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Real-time resource model updating for improved coal quality control using online data

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ABSTRACT

In recent years a real-time resource model updating concept has proven to increase the material quality control and process efficiency in geostatistics. The real-time resource model updating concept integrates online-sensor data, measured from the production line, into the resource model. This integration quickly improves the accuracy of the resource model. The aim of this contribution is to adapt this concept into coal production and to apply the developed framework on an industrial case. The result of this study will provide an additional improvement to coal quality management, by mainly focusing on the ash content in the deposit. This includes high ash values in coal seams, which are caused by sand intrusions and are greatly affecting the operational process. A tailored Ensemble Kalman Filter approach, specifically applicable in coal production, is presented after a detailed literature review. For validation, a 2D case study is performed in a fully controllable environment. Further, the approach is benchmarked against an alternative proven approach. To demonstrate the value added a full scale industrial application is performed focusing on improving the lignite quality control in the production process. The results of integrating online measurement data into the resource model indicate a significant improvement (in the order of 70%) in coal quality production.

1. Introduction

In mining, modelling of the deposit geology is the basis for many actions to be taken in the future, such as predictions of quality attributes, mineral resources and ore reserves, as well as mine design and long-term production planning. The essential knowledge about the raw material product is based on this prediction, which comes with some degree of uncertainty. This uncertainty causes one of the most common problems in the mining industry, predictions on a small scale such as a train load or daily production are exhibiting strong deviations from reality.

Some of the most important challenges faced by the lignite mining industry are marine and fluvial sand intrusions located in the lignite deposit. These intrusions are translated in the coal seams as the high ash values (e.g. more than 15% ash). Most of the times, these high ash values cannot be captured completely by exploration data and in the predicted deposit models. This lack of information affects the operational process significantly.

The current way of predicting the coal quality attributes is using geostatistical interpolation or simulation to create resource models based on exploration data, which are very precise but separated by large distances. Mining companies have lately started to benefit from the recent developments in information technology, including online-sensor technologies for the characterization of materials, measuring the equipment efficiencies or defining the location of the equipment. KOLA (an abbreviation for Kohle OnLine Analytics) and RGI (radiometric measuring system) online-sensor measurements are two different sensor measurement systems that are recently used for assessing the components of the produced lignite. The precision of the data is lower than exploration data, which are analysed in laboratories. However, these data are much more dense than exploration data and provide additional information about the coal seam.

To benefit from this available dense data, a close loop concept for mining has recently been introduced (Benndorf et al., 2015). To enable fast online interpretation of online sensor data combined with an automated near-real time updating of the resource model, a new algorithmic approach was developed. This extends current practice in lignite mining, where data are analysed off-line in a laboratory. Reconciliation exercises to integrate these data are done regularly, however intermittent involving time lacks often weeks or months. The proposed concept

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offers to continuously fuse the measured sensor data with the resource model by using sequential resource model updating methods that originate from data assimilation.

A simple geostatiscal re-modelling may not be sufficient for sensor-based updating out of several reasons. The first reason is that the online sensors might be measuring blended material originating from different benches/blocks. To unambiguously track back and update, a filter solution is required. The second reason is that the quality of the online sensor data differs from exploration data and may require co-simulation procedures including models of co-regionalisation, which adds complexity. The third reason is the change of support, which has to be taken into account due to the different reference volumes of resource blocks and sensor measurements. The fourth and most important reason is that linking the measurement with the resource block location to be updated is not straightforward. Sensors are installed in several stations of the extraction chain. To link measurements with blocks, a forward predictor is needed. This can be for example a material tracking system.

The reasons mentioned above motivate to explore alternative approached instead of simple re-estimation.

Data assimilation methods offer the tools for fast incorporation of observations in order to improve predictions. The definition of data assimilation translates in mining as the process of combining the sensor measurement data with a prior estimation of the resource model, in order to produce a more accurate estimate. Methods of data assimilation have found many successful applications in various fields. With the aim of improved numerical weather forecast, (Bengtsson et al., 1981; Daley, 1993; Ghil et al., 1981; Houtekamer and Mitchell, 1998, 2001; Houtekamer et al., 2005) examined and applied different data assimilation methods on dynamic atmospheric models. Applications to oceanographic problems, such as estimation and prediction of ocean eddy fields, wave propagation etc., (Barbieri and Schopf, 1982; Budgell, 1986; Ghil and Malanotte-Rizzoli, 1991; Heemink and Kloosterhuis, 1990; Miller, 1986; Tuan Pham et al., 1998; Verlaan and Heemink, 1997; Webb, 1989) deepened and broadened the understanding of ocean circulation on regional, basin and global scales. Similar to this research, (Bertino et al., 2002) successfully combined geostatistics and data assimilation methods and applied it in a estuarine system. More recently in reservoir engineering (Brouwer et al., 2004; Nævdal et al., 2005, 2002; Sebacher et al., 2013) applied a similar framework of resource model updating approach. The mentioned applications are all performed on nonstationary, dynamical models due the nature of their research fields. The initial difference in application of the resource model updating concept among others comes from the requirement of the stationary, non-dynamic models.

(Benndorf, 2015) has proven the approach to work well within a synthetic case study under a variation of several control parameters (number of excavators, precision of the sensor, update interval, measurement interval, extraction mode/production rate). An extended version of the developed framework includes a Gaussian anamorphosis of grid nodes, sensor-based measurements and model-based predictions; to deal with suboptimal conditions, an integrated parallel updating sequence; to reduce the statistical sampling error without the need of increasing the number of realizations and a neighbourhood search strategy; to constrain computation time and to avoid the spurious correlations, is introduced by (Wambeke and Benndorf, 2015). Yet, so far, the amount of literature is little, particularly when considering the industrial application of the developed concept.

The purpose of this paper is to provide a tailored method, which was adapted to update coal quality attributes in a continuous mining environment, in order to improve the resource model accuracy. Providing more accurate deposit models will lead to an improvement in the detection of sand intrusions in future production areas. As a result, this approach will allow quicker reactions to gained knowledge, which in turn allows quick changes in mine planning and operational decisions.

The research questions driving this study are as follows:

- Is it possible to update the coal quality attributes, namely the ash contents, by using data assimilation methods, which have so far mainly been applied other contents, in order to improve the resource model accuracy and mine planning?
- Is the defined updating framework applicable for a full scale lignite production environment?

The findings of this research are expected to assist the operational decision making in lignite production and improve the future applications of the resource model updating concept.

The remainder of the article is structured as follows: First, the geological formation of the lignite seams and the development of the sand intrusions in Garzweiler mine are provided in order to explain the intrusions from a geological perspective. Thereafter, current online-sensor measurement technology information is given. Next, the principles behind the resource model updating framework developed for a specific application in continuous mining and the mathematical formulation, are presented. For verification, a 2D case study in a fully controllable environment and it's validation study are illustrated. Findings of the study are then presented. This is followed by an industrial application in Garzweiler mine, Germany. Results are discussed and summarised. The article concludes with a summary of the research contributions and directions for the future research.

2. Geology and the available sensor data

This chapter explains the geological formation of the lignite seams and introduces the development of the main problem caused by the sand intrusions in Garzweiler mine. Next, the available sensor data are presented in order to guide the reader towards the solution.

2.1. Geological formation of the lignite seams

In Tertiary (Oligocene) times, the subsidence of the Central Graben in the North Sea created the Lower Rhine Embayment (LRE) as southernmost extension of the Central Graben (Klostermann, 1991). A new sedimentary basin was created. The LRE contains up to 1600 m of these Oligocene to Pleistocene siliciclastic sediments with intercalated lignite attaining a thickness of up to 100 m (Hager, 1986). The lignite is of considerable economic importance and has been exploited in open cast mines and near-surface operations since the 18th century, at locations where the seams were easily accessible (Schäfer et al., 2005). Since then, the exploitation of the coal by RWE Generation SE - formerly Rheinbraun AG – is forming a vital basis of German power supply.

Sedimentation in the LRE was mainly influenced by fault block tectonics and variations in sea level. In Upper Oligocene, a 70 Ma long phase of high sea levels came to an end. Short term sea level fluctuations became typical (Haq et al., 1987). As a consequence, sequences of marine sands (representing a sea level high) intercalated with terrestrial silts, clays and lignite seams (sea level low) were sedimented. 18 Ma ago, in lower Miocene times (Burdigalian) the uplift of the surrounding highlands named “Rhenish Schiefergebirge” relative to its foreland slowed down. This decreased the sedimentary flows being accumulated in the LRE. At the same time, the climate warmed up. The temperature of North Sea shallow waters rose to 16 °C (Buchardt, 1978). Higher precipitation led to a subtropical climate and rising groundwater tables (Zagwijn and Hager, 1987). Vegetation could gain ground extensively and left behind peat, which gradually was converted into lignite.

The place of this research area, the mine Garzweiler, was part of the Venlo block. During two marine regressions, 17 and 15 Ma ago, the deposition of the later lignite seams Morken (named 6 A after (Schneider