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Analysis and assessment of a critical event during an underground coal gasification experiment

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ABSTRACT

The main goal of the study presented in this paper was to analyse the mechanisms affecting an Underground Coal Gasification (UCG) process and to identify possible deviations of the system from normal work to limit, or even avoid, losses. The UCG process is one of the most innovative technologies connected with the exploitation of coal deposits that are currently being tested and developed all around the world. It allows the conversion of a coal seam into gas under in situ conditions of high temperature with the use of gasifying agents such as air, oxygen, steam or with a mixture of them.

The paper presents the results of the analysis and assessment of a critical event during the process: a dangerous gas accumulation that occurred during an underground coal gasification experiment in the Experimental Mine "Barbara" of the Central Mining Institute (Poland). The UCG experiment using the shaft method is described, together with its monitoring system and the problems that appeared during the process. The application of the Fault Tree Methodology allowed the establishment of the main factors that may lead to the explosion and to present possible scenarios of its occurrence.

Moreover, calculations were carried out to evaluate the risk level of explosion for the gas mixture and the minimum level of oxygen in the mixture that is necessary to initiate an explosion. These calculations were based on a modification of the formula proposed by Le Chatelier. During the course of the underground experiment, original information of the process behaviour has been acquired that can be used in the preparation of other UCG experiments in operational mines to guarantee the safety and the stability of the process.

1. Introduction

All new technologies planned to be implemented on an industrial scale should be thoroughly tested. Problems arising during the development of industrial processes often result from a lack of historical data on previous causes and circumstances of incidents, accidents and other failures. Such data are an essential source of information about problems that may occur during the start-up, operation and stopping process of installation tests. Research focused on the analysis of the mechanisms affecting a particular process and the identification of possible deviations from normal work of the system allows for the limiting, or even the avoiding, of losses. The UCG technology is currently being tested and developed both in Europe and around the world. The idea of UCG started at the beginning of the twentieth century in England (Klimenko, 2009; Siemens, 1868), and the first test of UCG was conducted in Russia (Dinis da Gama et al., 2010; Dziunikowski, 1968; Rauk, 1976). In contrast to standard exploitation methods, gas from coal is directly acquired in situ by providing the gasification agent into the ignited coal seam and collecting the gas on the surface (Siemens, 1868). The UCG process is analogous to the technology of coal gasification on the surface; however, UCG is more complex and difficult during the implementation process (Stańczyk et al., 2012). During the gasification process, coal in the seam reacts with a gasification agent such as air, oxygen, vapour or a mixture of these agents in specific proportions (DTI, 2005).

There is a need for further research of the UCG technology to evaluate its use on remaining coal resources in protection pillars and in unexploited coal beds in mined areas of active mines, as well

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as in liquidated mines. The process of UCG requires control systems for parameters such as the water flow rate, distribution of gasifying agents in the gasification area, velocity of process flow transfer (that may be calculated only by a temperature measurement), and qualitative and quantitative composition of the process gas (Rauk, 1976).

There are several methods of the UCG process. The two basic ones are the shaft-less method (with boreholes), based on reaching the coal seam through boreholes made from the surface, and the shaft method, where the coal seam is reached through a shaft or a descending gallery (Dziunikowski, 1968; Wiatowski et al., 2012).

In this paper, the issues and challenges of a UCG process with the shaft method together with the analysis and assessment of the risk of a critical event occurrence such as a gas explosion are presented. All of the analyses are based on results from the underground UCG test conducted in 2010–2013 in the Central Mining Institute in Katowice, Poland. The research was oriented towards acquiring gas with a high level of hydrogen content during the UCG process. Underground and aboveground installations were built to carry out tests of the gasification process on a semi-industrial scale. The installations were constructed as a part of the Experimental Mine "Barbara" project. An underground reactor was located 30 m deep, in close proximity to an exhausting shaft, and its location was surrounded by galleries reinforced with concrete with streamlined ventilation. The UCG tests were preceded by experiments conducted on the surface in an ex situ reactor (Smoliński et al., 2012a, 2012b, 2013; Stańczyk et al., 2010a, 2010b; 2011, 2012; Wiatowski et al., 2012) and modelling the coal gasification process using numerical fluid mechanics (Cempa-Balewicz et al., 2013).

2. Design of the underground reactor

The first stage of a UCG experiment is to choose a proper location and to design and construct an underground reactor. This reactor includes a part of the selected coal seam together with technological boreholes, responsible for the supply of gasification agents (oxygen, air, and water vapour) and the carrying of the process gas out to the surface. The UCG process starts with the ignition of coal from the seam in a gasification channel. Providing a gasification agent causes the development of the gasification process, whereas the front of the process moves along the direction of the process gas carried out to the surface (Kapusta and Stańczyk, 2009). It must be emphasized that the gasification process may flow in opposite directions as a result of the low velocity of the process.

The process of a semi-industrial UCG experiment was conducted in the Experimental Mine "Barbara" in August 2013, with an underground reactor located in the same place as the experiment carried out in 2010, 30 m deep. The underground reactor was placed in coal seam 310, surrounded by galleries made with brick and concrete casing. Fig. 1 presents an entrance to the borehole OI (ϕ 0.185 m) used for gasification product supply.

The galleries surrounding the selected parcel of seam 310 used streamlined ventilation; the air flow rate was 1 m^3/s and moved around the underground reactor's parcel. Air flow directions, together with air flow rates in the ventilation system around the underground reactor, are presented in a simplified diagram in Fig. 2. The air distribution method and the air flow rate in the ventilation system at the 30-m level were selected to limit the

Fig. 1. An entrance of the supply borehole OI, trespassing brick and concrete casing surrounding the underground reactor, responsible for media supply to the gasification process.