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Dilution and Mixing in transient velocity fields: a first-order analysis

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An appealing remediation technique is in situ oxidation, which effectiveness is hampered by difficulties in obtaining good mixing of the injected oxidant with the contaminant, particularly when the contaminant plume is contained and therefore its deformation is physically constrained. Under such conditions (i.e. containment), mixing may be augmented by inducing temporal fluctuations of the velocity field. The temporal variability of the flow field may increase the deformation of the plume such that diffusive mass flux becomes more effective. A transient periodic velocity field can be obtained by an engineered sequence of injections and extractions from wells, which may serve also as a hydraulic barrier to confine the plume. Assessing the effectiveness of periodic flows to maximize solute mixing is a difficult task given the need to use a 3D setup and the large number of possible flow configurations that should be analyzed in order to identify the optimal one. This is the typical situation in which analytical solutions, though approximated, may assist modelers in screening possible alternative flow configurations such that solute dilution is maximized. To quantify dilution (i.e. a precondition that enables reactive mixing) we utilize the concept of the dilution index [1]. In this presentation, the periodic flow takes place in an aquifer with spatially variable hydraulic conductivity field which is modeled as a Stationary Spatial Random Function. We developed a novel first-order analytical solution of the dilution index under the hypothesis that the flow can be approximated as a sequence of steady state configurations with the mean velocity changing with time in intensity and direction. This is equivalent to assume that the characteristic time of the transient behavior is small compared to the period characterizing the change in time of the mean velocity. A few closed paths have been analyzed quantifying their effectiveness in enhancing dilution and thereby mixing between the resident contaminant and an oxidant. In particular, we considered three different flow configurations: (1) a "circular" pattern, in which the vector of the mean velocity rotates at a constant celerity; (2) a "shake" pattern, in which the velocity has a constant magnitude and changes direction alternatively leading to a "back and forth" type of movement and finally (3) a more general "shake and rotate" pattern, which combines the previous two configurations. The new analytical solution shows that dilution is affected by the configuration of the periodic mean flow. Results show that the dilution index increases when the rotation-shake configuration is adopted. In addition, the dilution index is augmented with the oscillation amplitude of the shake component. This analysis is useful to identify optimal flow configurations that may be approximately reproduced in the field and which efficiency may be checked more accurately by numerical simulations, thereby alleviating the computational burden by efficiently screening among alternative configurations.

References

[1] Kitanidis, P. K. (1994), The concept of the Dilution Index, Water Resour. Res., 30(7), 2011–2026, doi:10.1029/94WR00762.