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Coupled Thermal-Hydraulic-Mechanical-Chemical Simulation for Underground Coal Gasification

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China, as the world's foremost consumer and producer of coal, portrays an energy landscape marked by an abundance of coal, a scarcity of oil, and a limited presence of natural gas. The collective coal consumption exceeds half of the global total, and there is an expectation that coal will continue to play a predominant role in the energy paradigm for an extended future period. However, a significant portion of China's coal reserves is situated in deep strata, presenting formidable challenges arising from intricate geological conditions. Consequently, the imperative to innovate advanced technologies for the clean and efficient extraction of coal, particularly from deep seams, becomes paramount.

Underground Coal Gasification (UCG) emerges as a viable, sustainable approach for exploiting these deep-seam coal deposits. This intricate process involves multifaceted elements such as heat transfer, fluid dynamics, mechanics, and chemical reactions, posing significant complexities for effective management. While the UCG in deep seams primarily relies on injection and production controls, the lack of transparency hampers the identification of optimal operational parameters. Addressing these intricacies necessitates the development of a comprehensive numerical simulation model that integrates mechanical, fluid, chemical, and thermal dynamics. In this research, we introduce a Thermal-Hydraulic-Mechanical-Chemical (THMC) model employing sequential coupling, further enriched by an interface code linking the reservoir simulator with the geomechanics module. A pivotal component of our investigation centers on discerning the influence of geomechanics on porosity and permeability during the UCG process, alongside evaluating stress distribution within the cavity to assess potential risks of spalling and collapse.

The results elucidate that, during UCG, coal undergoes heating and decomposition, resulting in the formation of coal char. The interaction between the char and the gasification agent initiates a multifaceted chemical reaction, yielding gases such as CO, CO2, H2, CH4, among others. Notably, the temperature within the coal seam can reach a peak of 1500℃, giving rise to the development of a semi-circular cavity. Intriguingly, the boundary of this cavity coincides with the region exhibiting the highest concentration of CO2. It is observed that as the injection pressure and flow rate of the gasification agent increase, there is a corresponding rise in the amount of syngas calorific value and CO2, along with the amount of coal processed per unit time. However, this increase ultimately diminishes the energy conversion efficiency of coal gasification. The composition of the gasification agent emerges as a pivotal factor in the UCG process. For example, water has the capacity to augment the rate of coal consumption, promote CH4 production, and elevate the calorific value of the syngas. Nevertheless, an excess of water can lead to a reduction in operational temperature, impeding the generation of high-calorific syngas. Furthermore, the presence of CO2 in the gasification agent can augment CO production without adversely affecting the properties of the syngas. In the upper reaches of the cavity, stress concentrations are discernible, with shear stresses registering several times higher than their initial levels. This phenomenon induces deformation around the cavity.

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Primary authors: HU, Zhuocheng (China University of Petroleum (East China)); YAO, Jun (China University of Petroleum); SUN, Hai (China University of Petroleum (East China))

Presenter: HU, Zhuocheng (China University of Petroleum (East China))

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