Thermal energy storage in old flooded mines: how to tackle the hydrogeological issues

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Groundwater in flooded abandoned mines could be used for geothermal purposes using heat pumps and an open loop involving pumping and re-injection. Hydraulic conductivity values of the mined rock zones have been artificially increased. However, long-term efficiency and the possible impacts of geothermal doublets must be studied involving a series of hydrogeological challenges. Hot water would be pumped from the deep parts of the mine works, and cold water re-injected in a shallower gallery or in shallow fractured rocks, with a seasonal flow inversion for building cooling during the hot season. Indeed, a 'short-cut' groundwater flow is to be avoided between the deep and the shallow parts of the mine. The true geometry of the interconnected network of open galleries and shafts can be highly complex and must be conceptualized realistically to ensure that the model is feasible but also reliable. This model must involve groundwater flow and heat transport, with temperature-dependent density and viscosity, in a complex 3D heterogeneous domain made of highly fractured rocks and partially collapsed exploitation zones, galleries, and shafts. Such a model is nevertheless widely recommended to design and optimize the short-, mid-, and long-term efficiency of the geothermal system as well as to assess possible environmental impacts. An example of simulations on a synthetic case will be used for illustration and preparation work before further application on a real case study.

References

- Abesser, C., and Walker, A. 2022. Geothermal Energy. POST Brief 46. Available at: https://researchbriefings.files.parliament.uk/documents/POST-PB-0046/POST-PB-0046.pdf
- Adams, C., Monaghan, A., and Gluyas, J. 2019. Mining for Heat. *Geosciences* 29 (4), 10–15.
- Bailey, M.T., Gandy, C.J., Watson, I.A., Wyatt, L.M. and A.P. Jarvis. 2016. Heat recovery potential of mine water treatment systems in Great Britain, *International Journal of Coal Geology* 164: 77-84.
- Banks, D., Athresh, A., Al-Habaibeh, A. and Burnside, N., 2019, Water from abandoned mines as a heat source: practical experiences of open- and closed-loop strategies, United Kingdom, *Sustainable Water Resources Management* 5: 29-50.
- Bulté M., Duren T., Bouhon O., Petitclerc E., Agniel M. and A. Dassargues. 2021. Numerical modeling of the interference of thermally unbalanced Aquifer Thermal Energy Storage systems in Brussels (Belgium). *Energies* 14, 6241.
- Burnside, N. M., Banks, D., and Boyce, A. J. 2016. Sustainability of Thermal Energy Production at the Flooded Mine Workings of the Former Caphouse Colliery, Yorkshire, United Kingdom. *Int. J. Coal Geol.* 164, 85–91.
- Chudy, K. 2022. Mine Water as Geothermal Resource in Nowa Ruda Region (SW Poland). *Water* 14,136.
- Dassargues A., 2018. *Hydrogeology: groundwater science and engineering*, 472p. Taylor & Francis CRC press, Boca Raton.
- Dassargues A. 2020. *Hydrogéologie appliquée : science et ingénierie des eaux souterraines*, 512p. Dunod. Paris.
- De Paoli, C., Duren, Th., Petitclerc, E., Agniel, M., and Dassargues, A. 2023. Modelling interactions between three Aquifer Thermal Energy Storage (ATES) systems in Brussels (Belgium). Special Issue on Advances in Underground Energy Storage for Renewable Energy Sources, Volume II. *Applied Sciences* 13, 2934
- Eppelbaum, L., Kutasov, I. and A. Pilchin. 2014. *Applied Geothermics*, Series: Lecture Notes in Earth System Sciences. Berlin Heidelberg :Springer-Verlag.
- Florea, L. J., Hart, D., Tinjum, J. and C. Choi. 2017. Potential impacts to groundwater from ground-coupled geothermal heat pumps in district scale. *Groundwater* 55(1): 8-9.

- Fossoul, F., Orban, P. & Dassargues, A., 2011, Numerical simulation of heat transfer associated with low enthalpy geothermal pumping in an alluvial aquifer, *Geologica Belgica*, 14(1-2), pp. 45-54.
- Fox, D. B., Koch, D.L. and J. W. Tester.2016. An analytical thermohydraulic model for discretely fractured geothermal reservoirs, *Water Resources Research* 52 : 6792–6817.
- Fraser-Harris, A., McDermott, C., Receveur, M., Mouli-Castillo, J., Todd, F., Cartwright-Taylor, A., Gunning, A. and M.Parsons, 2022, The Geobattery Concept: A Geothermal Circular Heat Network for the Sustainable Development of Near Surface Low Enthalpy Geothermal Energy to Decarbonise Heating. *Earth Sciences, Systems and Society* 2:10047
- Gluyas, J. G., Adams, C. A., and Wilson, I. A. G. 2020. The Theoretical Potential for Large-Scale Underground Thermal Energy Storage (UTES) within the UK. *Energy Rep.* 6, 229–237.
- Gonzales-Quiros, A. and J.P. Fernandez-Alvarez, 2019, Conceptualization and finite element groundwater flow modeling of a flooded underground mine reservoir in the Asturian Coal Basin, Spain. *Journal of Hydrology* 578: 124036.
- Gossler, M. A., Bayer, P., Rau, G. C., Einsiedl, F., & Zosseder, K. 2020. On the limitations and implications of modeling heat transport in porous aquifers by assuming local thermal equilibrium. *Water Resources Research*, 56, e2020WR027772.
- Graf T. and C.T. Simmons. 2009. Variable-density groundwater flow and solute transport in fractured rock: Applicability of the *Tang et al.* [1981] analytical solution. *Water Resources Research* 45 :W02425.
- Hall, A., Scott, J. A., and Shang, H. (2011). Geothermal Energy Recovery from Underground Mines. *Renew. Sustain. Energy Rev.* 15, 916–924.
- Hamm, V. and B. Bazargan Sabet. 2010. Modelling of fluid flow and heat transfer to assess the geothermal potential of a flooded coal mine in Lorraine, France. *Geothermics* (39) :177-186.
- Hermans, T., Wildemeersch, S., Jamin, P., Orban, P., Brouyère, S., Dassargues, A. and F. Nguyen. 2015. Quantitative temperature monitoring of a heat tracing experiment using cross-borehole ERT, *Geothermics* 53 : 14-26.
- Hoffmann R., Goderniaux P., Jamin P., Chatton E., de la Bernardie J., Labasque T., Le Borgne T. and A. Dassargues, 2020. Continuous dissolved gas tracing of fracture-matrix exchanges. *Geophysical Research Letters* 47(17): e2020GL088944
- Hoffmann R., Maréchal J.C., Selles A. and A. Dassargues. 2022. Heat tracing in a fractured aquifer with injection of hot and cold water. *Groundwater* 60(2): 192-209.
- Huysmans, M. and A. Dassargues. 2005. Review of the use of Peclet numbers to determine the relative importance of advection and diffusion in low permeability environments. *Hydrogeology Journal* 13(5-6) : 895-904.
- Kabuth, A., Dahmke, A., Beyer, C., Bilke, L., Dethlefsen, F., Dietrich, P., Duttmann, R., Ebert, M., Feeser, V., Görke, U.-J., Köber, R. Rabbel, W., Schanz, T., Schäfer, D., Würdemann, H. and S. Bauer. 2017. Energy storage in the geological subsurface: dimensioning, risk analysis and spatial planning: the ANGUS+ project. *Environmental Earth Science* 76: 23.
- Klepikova, M., Wildemeersch, S., Jamin, P., Orban, Ph., Hermans, T., Nguyen, F., Brouyere, S. and A. Dassargues. 2016. Heat tracer test in an alluvial aquifer: field experiment and inverse modelling, *Journal of Hydrology*, 540 :812-823.
- Love, A. J., Simmons, C.T. and D. A. Nield. 2007. Double-diffusive convection in groundwater wells, *Water Resources Research* 43(8) : W08428.
- Ma, R. and Ch. Zheng. 2010. Effects of density and viscosity in modeling heat as a groundwater tracer. *Ground Water* 48(3) : 380–389.
- Monaghan, A.A., Bateson, L, Boyce, A.J., Burnside, N.M., Chambers, R, de Rezende, J.R., Dunnet, E., Everett, P.A., Gilfillan, S.M.V., Jibrin, M.S., Johnson, G., Luckett, R., MacAllister, D.J., MacDonald, A.M., Moreau, J.W., Newsome, L., Novellino, A., Palumbo-Roe, B., Pereira, R., Smith, D., Spence, M.J., Starcher, V., Taylor-Curran, H., Vane, C.H., Wagner, T. and Walls, D.B., 2022, Time Zero for Net Zero: A Coal Mine Baseline for Decarbonising Heat. *Earth Sci. Syst. Soc.* 2:10054.
- Perez Silva, J., McDermott, C. and Fraser-Harris, A., 2022, The Value of a Hole in Coal: Assessment of Seasonal Thermal Energy Storage and Recovery in Flooded Coal Mines, *Earth Science, Systems and Society* 2, 10.3389/esss.2022.10044
- Ramos, E. P., Breede, K., and Falcone, G. 2015. Geothermal heat recovery from abandoned mines: a systematic review of projects implemented worldwide and a methodology for screening new projects. *Environ. Earth Sci.* 73, 6783–6795.
- Stauffer, F., Bayer, P., Blum, Ph., Molino-Giraldo, N. and W. Kinzelbach. 2014. *Thermal use of shallow groundwater.* Boca Raton: CRC Press, Taylor & Francis Group.
- Verhoeven, R., Willems, E., Harcouët-Menou, V., De Boever, E., Hiddes, L., Op'T Veld, P., et al. 2014. Minewater 2.0 project in Heerlen the Netherlands: transformation of a geothermal mine water

pilot project into a full-scale hybrid sustainable energy infrastructure for heating and cooling. *Energy Procedia* 46, 58–67.

- Walls, D. B., Banks, D., Boyce, A. J., and Burnside, N. M. 2021. A review of the performance of minewater heating and cooling systems. *Energies* 14, 6215.
- Watzlaf, G. R., and Ackman, T. E. 2006. Underground mine water for heating and cooling using geothermal heat pump systems. *Mine Water Environ.* 25, 1–14.
- Wildemeersch, S., Jamin, P., Orban, P., Hermans, T., Klepikova, M., Nguyen, F., Brouyère, S. and A. Dassargues. 2014. Coupling heat and chemical tracer experiments for estimating heat transfer parameters in shallow alluvial aquifers. *Journal of Contaminant Hydrology* 169(0): 90–99.