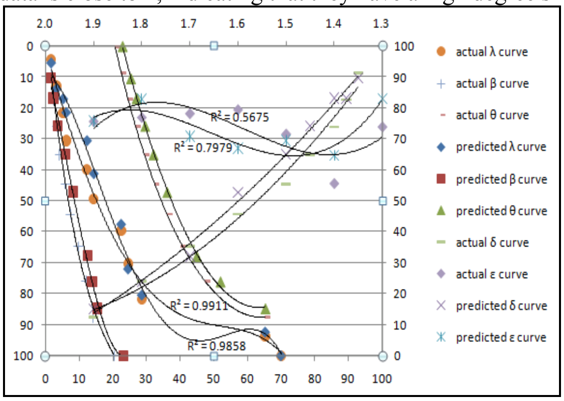

Figure 1. the actual washability curve and the predicted washability curve

In figure 1, the similarity of actual and predicted curves is consistent with the data shown in Table 3. As there is a certain mismatch rate for the prediction of density level of coal particle, the prediction of the productive rate for each density level will definitely have a certain deviation. However, the experiment proves to have less influence on λ, β, θ and δ curve, but a greater impact on the ξ curve.

5. Conclusions

As can be seen from the above study, using the digital image processing method to forecast the washability curve is feasible and the prediction on the total ash have already neared to the Chinese national standard as well as actual and predicted washability curve have a high degree similarity. This research will provide a kind of all new way of thinking and method for real-time control and digital coal preparation, then more efficiently realize the policy of coal efficient and clean use.

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