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Application of a Shewhart control chart to monitor clean ash during coal preparation

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ABSTRACT

In coal preparation, clean coal ash content is a key indicator for evaluating the quality of clean coal. Online ash analysers are employed to rapidly measure the clean ash, and the resulting measurements are monitored for productive process control. However, the ash observations often fluctuate and are disorganized due to random errors and analyser measurement errors, local variations in coal flow, and changing equipment and processes. Thus, this paper attempts to use the Shewhart control chart method to monitor clean ash in a statistical and global manner. From investigations of the coal preparation process, three types of variability can occur in ash process data: random variability, special variability and systemic variability. An effective $\overline{X}$-Shewhart control chart can detect all abnormal variations under the condition that the control chart parameters (subgroup and control limits) are properly determined. To achieve this, an error analysis of an ash analyser and the influence of data autocorrelation were considered before structuring a clean ash control chart. In phase I, a preliminary dataset was collected from actual ash observations. After an autocorrelation analysis, which excluded abnormal variations, a sampling scheme comparison and the selection of a population standard deviation for the preliminary data, the control chart parameters were precisely estimated. In phase II, the phase I analysis procedure was broadly used to structure a $\overline{X}$ chart with given standard values for monitoring clean ash. Therefore, an application example is presented, and the results are discussed to demonstrate the positive impact of this method on a coal preparation plant.

1. Introduction

For a coal preparation plant, the clean coal ash content is closely related to product quality and productivity. The goal of the coal preparation process is to ensure that the production process is stable and accurate such that the clean ash satisfies the requirements of the customers and producers. However, the complex nature of the production methods and product structure often inhibit efforts to obtain products of high quality. Statistics is a basic means for solving such problems. The application of statistical process control (SPC) techniques in mineral processing is as important as it is in many other industries, as management aims for a certain quality that will enhance reputation and future progress (Ipek et al., 1999).

The aim of SPC is the establishment and maintenance of a process at an acceptable and stable level to ensure the conformity of products and services to specified requirements. If there is any abnormality in an industrial process, SPC seeks to determine the reasons for that abnormality and to eliminate those sources. Another aim of these charts is to continuously keep the process under control (Ipek et al., 1999). Therefore, the application of SPC for monitoring clean ash helps to scientifically identify abnormal circumstances in the process and to ensure the stability of the coal preparation process.

The major statistical tool used for this application is the Shewhart control chart, which was established by W. A. Shewhart in 1924. It is a graphical method of presenting and comparing information based on a sequence of samples that represent the current state of a process against limits established after considering inherent process variability. Shewhart charts are used to determine the quantitative and qualitative variations that occur in processes over certain time frames. Subsequently, a researcher can investigate the reason for those variations by comparing the expected and measured values (Ipek et al., 1999). The key to constructing a control chart is to determine its rational nature and characteristics (such as subgroup size, sampling frequency and standard values) and to consider the influence of the time series and actual situation.

Successful process control is heavily based on the availability of suitable online process instrumentation to provide the data and feedback necessary for its implementation. Online analysers can provide ash measurements in near real time and are the basis of modern quality control systems (Galetakis et al., 2009). Most modern coal preparation plants have adopted online ash analysers to measure coal ash rapidly and accurately. Commercial online ash analysis systems are based on different techniques such as gamma-ray, gamma-ray neutron-activation, natural gamma-ray activity and dual energy

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gamma-ray transmission (DUET) (Galetakis et al., 2009; Galetakis and Pavloudakis, 2009). Among the various types of online ash analysers, the most widely used is the DUET online ash analyser, which has an acceptable accuracy, short analysis time, good radiation safety, and relatively low cost. In conventional laboratory methods (sample combustion) and instrumental methods, measurement errors occur due to the influence of different disturbances on the measurement results (Cierpisz, 2006). The elemental composition of clean coal (for example, type of coal, size distribution of coal, and chemical composition of ash) and harmful substances doped in clean coal (for example, magnetic media and moisture) may cause measurement errors in ash analysers (Galetakis et al., 2009; Galetakis and Pavloudakis, 2009). As a consequence, measured values deviate from the true value. Such errors are meaningless in the product itself but may lead to out-of-control processing in the future; therefore, these errors should be taken seriously in SPC. In this study, ash analyser measurements were regarded as the monitoring variables of SPC, and the errors between the laboratory methods (burning method) and instrumental methods were not examined in detail.

The premise of a control chart is the analysis of process variation. It uses acceptable inherent process variation to determine rational control limits, which can be used to identify the abnormal variations in the actual production. A concrete description of the types of variability in the coal preparation process and an introduction to Shewhart control chart theory are provided in Section 2. The influence of the ash analyser counting time and the autocorrelation of the time series on structuring an applicative control chart are considered in Section 3. In Shewhart control chart theory, observations are divided into several subgroups, and the mean of each subgroup is detected by comparison with the control limits. The estimation of rational control chart parameters for a coal preparation process are introduced and analysed in Section 4. An application example is presented in Section 5 to discuss the potential positive impact in a coal preparation process. Finally, the paper is summarized and a topic for future research is presented in Section 6.

2. Types of coal processing variability and Shewhart control chart theory

2.1. Types of process variability in coal preparation

Control charts aid in the detection of unnatural patterns of variation in data resulting from repetitive processes and provide criteria for detecting a lack of statistical control. A process is in statistical control when the variability is only the result of random causes. Once the acceptable level of variation is determined, any deviation from that level is assumed to be the result of an assignable cause that should be identified and either eliminated or reduced.

The ISO 8258 standard proposes two types of variability. The first type is inherent variability due to the wide variety of random causes that are consistently present and not readily identifiable, each of which constitutes a small component of the total variability but none of which contributes a significant amount. Nevertheless, the sum of the contributions of all such unidentifiable random causes is measurable and is assumed to be inherent to the process. The elimination or correction of random causes requires a management decision to allocate resources to improve the process and system. The second type is abnormal variability, which represents a real change in the process. Such a change can be attributed to identifiable causes that are not an inherent part of the process and that can, at least theoretically, be eliminated. Furthermore, the abnormal variability may be subdivided different types according to different assignable causes. For example, some short-term and fugacious assignable causes may result in a special variation; and some long-term and continuous assignable causes may result in a systemic variation.

The coal preparation process is a dynamic process with a gas-liquid-solid multiphase mixture; thus, the factors that influence clean ash are highly complex and include the equipment, process, and ash analyser. Considering the characteristics of the coal preparation process, three types of variability for the process are proposed.

The first type of variability is the random variability caused by random errors due to the inherent characteristics of the object and the inherent variability in the process. Random variations present unclear and random patterns in the control chart but follow normal distributions. The statistical distribution of the observations over time for only random variability in the process is presented in Fig. 1. From the figure, the process output will grow into a stable distribution over time and can be predicted. This state can be considered as a process under control that does not require adjustment. In the coal preparation process, the random variation may be caused by the inherent error of the ash analyser, which is mainly derived from the statistical error of the photon number γ emitted from the radioactive source of the ash analyser. The inherent error of the ash analyser can be corrected by the counting time, which will be explained further in Section 3.1.

The second type of variability is the special variability caused by short-term assignable causes. It lies somewhere between the inherent variability and abnormal variability. Special variation is typically fugacious, intermittent, accidental, unpredictable and unstable and consists of many assignable variation sources that can be largely corrected. When special variation occurs, points beyond the control limits or a non-random chain or trend are presented in the control chart. The statistical distribution of the observations over time for exclusively special variability in the process is presented in Fig. 2. From the figure, the process output will grow into an unstable distribution over time and cannot be predicted. This state can be considered as a process that is out of control and that requires local measures to eliminate the assignable causes of variation in the process. In the coal preparation process, the measurement errors of the ash analyser and the short-term process fluctuations result in special variations. The short-term changing of the elemental composition of the coal itself (such as the nature of coal) and the large number of impurities that are doped in clean coal (such as the magnetic medium, and water) may result in momentary measurement deviations and process fluctuations. These assignable variation sources should be accepted in the control process if they are incidental or short term and slightly affect the entire process. However, a high incidence or long duration of these variations will influence the stability of the coal preparation process; in such cases, local measures should be taken to eliminate the corresponding assignable cause. Otherwise, the variations will likely develop into systemic variability, causing the process to become out of control and reducing the process capability.

The third type of variability is the systemic variability caused by certain and regular long-term assignable causes. It is abnormal variability and causes real changes in the process. These variations are continuous, predictable and stable and present points or a chain or trend toward a certain direction in the control chart. The statistical distribution of the observations over time for exclusively systemic variability in the process is presented in Fig. 3, which illustrates that the process output forms a stable trend and can be predicted. This state is considered an

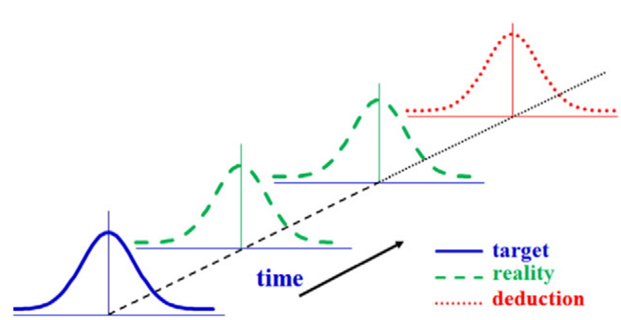

Fig. 1. Statistical distribution for exclusively random variability over time.