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Water chemical evolution in Underground Pumped Storage Hydropower plants and induced consequences

Estanislao Pujades[a,]*, Philippe Orban[a], Anna Jurado[a], Carlos Ayora[b], Serge Brouyère[a], Alain Dassargues[a]

[a]*Hydrogeology and Environmental Geology, Geo3, Dpt ArGEnCo, Aquapole, University of Liege, 4000 Liege, Belgium*
[b]*GHS, Institute of Environmental Assessment & Water Research (IDAEA), CSIC, Jordi Girona 18-26, 08034 Barcelona, Spain*

Abstract

Underground Pumped Storage Hydropower (UPSH) is an alternative to manage the electricity production in flat regions. UPSH plants consist of two reservoirs of which at least one is underground. For this last reservoir, abandoned mines could be considered. UPSH related activities may induce hydrochemical variations, such as the increase of the oxygen (O_2) partial pressure (pO_2), which may entail negative consequences in terms of environment and efficiency, especially in coal mined areas where the presence of sulfide minerals is common. This work assesses the main expected environmental impacts that UPSH using abandoned coal mines may induce.

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Keywords: Groundwater; Coal mine; Pumped Storage Hydropower; Reactive transport

1. Introduction

One of the main concerns with respect to solar and wind energies, is that the electricity production is highly variable and is hardly adapted to the demand [1-5]. This fact tends to reduce their efficiency and limits their applicability. Energy storage systems (ESSs) are needed to manage the electricity production from renewable

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sources and increase their utilization [6]. Underground Pumped Storage Hydropower (UPSH) [7] is an ESS that allows a large amount of electricity to be stored and produced. UPSH plants consist of two reservoirs, the lower one is underground while the upper one is located at the surface or at shallower depth [8]. The main advantage of UPSH is that it is not limited by the topography. Thus, UPSH is a potential alternative to manage the electricity production in flat regions, where conventional Pumped Storage Hydropower plants cannot be installed.

The underground reservoir for UPSH plants can be excavated, but possibly the cheapest option, which is that considered in this work, consists in using abandoned underground cavities such as deep mines. The main concern regarding the use of abandoned mines is that their walls are not generally impervious, and thus pumped and stored water will interact with the surrounding porous medium. In previous studies, this interaction only has been considered from a water flow point of view determining the impacts produced by the water exchanges (1) on the natural piezometric head of the surrounding porous medium [9,10], and (2) on the efficiency of the plant [11,12]. Here, we focus on hydrochemistry modifications induced by UPSH related activities and predicted associated impacts on the environment.

In a hypothetical UPSH plant using an abandoned mine, pumped water to the surface (i.e., upper) reservoir is aerated and its initial chemical composition evolves to be in equilibrium with the atmosphere leading to an increase of pO_2 and associated chemical reactions. In addition, when this water is released into the underground reservoir, this may react with the surrounding porous and fractured medium and with the water occupying the reservoir. It may induce the precipitation or dissolution of minerals and its associated impacts (e.g., reduction or increase of the pH). In the specific case of abandoned coal mines, where sulfides are frequent [13], the increase of pO_2 in the upper reservoir may induce sulfide oxidation when the water is released in the underground reservoir. This fact would lead to very low pH values [14] (i.e., acidification) and then affect the surrounding groundwater quality through the seepage exchange fluxes between the underground reservoir and the surrounding geological layers.

It is thus of paramount importance to assess the environmental impacts and hydrochemical variations induced by UPSH when abandoned coal mines are used. This assessment must be done with regards to the Water Framework Directive [15] adopted by the European Union in October 2000, requiring that nations must guarantee the “good state” of the “water bodies”. Here, those groundwater quality impacts are investigated through a numerical reactive transport model. The main objective of this study is to establish potential impacts on the environment and highlight the importance of considering them for the design of future UPSH plants.

2. Materials and methods

2.1. Problem statement

The problem is sketched schematically in Fig. 1. The underground reservoir consists in a cavity of 50 by 50 m on 10 m height. The top and bottom of the underground reservoir are at 95 and 105 m depth, respectively. The underground reservoir is linked to the surface through a shaft of 10 by 10 m on 95 m height. The surrounding porous medium is 200 m thick and the external boundaries of the model are located at a 1000 m distance far from the underground reservoir. Under natural conditions, groundwater flows along the domain from the west to the east boundary since the head is chosen at 90 and 110 m depth on the west and east boundaries, respectively. The unconfined aquifer has a saturated thickness ranging between 110 and 90 m. In the central part of the domain, where the underground reservoir is located, the initial natural water level is corresponding to the top of the reservoir (95 m depth). Thus, it is totally saturated at the beginning.

Representative results are obtained assuming day/night cycles of 12 hours (i.e., water is pumped during 12 hours and released during the next 12 hours). Pumping/injection rates are 43000 m^3/d. Thus, the underground reservoir is almost emptied and filled during each pumping/injection cycle (only 1.4 m remains saturated after pumping).