Renz et al

High roughness and large diameter of mine voids = turbulent flow (Wolkersdorfer 2008)

Laminar flow (Darcy’s equation or Hagen and Poiseuille equation) expected in backfilled parts or goaf (Diersch 2005). Assume a linear dependency of flow velocity on the gradient of hydraulic head. Under turbulent flow conditions, this assumption is no longer valid.

Empirical flow equations for turbulent flow, such as Manning’s equation (e.g., Diersch 2005), can provide a better approximation. Shafts or tunnels may be considered as one-dimensional, while mined coal seams can be approximated as two-dimensional (allow easier application of Manning’s equation). However, the reduction of flow geometry to 1D may not be suitable in all cases as the development of convection cells is possible at higher Rayleigh numbers, supporting heat transport in the system.

Convection cells in shafts (mixing of hot and cold waters) appear for high conductivity contrasts between mine voids and host rock (Kvoid>104 m/s), leading to faster transport of cold water toward extraction well.

Bao and Liu 2019

Field measurements showed that the salinity in mine water is in a range of 65.4–610.4 ppm and it will increase as the depth goes deeper because of the geochemical gradient [34,35]. Thus, the realistic mine water movement in most flooded mines is driven by a special heat and mass transport mechanism: Double-Diffusive Convection (DDC) [35]. The buoyancy force that drives mine water to move is affected by heat and salt transport with different diffusivities, where the distributions of heat and salinity affect the vertical density gradient of mine water in the opposite way [36].

For initial conditions, 3 temperature and salinity layers were assumed to consider the thermohaline stratification that is present prior to heat extraction (obtained by running transient simulation without heat extraction, in which the initial temperature and salinity conditions were linearly distributed with the water depth).

Pumping conditions for extracting heat, 0.0014m3/s (22.2 gpm), 0.0076m3/s (210.5 gpm), and 0.03m3/s (475.5 gpm) were chosen to consider low, medium, and high pumping rates.

Transient heat extraction lasting a week was simulated to compare the inlet and outlet water temperature variations in the simulation with those weekly measured from a real running project in the U.K. [20]. The parameters used in the simulation are tabulated in Table 1. A small time-step of 0.08 s was adopted to avoid stability issues when running the simulation.