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A novel distribution rate predicting method of dense medium cyclone in the Taixi coal preparation plant

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ABSTRACT

To predict real-time distribution curve of dense medium cyclone in the Taixi coal preparation plant, a new method based on field data was presented. A group of uniformly designed single machine checks (sampling test of a dense medium cyclone) were carried out for modeling field operating parameters and distribution curve indexes. Then three real-time indexes could be predicted by onsite sensor values, and the present distribution curve model was able to be calculated. Predicting part of the method was also compared with the usual approximate formula method based on the proposed models. The models were proved to be acceptable as the RMS accuracy reached 0.73%, 0.77%, and 0.90% respectively in the training set and 0.76%, 0.63%, and 0.51% for the test example. The predicting results were also verified to be better and more reasonable than the approximate formula method.

1. Introduction

Dense medium cyclone (DMC) is one of the most important cleaning units in coal washery. It essentially separates coal particles in the light of their differences in density, and is capable of realizing sharp separations and heavy loads at the same time (Holtham, 2006).

Although DMC research has made a tremendous development in the last four decades focusing on size design (Wang et al., 2011; Magwai and Bosman, 2008; Chen et al., 2012) and flow field (Narasimha et al., 2006; Wang et al., 2009; Chu et al., 2012), their industrial model study based on field data is hardly reported. However, a factory study of DMC is considered as significant as those above in the laboratory, it can improve productivity on site, and tends to be more and more attractive nowadays. For example, experience-driven models for the density components of raw coal, the float-and-sink data composition, and the expression of distribution curves were built by analyzing a month comprehensive material of float-and-sink tests of raw coal (Wang et al., 2012). A coal preparation plant in Zonguldak was optimized by equalization of incremental product quality method which maximizes plant yield with a given ash requirement based on float-sink data (Cebeci and Ulusoy, 2013).

Once an industrial DMC goes into operation, both the body sizes and process flow are fixed, therefore, operating parameters are the only practical element affecting the separating performance or product quality when the properties of the raw coal do not change significantly with time. However, it is quite surprising that — to our knowledge — there is little literature studying the models between the operating conditions and DMC indexes on the basis of field data.

There are two bottlenecks restricting the development of integrated automation in DMC processes. The first is the fast gauging of raw coal material. There seems to be two approaches solving this bottleneck. 1) analyzing a month comprehensive material of float-and-sink tests of raw coal to make an estimation (Wang et al., 2012). 2) real-time prediction by image analysis (Zhang et al., 2012, 2013a,b, 2014a,b). The second is the field models of separation indexes e.g. distribution curves (rates).

Usually, the separation indexes of DMCs cannot be monitored directly. Therefore, soft sensor modeling is adopted. A soft sensor comprises a group of measurement signals and a model to estimate an immeasurable parameter. Soft sensors can thus provide a tool for supporting or replacing the potentially difficult and expensive measurements. It has been used successfully in measuring the coal moisture (Zeng et al., 2015) and particle size in a grinding process (Pani and Mohanta, 2014).

In this paper, a new soft sensor modeling method for predicting real-time distribution curve of dense medium cyclone in the Taixi coal preparation plant by field operating parameters was proposed. A group of

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Table 1
$U_6(3^2 \times 2^1)$.

No.	Factor 1	Factor 2	Factor 3
1	1	1	1
2	1	2	2
3	2	3	1
4	2	1	2
5	3	2	1
6	3	3	2

specially designed single machine checks were carried out for modeling field operating parameters and distribution curve indexes. Then real-time indexes could be predicted by onsite sensor values, and the present distribution curve model was able to be calculated. An additional experiment was arranged for testing the method and illustrating the prediction process. Based on the models, the method was also compared with the approximate formula method.

2. Soft sensor modeling of DMC

2.1. Uniform design

Uniform design (UD) is established on the uniform distribution in number theory. Following UD, experiment points are scattered uniformly within the factor range for obtaining more information by less experiments. UD just takes into account uniform, so the points have a better representative. As orthogonal design, UD provides various experimental tables for users. For example, $U_6(3^2 \times 2^1)$ with multiple levels is given in Table 1. It can arrange two three-level factors and another two-level factor in six experiments (Liang et al., 2001; Song et al., 2012). It is believed that for experiments with too many parameters or expensive costs, UD may be preferred.

2.2. Modified single machine check

Raw coal, clean coal, middings and gangue are sampled simultaneously from a three product dense medium cyclone. It lasts 20 min continuously, during which the values of sensors are recorded once a minute. The averages of each sensor values are documented to represent the work conditions of the time. Then, sample quartering is employed locally to cut down each sample to about 80 kg first.

The four samples are transported to a laboratory for further sample splitting to 30 kg each and then float-sink tests are carried out. Finally,

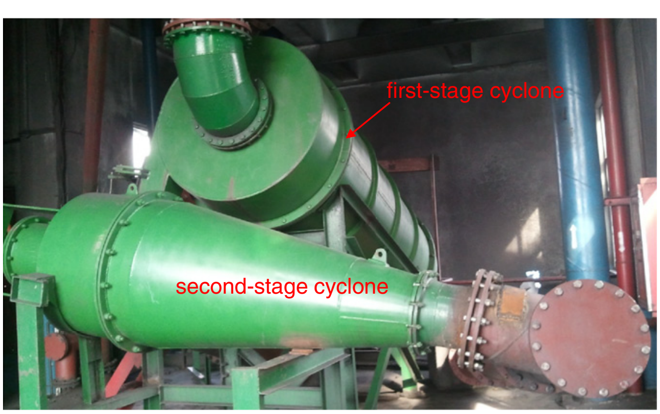

Fig. 1. Three-product cyclone in Taixi plant.

Table 2
$U_{12}(4^2 \times 3^2)$.

No.	d kg/L	c kg/L	p MPa	r t/h
1	1.600	0.800	0.265	400
2	1.570	0.800	0.255	350
3	1.520	0.650	0.275	300
4	1.570	0.750	0.265	300
5	1.520	0.700	0.255	400
6	1.620	0.800	0.275	350
7	1.520	0.650	0.255	350
8	1.570	0.750	0.275	300
9	1.600	0.700	0.265	400
10	1.620	0.700	0.255	400
11	1.600	0.750	0.275	350
12	1.620	0.650	0.265	300

the distribution rates of each density level can be computed according to the Grumbrech method (Lu, 2005).

To plot a partition curve, the modified logistic model is adopted (Dou et al., 2015),

$$f(x) = \frac{100}{1 + e^{(-m\cdot(x-n))}} + l \tag{1}$$

where x indicates the density level, $f(x)$ indicates the distribution rates, and l, m, and n are constant coefficients.

The least square model identification method is utilized to reckon the above coefficients by the float-sink test data, and the partition curve can be got.

3. Distribution curve prediction on field parameters

3.1. Selecting field parameters

Four factors, i.e. density of dense medium suspension (d), content of magnetic substance (c), inlet pressure of dense medium suspension (p) and coal feed rate (r) are selected as our field parameters because they are common, indispensable measuring variables in usual DMC circuits. They are also primary process parameters manipulated by workers in the factory and affect the running performance of DMC significantly.

3.2. Predicting distribution curve

To rebuild the distribution curve model as shown in Eq. (1), three points are needed for coefficients l, m, and n. On the basis of two well-known performance characteristics of DMC i.e. the actual separation

Table 3
Actual UD table.

No.	d kg/L	c kg/L	p MPa	r t/h
1	1.609	0.803	0.257	412
2	1.593	0.761	0.251	350
3	1.524	0.655	0.272	337
4	1.577	0.682	0.266	330
5	1.522	0.617	0.258	403
6	1.614	0.863	0.274	327
7	1.517	0.623	0.261	392
8	1.574	0.734	0.281	340
9	1.617	0.663	0.264	415
10	1.616	0.838	0.256	455
11	1.596	0.798	0.278	283
12	1.631	0.936	0.261	398