Granular polyacrylamide (PAM) gel as dual porosity borehole methodology

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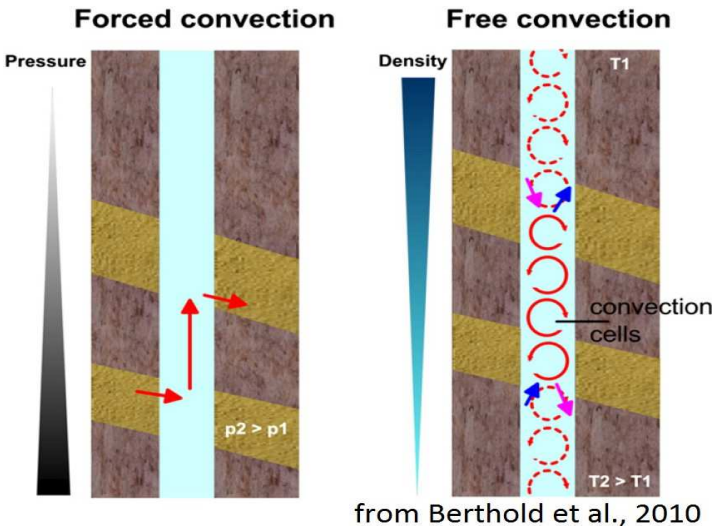
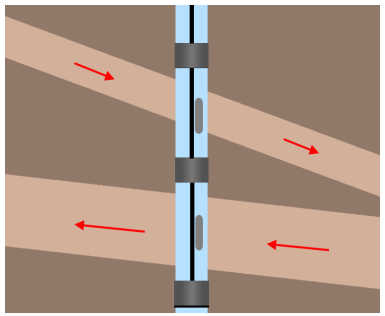
Flow in open boreholes



Open and screened boreholes distort natural flow field

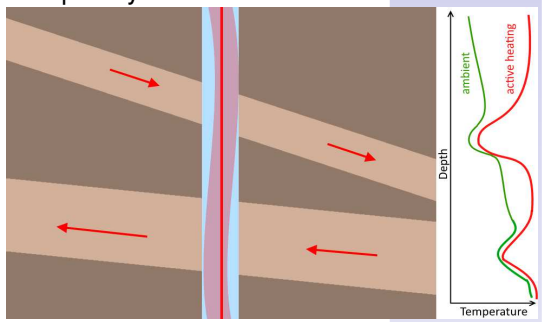
Investigation of hydraulic behavior of aquifers from boreholes

Eliminate vertical flow with packers or borehole grouting



Time-consuming or permanent installation and always expensive

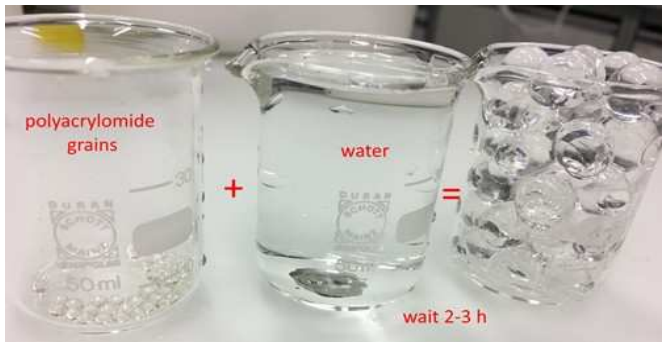
Use temperature measurements to quantify borehole inflows



Forced convection +
Temperature gradients induced by

Hydrogel as a tempoary borehole grouting

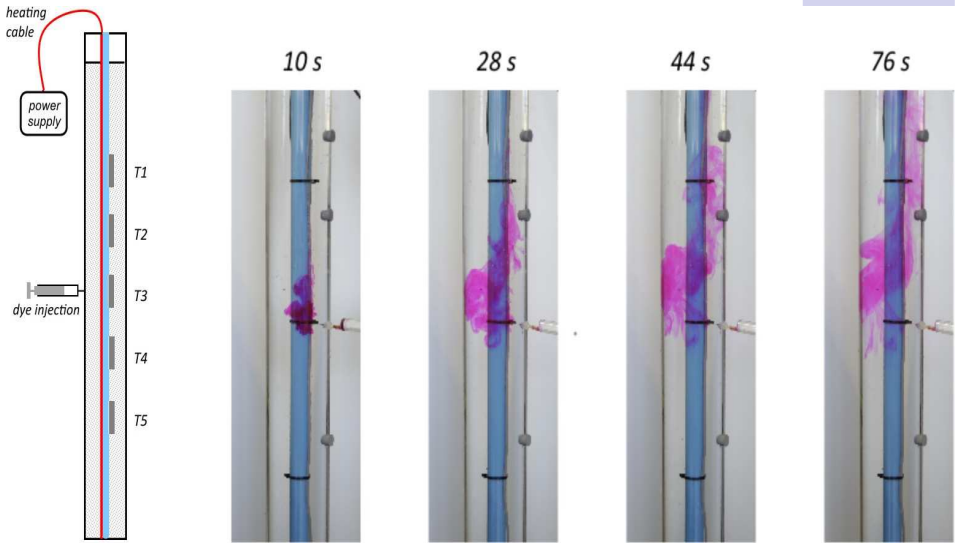
PAM gels are used in food industry,
construction, medicine, agriculture, oil and gas



- No gravitational compaction
- Permeability of a gel packing depends on polymer concentration and an external load applied [Oyen, 2014]
- Chemical inertness [Spalding et al., 2010]

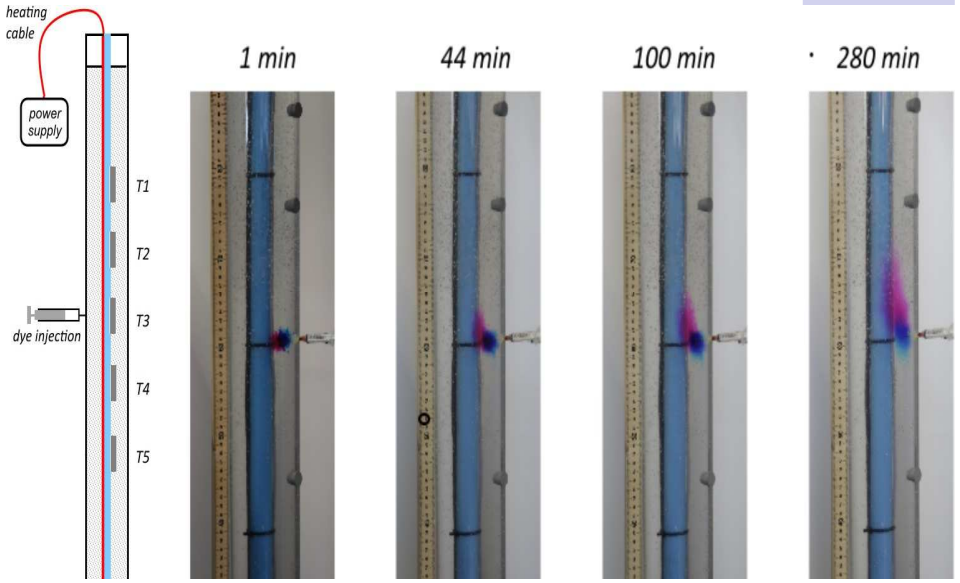
A-DTS in the lab column

Formation of convective cells in a borehole filled with water during A-DTS experiment

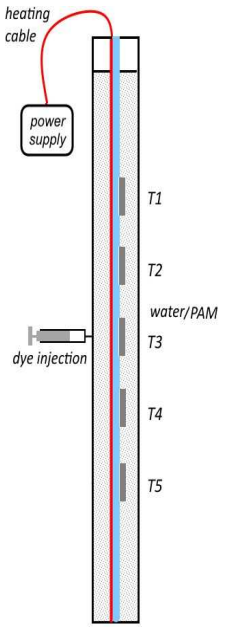


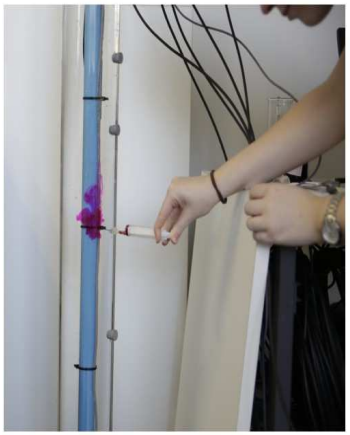
A-DTS in the lab column

Suppression of free convection with TAMP



A-DTS in the lab column





10 cm

Dye plume propagation in a irregularly shaped grains of PAM

2 cm

Laboratory study of hydrogel hydraulic properties

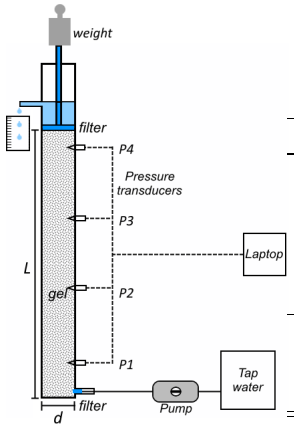


Table: Measured permeability of PAM packs

PAM type	Load, *kg*	φ	K, *m/s*
Spherical	2	0.17	$9.0e-3$
	7	0.146	$3.7e-3$
	10	0.136	$2.2e-3$
	15	0.121	$6.5e-4$
	20	0.117	$3.5e-4$
Fine	5	0.06	$1.6e-4$
	10	0.05	$1.2e-4$
	15	0.046	$2.0e-5$

TAMP transitions from highly permeable to nearly impermeable grouting

Cargese Hydrogel Column experiment protocol

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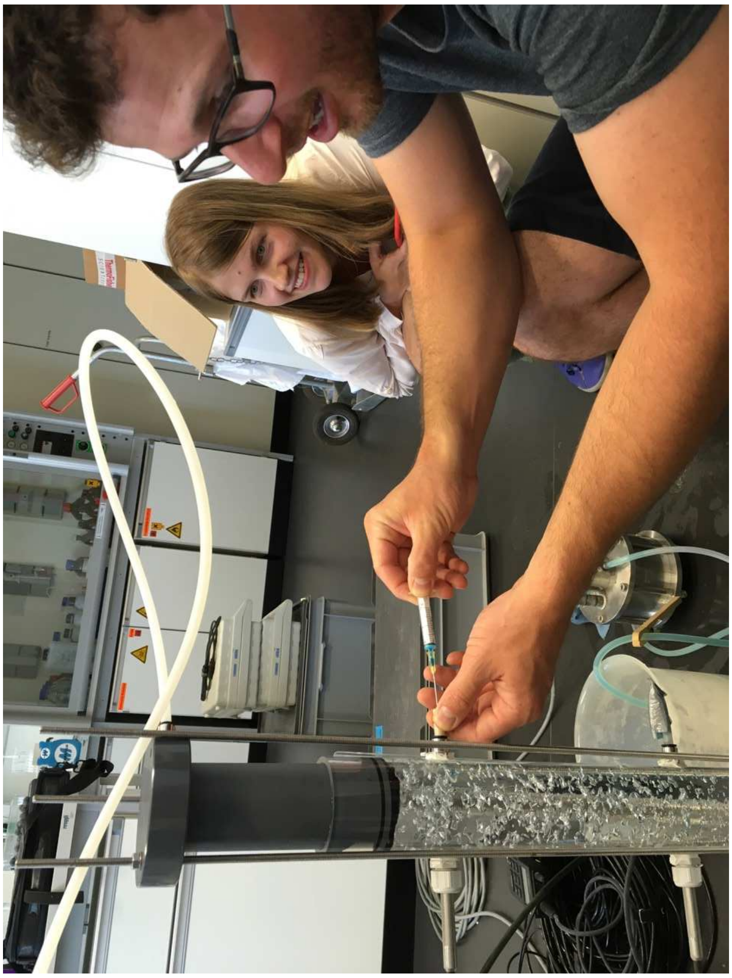
1. Objectives:
    a. Determine the relationship between degree of compression and conductivity for various shape media. Relate to porosity, gel intrinsic permeability, and gel shape.
    b. Determine the relationship between pore-water velocity, degree of compression, gel shape, gel size and retardation for salts and dyes.
    c. Develop a physically-based argument for whether gels can be used as pressure-isolation media in tomographic studies.
2. Experiments
    a. Measure the mean dry particle size for each of the gels
    b. Measure the mean hydrated particle size for each gel
    c. Establish a measurement for gel stiffness
    d. Run a batch study of exchange rate into and out of the gels.
    e. Pack column with a gel
        i. Determine the porosity of the packing
        ii. Determine the conductivity of the packing
        iii. Run two transport experiments which differ in transport velocity of a factor of 10 using dye and salt. Can you see the difference in breakthrough?
        iv. Compress the column by 5% and repeat ii and iii
        v. Compress the column by 10% (approx. – as appropriate) and repeat ii and iii
3. Analysis
    a. Determine the % swelling (by mass or volume) for each gel and relate that to gel stiffness.
    b. Explain the batch study results under the assumption of pure Fickian diffusion into and out of the gel. Do the results support the hypothesis that the exchange is diffusion limited?
    c. Determine the macro-porosity of each of the columns as a function of compression.
    d. Compare the conductivity results with compression with the predictions of Kozeny-Carmen for permeability versus porosity. Are the results consistent with the results for non-deformable, non-permeable media?
    e. Explain the column transport studies in terms of the batch study parameters for the two tracers.
4. Materials and supplies
    a. Tracers: Brilliant blue, Rhodamine, salt
    b. Calipers to measure particles
    c. EC sensors.
    d. Erlenmeyer flasks; Graduated cylinders; Syringes to make injections
    e. Digital balance to weight reagents.

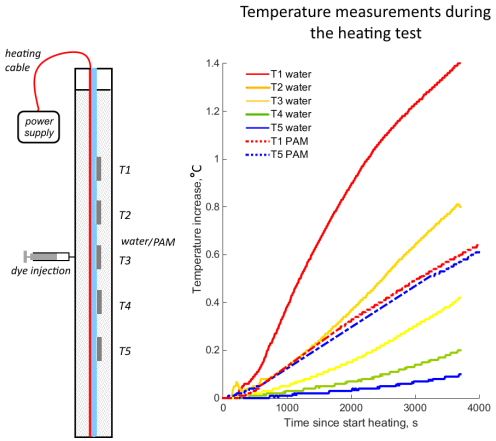


Conclusions

PAM media allows temporary borehole grouting to minimize free and forced convection in the borehole:

- If no compressive stress is applied, a gel packing (permeability similar to open gravel) suppresses free convection in the borehole, allowing for local temperature and/or chemical measurements and groundwater sampling through free-flowing gel packing.
- When an external load applied to a gel packing, the shape and volume of soft grains adjust to the load, thus decreasing the porosity and, consequently, the permeability of a packing. This configuration allows monitoring of local pressure responses from the formation.

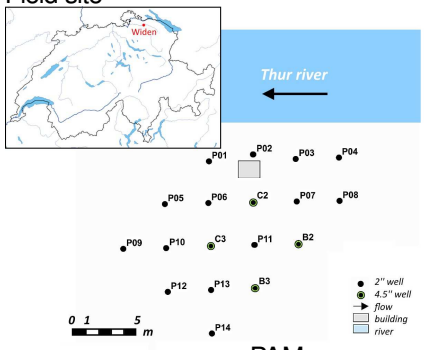
A-DTS in the lab water column



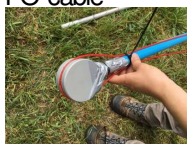
Temperature measurements confirm visual observations

A-DTS in the field

Field site

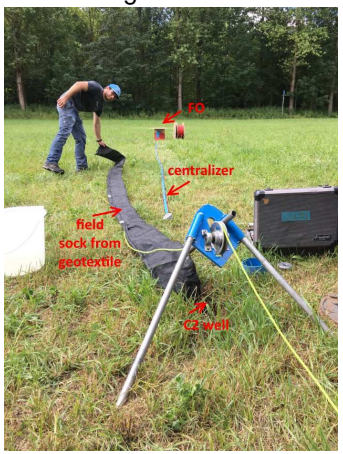


FO cable

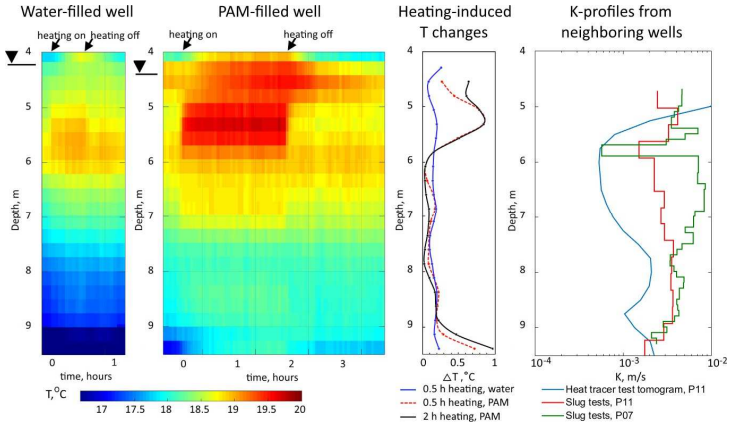


PAM

Permeable field sock preventing grains of PAM from leaving the borehole



A-DTS in the field



PAM gel compresses free convection in boreholes thus allowing more complete/efficient characterization of heterogeneous flow

Future plans/Open questions

- Groungwater sampling:
  (1) using sampling pump in a PAM-filled borehole
  (2) toxicity and any regulatory aspects
- Tomography study:
  (1) ”packer” engineering
  (2) learn how to compress the gel packing in the field
- Chemical sampling study:
  (1) chemical inertness
  (2) freedom from biodegradation or alteration during use

Though yet to be confirmed in the field, we expect that this technique will find many other applications in aquifer characterization