Geophysical Research Abstracts
Vol. 20, EGU2018-6479, 2018
EGU General Assembly 2018

Interactions between underground coal fires and air infiltration through cracks driven by thermal buoyancy force

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Underground coal fires (UCFs) have been slowly shaping lithosphere by geomorphic (Kuenzer and Stracher 2012), metamorphic, and mineral means for at least several million years (Heffern and Coates 2004). This pace becomes fast and extensive at modern times, trigged by massive mining activities (Song and Kuenzer 2014). Air infiltration through cracks into underground coal seams is an essential condition for UCFs. Air infiltration could be driven by atmospheric fluctuation, topographic effect, wind force and thermal buoyancy force induced by hot smoke from UCFs. Recently, fieldwork demonstrated that thermal buoyancy force played a predominant role in air infiltration (Krevor, Ide et al. 2011). However, an in-depth and key issue, that is, how air infiltration and UCFs interact with each other, remains unknown yet. We developed a novel experimental framework in laboratory to explore this issue. This framework highlights hydraulic-thermal-chemical effects of UCFs, ignoring thermal-mechanical effects on the overlying rocks. All experiments were conducted in a sealed large-scale laboratory to exclude wind. Several factors e.g., depth, crack size, coal-bed permeability and coal rank (high-volaite bitumious and semi-anthracite) were considered. Air velocity, coal-bed temperature, smoke temperature and concentrations (O_2, CO_2, CO, and NO) were on-line measured. Results showed that at beginning of UCF air flow was quite small (<3.4 L/min) due to weak thermal buoyancy of low-temperature smoke ($\sim$50 Celsius degree). Nevertheless, such small air flow was sufficient for sustaining smoldering combustion once coal bed was heated to a certain temperature (bituminous: 600 Celsius degree and semi-anthracite: 800 Celsius degree). In this case, the ratio of CO/CO_2 was approximately 0.238 ± 0.062 and 0.415 ± 0.025 for bituminous and semi-anthracite, respectively. With temperature rise, volatile came out of coal due to pyrolysis and coal bed became shrank, which was crucial for the following UCF dynamics and air infiltration. For high volatile bituminous, gas flow pressure difference between coal bed increased remarkably because coal bed was shrunken by 71.4%, resulting in mutual enhancement of air infiltration and temperature rise. The maximum of CO/CO_2 of bituminous was increased by 14-24 times depending on depth and crack size. By contrast, for semi-anthracite, coal bed was barely shrunken (shrunken volume = 28.57%), leading to stable air infiltration, smoldering temperature and CO/CO_2 ratio. It is the first time that interactions between UCFs and air infiltration through cracks driven by thermal buoyancy force are revealed by the novel experimental framework, which helps to understand geochemistry mechanism of UCFs.

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