Supporting Information for "Leakage dynamics of fault zones: experimental and analytical study with application to CO_2 storage"

Kieran A. Gilmore[1]†, Chunendra K. Sahu[2], Graham P. Benham[1], Jerome A. Neufeld[1,3,4] and Mike J. Bickle[5]

[1]Bullard Laboratories, Department of Earth Sciences, University of Cambridge, Madingley Rise, Madingley Road, Cambridge, CB3 0EZ, UK

[2]Department of Civil Engineering, Indian Institute of Technology Kanpur, Uttar Pradesh 208016, India

[3]BP Institute, University of Cambridge, Madingley Road, Cambridge, CB3 0EZ, UK

[4]Institute of Theoretical Geophysics, Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Cambridge, CB3 0WA, UK

[5]Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge, CB2 3EQ, UK

1. Determining the breakthrough time

The model considering buoyancy in the fault assumes that the fault is initially full of the injected fluid. Furthermore, the thinning plume model assumes that a secondary plume has reached a quasi-steady state profile above the fault. In reality, at early times the fault remains filled with the ambient fluid so the only driving force is the hydrostatic pressure in the underlying current. To account for this, a breakthrough time is introduced, defined as the time it takes for the injected fluid to fill the fault and breakthrough into the upper reservoir. The breakthrough time is obtained from experimental observation by calculating the average concentration just above the fault as a function of time (figure 1).

The concentration is initially low before breakthrough, then rises sharply before levelling off at a constant value. The grey shaded area in figure 1 shows the potential range in breakthrough time. The lower limit is when injected fluid first starts to enter the lower reservoir. The upper limit is when the fault is full of injected fluid and so the concentration just above the fault becomes constant. Across all the experiments, the average difference between the upper and lower limit is ~ 50 s. The upper limit breakthrough time is chosen when running the numerical models as this is the point where the fault is filled with fluid of a concentration similar to the gravity current and the plume above the fault has reached a steady concentration.

Prior to the breakthrough time, all three models only consider the contribution from the underlying current. After the breakthrough time, the other driving forces are taken into account. The sensitivity of the plume thinning model to the range of breakthrough times is shown in figure 2. Here, the leaked dye mass and leakage flux are plotted as a function of time for experiment D4, and compared against results from the model with

† Email address for correspondence: kg382@cam.ac.uk

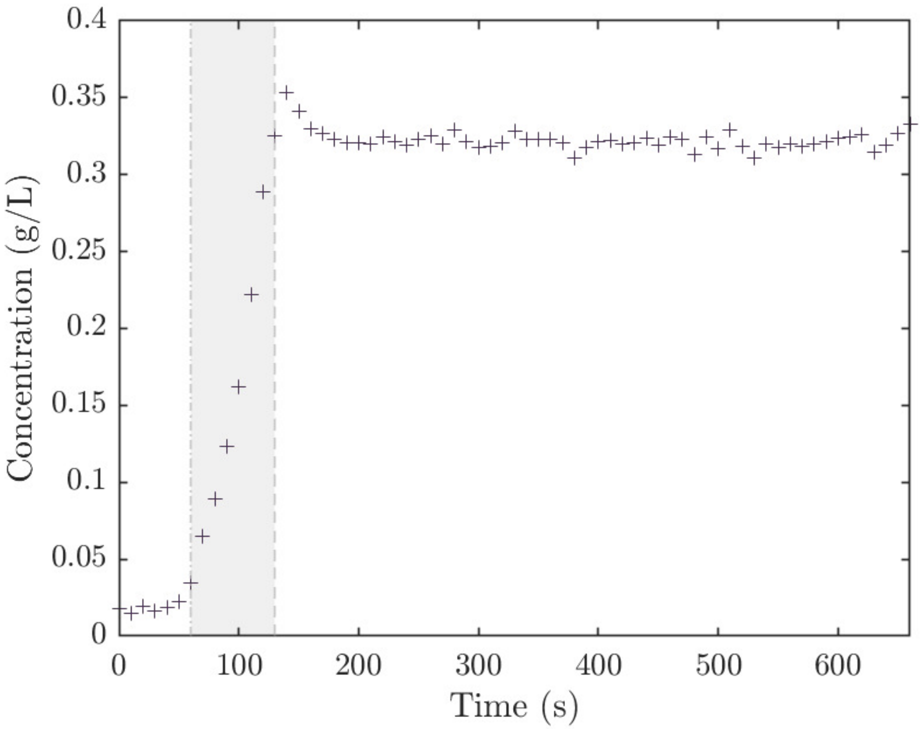

Figure 1: Average concentration directly above the fault plotted as a function of time for experiment D4. Dashed lines show the upper and lower bounds for the breakthrough time t_b, defined as the time it takes for the injected fluid to fill the fault and breakthrough into the upper reservoir.

leakage only driven by hydrostatic pressure in the underlying current and the thinning plume model. The thinning plume model has been calculated using the upper and lower bound breakthrough times ($t_b - high$ and $t_b - low$), obtained from figure 1. The models converge to a similar solution, within the range of experimental error.

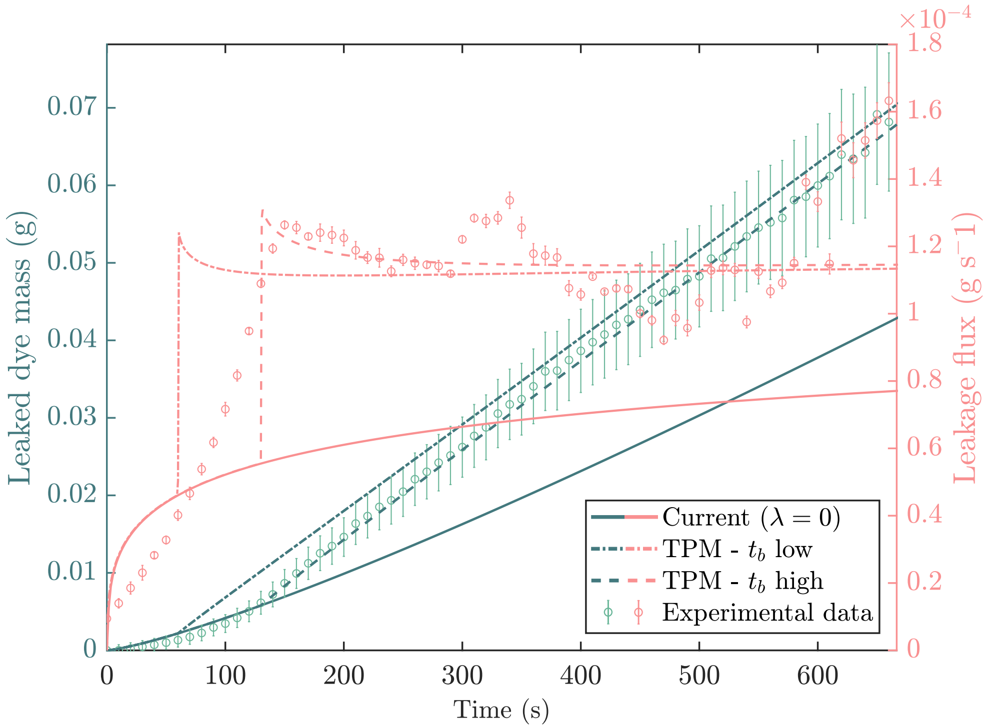

Figure 2: Total leaked dye mass (green circles) and leakage flux (pink circles) plotted as a function of time for experiment D4 along with results for leakage driven by hydrostatic pressure within the underlying current (unbroken line), and thinning plume model (dashed and dash-dotted) for upper and lower bound breakthrough time t_b.