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# Noble gases– emerging artificial tracers for routine hydrogeological investigations

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Noble gases have emerged as promising artificial tracers in hydro(geo)logical investigations following the development and increased adoption of portable, high-resolution dissolved gas measurement technology [1-5].

Such tracers are ideal in settings where water quality and appearance need to be strictly enforced, such as drinking water production in river fed aquifers. Indeed, and contrary to many other conventional tracers, noble gases have no perceptible impacts on water resources as they are inert, non-toxic, and invisible.

The quantitative interpretation of measured tracer concentrations in any field setting usually requires accurate knowledge of applied tracer quantities. This poses unique challenges for the use of dissolved gases as tracers in aqueous systems, as potential degassing needs to be accounted for, and ideally avoided, at all stages of tracer application.

Here we present a simple and efficient methodology allowing the preparation and injection of tracer solutions containing precisely-controlled dissolved gas concentrations. Through a two-step degassing – pure gas saturation approach, our method allows rapid preparation of tracer solutions with high tracer partial pressures using commonly available materials.

We demonstrate the applicability of our method to conduct well-to-well tracer tests in a riverbank filtration setting. Known quantities of the noble gas helium ($^4$He) were injected into several observation wells upgradient of a large pumping well. Dissolved gas concentrations were continuously monitored in the pumping well with as portable mass spectrometer ("miniRUEDI" GE-MIMS device, [3]). $^4$He breakthrough at the pumping well allowed accurate assessment of inter-well travel times, groundwater flow velocities and tracer recovery rates.

These results highlight how dissolved gases may complement traditional tracer methods used for typical hydrogeological investigations. Several additional candidate gas species may also be used for such tests (e.g., Ne, Kr, Xe, hydrocarbons, ...), vastly expanding the range of tracer methods available in operational groundwater management settings.

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[5] Weber et al., 2023. Sci. Rep. 13, 17006