Mechanisms of gas migration in flooding post-mining context

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Abstract The French National Institute for Industrial Environment and Risks (INERIS), in a support mission to state services and as a partner of the European project FLOMINET, is studying gas migration during and after mine flooding. In situ flow measurements and laboratory records acquired with an experimental device are being used to study gas transfer and to characterize the influence of hydrostatic pressure on methane release from coal. In parallel, several models are in development using the HYTEC code to describe mine methane migration. The combined use of numerical and experimental approaches will make it possible to improve risk prevention concerning surface gas emission above the old mines.

Key Words gas migration, flooding, methane, post-mining

Introduction

Residual mine voids, during exploitation and after closing, have significant environmental impacts. Numerical models are being developed to characterize the impact of old mines at the watershed scale. The French National Institute for Industrial Environment and Risks (INERIS) is studying the mechanisms of gas transfer and migration in flooded mines, in partnership with MINES ParisTech and as a partner of the European project FLOMINET (FLOoding management for underground coal MInes considering regional mining NETworks) program. The mines we are interested in are the coal mines of the Lorraine basin (in northeastern France). Among the diverse underground gas products, this study is restricted to methane, carbon dioxide and radon. In this paper, we will focus on methane, CH_4.

This study has two main objectives: to characterize underground mine gas migration and to determine the influence of flooding on mobilization of sorbed gases. Several gases are naturally produced by rocks, so mine voids can contain different gases, for example methane from coal beds (e.g. Doyle 2001; Scott 2002; Besnard 2004). According to Scott (2002), hydrologic parameters significantly influence gas distribution in coal beds. During flooding, two phases are passing through mine voids and porous media: a gaseous phase and water. Despite the dissolution of a part of the gaseous phase, two-phase flow occurs in old mines, pushing the gas with water and/or bubble flow. Due to competition between CH_4 and water molecules for sorption sites (Joubert et al. 1973; Doyle 2001; Crosdale et al. 2008; Charrière,2009), mine water can be enriched in CH_4 and carry it through galleries, fractures, porous media, possibly up to the surface. The water can degas where pressure decreases, either naturally or due to pumping. The released gas can accumulate under gastight structures, like the caps of obstructed wells.

Methods

Aiming to improve our knowledge of gas migration during and after flooding, two complementary tools are being used: an experimental device and a numerical approach. The experimental device makes it possible to reproduce the effects of coal flooding; the results are used in numerical models which simulate the migration of CH_4 in old mines.

Laboratory experiment (CASPER)

An experimental device named CASPER (sorption capacity under high hydrostatic pressure during rock flooding) has been developed at INERIS to evaluate gas sorption and gas release under variable hydrostatic pressure. It reproduces the depth conditions in water-saturated context in an autoclave cell. At the equilibrium, we measured the released quantity of CH_4. The main objective of this experimental device is to determine the necessary hydrostatic pressure level to stop gas release from coal. This topic has already been introduced by Pokryszka et al. (2005) and Pokryszka and Krauser (2007). Knowledge of this parameter is essential to estimate the possibility of gas migration from flooded mines to the surface.

Modelling with HYTEC

A reactive transport model developed by MINES ParisTech: HYTEC (van der Lee et al. 2003) simulates migration of aqueous species, and has recently been improved to take into account gas migration. Numerical models are developed in order to reproduce and characterize methane migration during and after mine flooding. Several parameters are considered: the saturation of the media, the porosity, the permeability, the diffusivity, the dispersion. The methane sorption phenomenon on coal has been defined for our particular case with the geochemical module CHESS. Considering the solubility of CH_4 at a given temperature and pressure, and the properties of coal, we have been able to determine sorption constants under high hydrostatic pressure.

Results

Laboratory experiment

A first run was performed with a reduced apparatus (still incomplete monitoring environment). The obtained qualitative results were consistent with the solubilities calculated using the Duan and Mao (2006) model. The experimental results were compared with predictions based on our hypothesis concerning the dissolution of CH_4 after desorption from the coal surface.

The CASPER device is currently being improved. Once the device is complete and the gas chromatograph calibrated, and the first tests with the ROLSI™ are performed, further quantitative results will be available. The CASPER device will allow for the monitoring of the evolution of dissolved CH_4 and validate that equilibrium is reached. Additionally, the kinetic of desorption under high hydrostatic pressure will be characterized.

Simulation of CH_4 migration and flooding

The first step of modelling was to determine adsorption constant of the experiment. Figure 1 shows the CH_4 adsorption equilibrium curve on coal surface in flooded conditions. Once this constant is established at given temperature and pressure, the coal influence can be taken into account within migration models. The next step was to reproduce CH_4 migration through different structures like galleries, wells and fractures including sorption on coal. For lack of strong sorption data yet, we will focus on migration mechanisms at the gallery scale.

Considering a CH_4-enriched water that enters a flooded gallery surrounded by a damaged zone connected to a fracture, the migration of aqueous CH_4 has been simulated (fig. 2): in this scenario, the model highlights the effect of a fracture on the migration of a CH_4-enriched plume.

Galleries and open fractures are preferential pathways for water flow. As a consequence, they enhance the migration of dissolved CH_4. Figure 2, which shows two different models results, il-

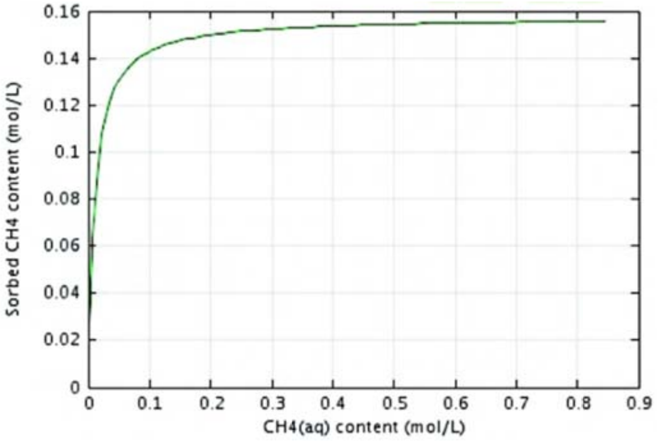

Figure 1 *CH_4(aq) adsorption equilibrium curve on coal at 25 °C and 25 bar (experimental conditions)*

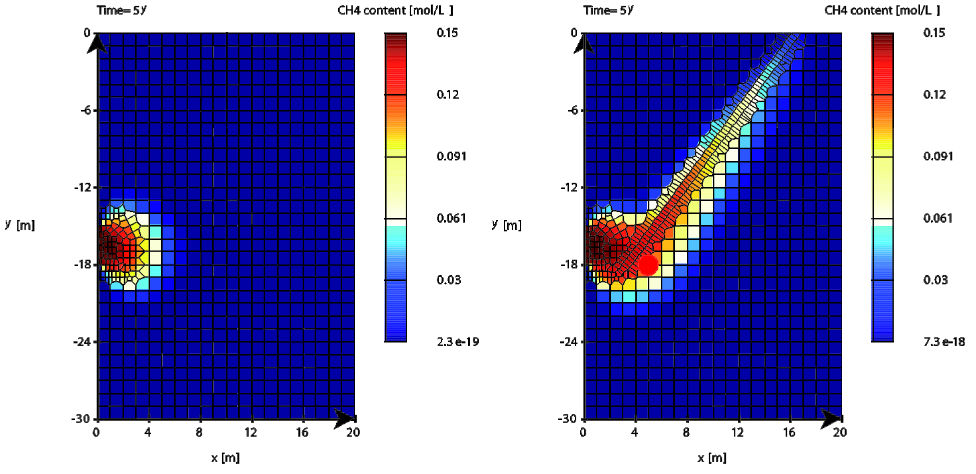

Figure 2 *Migration of aqueous CH_4 through fresh porous medium (left) and fractured rock (right), with a head gradient equal to 0.01 after 5 years simulation. The red point corresponds to the evolution curves of figure 3*

lustrates the effect of a fracture on aqueous CH_4 migration. In the case of a gallery surrounded by a fresh rock, the CH_4 plume spreads over 7 m on the horizontal axis within 5 years simulation. When the gallery is connected to a fracture, the CH_4 plume front reaches 14 m on the horizontal axis in the same time interval. When the water rises to the surface, surface emission of methane (or other gases) can be increased. Indeed, it appears that a fracture connected to a gallery can enhance the migration of methane to the surface, as a function of its own geometry and hydrodynamic properties. The damaged zone surrounding the gallery can also act like a drain.

The presence of coal in the medium induces CH_4 adsorption. Figure 3 shows the evolution of the distribution of CH_4 in the rock at 2 m from the damaged zone, just below the fracture. As the CH_4 penetrates the porous medium, the sorption sites on the coal surface are progressively saturated.

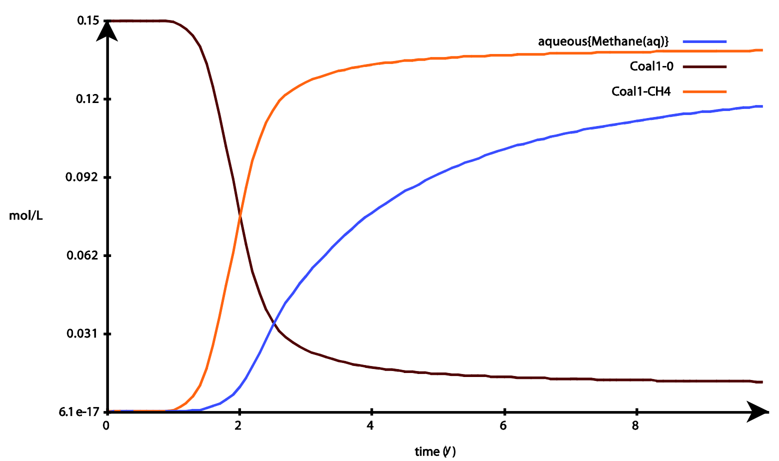

Figure 3 *Evolution of the CH_4 distribution in the coal-water system in the fresh rock at the red point of the figure 2.The blue curve is the free CH_4 content; Coal1-CH4 is the bound CH_4 content; Coal1—0 is the empty sites content*

The third part of modelling aims to reproduce mine flooding. These models are still in development, and will not be further discussed in this paper.

Conclusions and perspectives

The experimental device gave an initial result that was consistent with the solubility model of Duan and Mao (2006). It also confirmed the hypothesis of competition of water and methane molecules on sorption sites. The results are used in numerical models to investigate the parameters of CH_4 sorption on coal. This work will make it possible to precisely quantify the CH_4 release from flooded coal and improve our knowledge of sorption kinetic under high hydrostatic pressure.

The numerical models showed the influence of various structures like galleries, damaged zones, and fractures. Permeable structures enhance the transfer of aqueous CH_4. Our models also account for CH_4 adsorption on coal during the migration of the enriched plume. We are also able to reproduce mine flooding and we are improving the models to better simulate the reality of the Lorraine basin, reproducing gallery filling and medium saturation. Also two-phase flow is currently incorporated to HYTEC: making it possible to describe gas diffusion in porous medium. Combined flow of gas and water in mine voids will thus be integrated in our models.

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