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Underground coal gasification – Part II: Fundamental phenomena and modeling

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A B S T R A C T

Underground coal gasification can convert deep coal into synthesis gas for use in the production of electricity, fuels and chemicals. This paper provides a review of the fundamental physical phenomena in underground coal gasification and associated modeling efforts. The relevant fundamentals of coal gasification are described and the phenomena of cavity growth at the sidewall and roof of the underground cavity are examined in detail. The transport phenomena and chemical reactions occurring in the permeable bed of char and ash and the void space are reviewed. The modeling of the transport of heat and mass, including contaminants, in the near- and far-fields surrounding an underground coal gasifier are also summarized. An overview of the geomechanical phenomena and the coupled interactions between transport and mechanical phenomena are provided. Finally, integrated UCG models are reviewed and recommendations for future model development are provided.

Contents

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1. Introduction

Underground coal gasification (UCG) is the process of converting hydrocarbon materials into synthesis gas in-situ. The process has been developed over more than a century and many aspects of the process are well understood. Despite this, no large scale commercial UCG plants have been constructed recently, with only one Soviet-era plant from the 1960s still operating in Uzbekistan. Various articles and studies indicate that UCG is technically feasible and economically attractive as a method to utilize the energy of deep coal resources (e.g. [1–8]) and there is ongoing interest to develop the technology in several nations with large coal reserves, such as China, India, Pakistan, Bulgaria and Poland [9–12].

Reviews on UCG have been reported by Gregg and Edgar [13], Shafirovich et al. [14], Bhutto et al. [15] and Khan et al. [16]. This paper, which is Part II of a two part series, focuses on the fundamental physical phenomena occurring within UCG together with associated modeling efforts. Fig. 1 shows a schematic of an underground coal gasifier and the main zones which are reviewed in this paper, including the sidewall and roof, the permeable bed, the void space and the near-field which immediately surrounds a UCG cavity. Beyond the near-field, there exists the far-field which is not shown on Fig. 1. The physics of cavity growth, permeable bed gasification and transport phenomena in the void spaces within a developing cavity are comprehensively examined in this work. The controlling physics in the various regions of the gasifier are investigated and the transport and geomechanical phenomena in the near- and far-fields surrounding an underground coal gasifier are reviewed. Collectively, this work provides a comprehensive review of the fundamental phenomena and mathematical modeling of underground coal gasification.

2. Phenomena of coal gasification in UCG

2.1. Coal pyrolysis

The first stage of coal gasification in UCG, is the slow heating and pyrolysis of large blocks of coal. Moisture is evaporated at low temperatures (~100 °C) and at higher temperatures (~350–600 °C) pyrolysis occurs over many hours and is accompanied by simultaneous changes in chemical and physical structure [17–19]. Heating rates in UCG are on the order of 1 to 10 °C/min, which is much slower than in other coal gasification technologies, such as fixed and fluidized beds. For low rank coals with moisture contents greater than ~15 wt% coal pyrolysis leads to extensive decrepitation, increases porosity and permeability and leads to shrinkage and fissuring of the coal matrix [20,21]. Under in situ conditions, it is believed that many lower rank coals fail mechanically, breaking into pieces and falling into the developing cavity, in a process known as thermo-mechanical spalling [22]. The relatively high volatile content of low rank coals makes them easier to ignite and the decrepitation of the coal matrix increases the surface area available for reaction and does not inhibit the transport of heat and mass [20]. High rank coals, such as bituminous coals, are more likely to soften and may go through a plastic phase, in which gas bubbles form from the release of volatile matter, grow and migrate through the softened coal matrix inhibiting heat and mass transport [23].

Experimental studies performed with small coal particles show that the ultimate yield of the volatiles released from the coal