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Thermal Retardation in Highly Conductive Aquifers for Parameter Estimation

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Background

- Near surface geothermal energy systems play a significant part in the aim of increasing the share of renewable energy
- To ensure economically and environmentally sustainable usage of these systems, information about heat transport parameters (thermal and hydrodynamic parameters) is crucial (Banks 2015)
- Heat can be used as a tracer to derive thermal and hydrodynamic parameters (e.g. Anderson 2005) and for residence time determination in Managed Aquifer Recharge systems (e.g. Bekele et al. 2015)
- One possibility to derive these parameters is the usage of the **thermal retardation factor** as introduced by Bodvarsson (1972) and Shook (2001) which **requires certain assumptions to be valid**:
  - Effective thermal conductivity negligible
  - Fluid and solid are in local thermal equilibrium (LTE)

Research Goals

- Under which hydraulic conditions is the non-consideration of effective thermal conductivity valid to use the thermal retardation factor for determining thermal and hydrodynamic aquifer parameters in highly conductive aquifers?
- How big are the resulting errors?
- When is the assumption of local thermal equilibrium (LTE) violated in conditions of a highly conductive, heterogeneous aquifer like the Munich Gravel Plain?

Laboratory Experiments

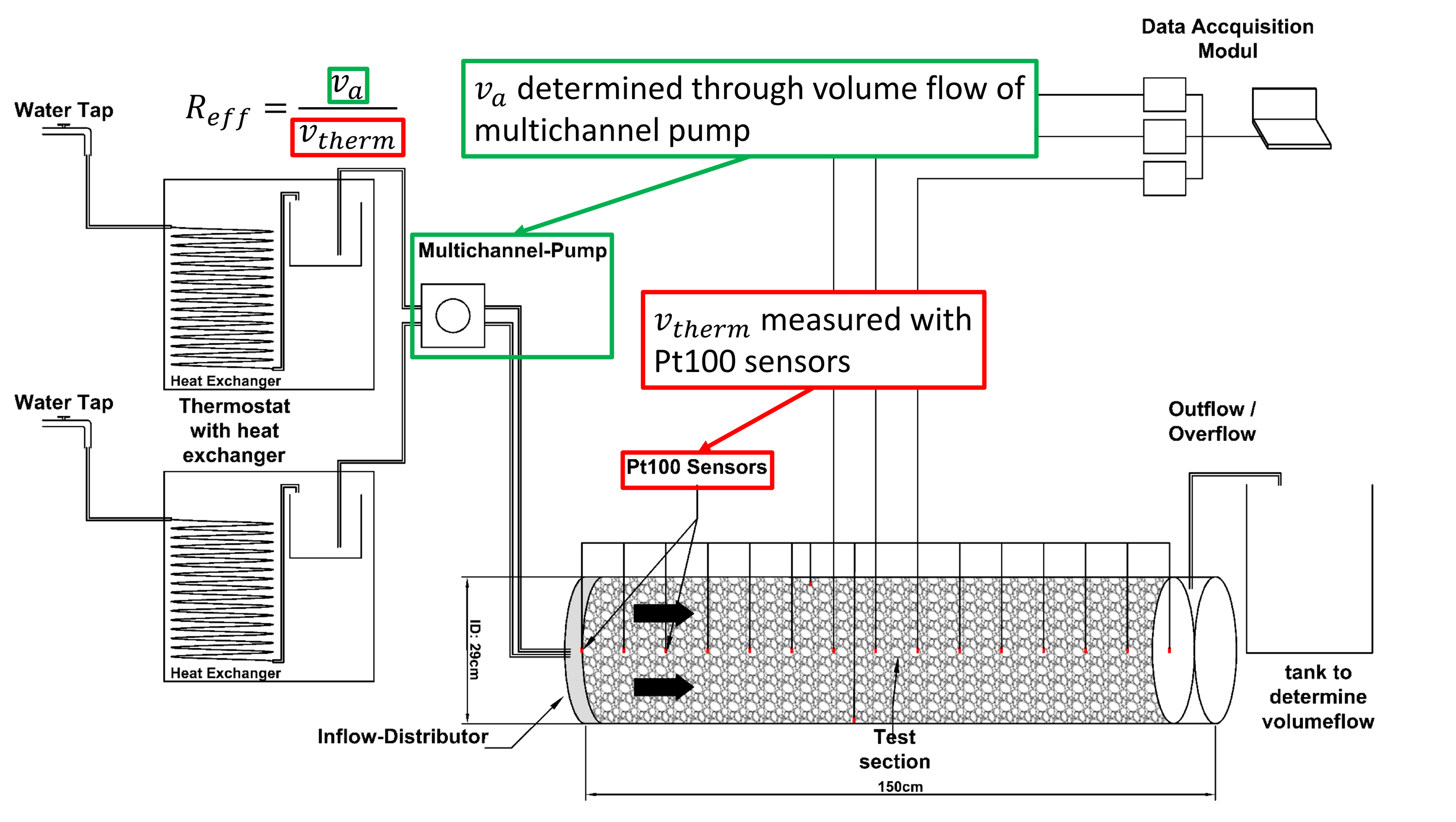


Fig. 1: Schematic setup of laboratory experiment. Thermostats are used as hot and cold reservoirs. Volume flow is controlled by a multichannel peristaltic pump. Temperature is monitored with high precision Pt100 sensors.

Research Approach:

1. Heat pulse is created by injection of hot water for defined amount of time
2. After that, volume flow is kept constant, injection temperature is reduced to initial temperature
3. Temperature development of fluid and solid is monitored along the center line of column

Effective thermal retardation is calculated by:

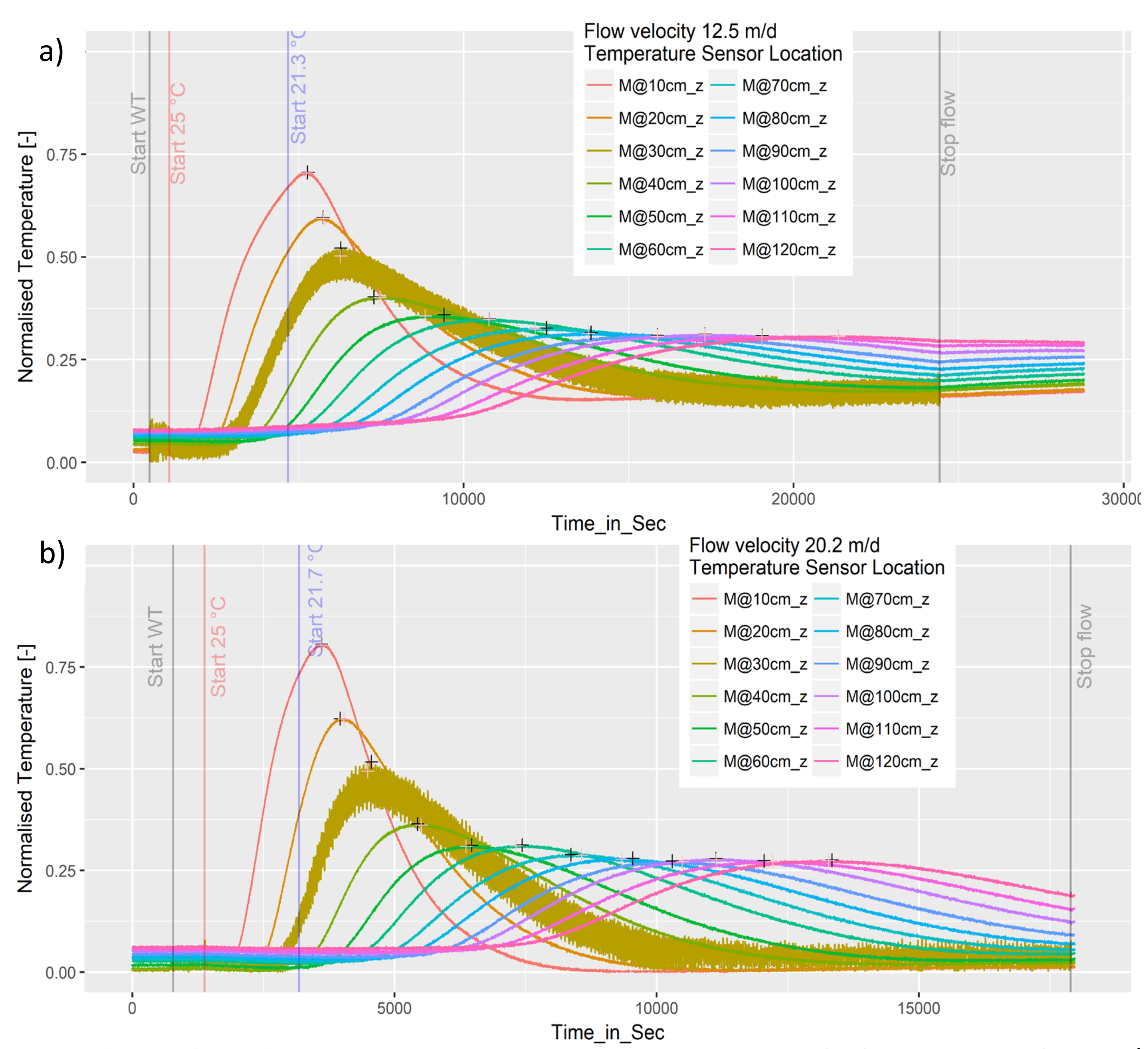
$$R_{eff} = \frac{v_a}{v_{therm}}$$

and compared with the predicted retardation:

$$R_{app} = \frac{\rho c_{bulk}}{n_{eff}\rho_f c_f} = 1 + \frac{(1-n_{eff})\rho_s c_s}{n_{eff}\rho_f c_f}$$

→ This procedure is repeated for different flow velocities

First Results



Evaluation of thermal breakthrough curves to determine v_{therm} for different flow velocities

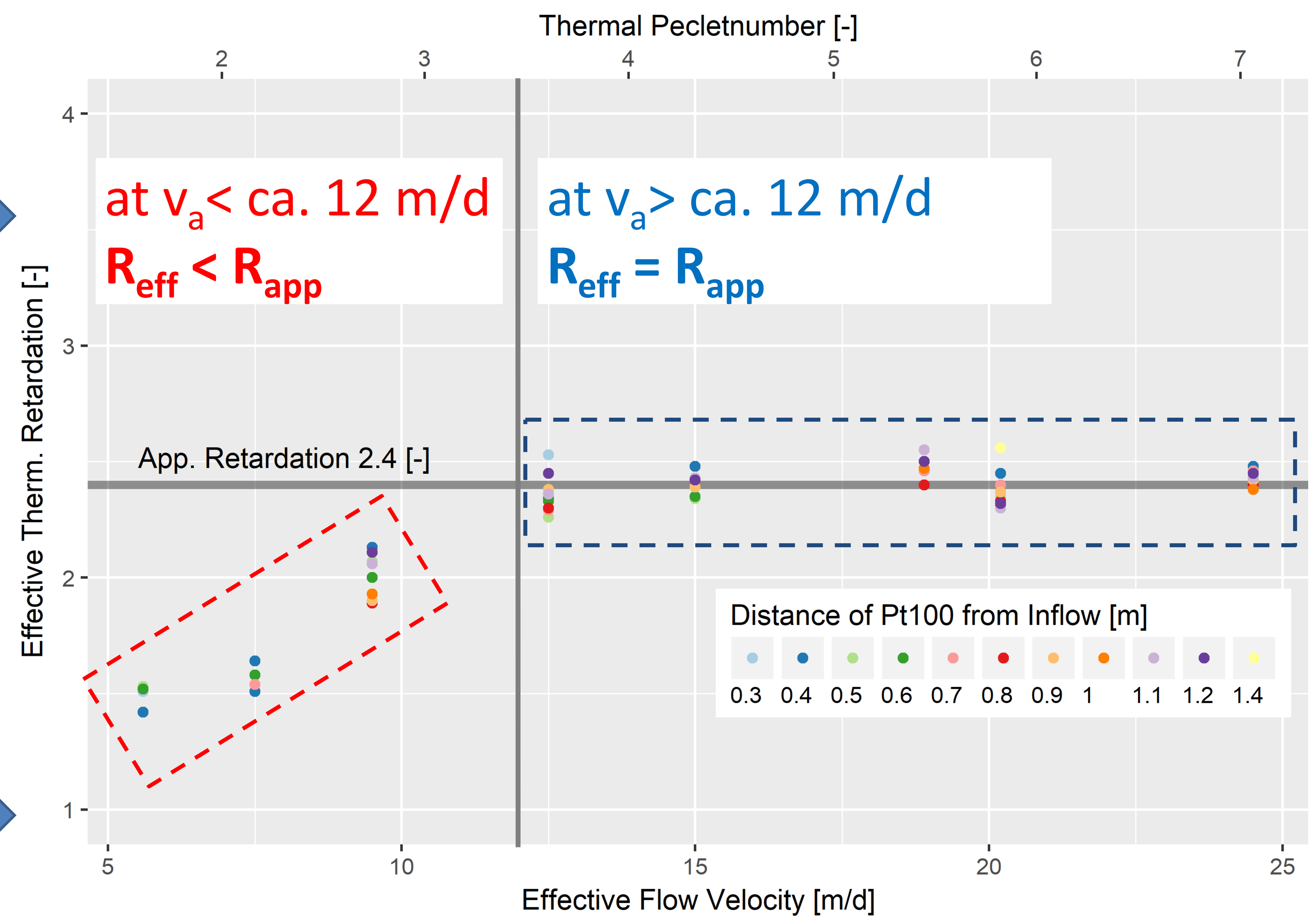


Fig. 2: Thermal breakthrough curves at center line temperature sensors for flow velocities of 20,2 m/d (a) and 12,5 m/d (b) are used for determination of v_{therm}. The + symbol (black = absolute, pink = mean) highlights the peak temperature of the break through curve.

Fig. 3: Dependency of the effective thermal retardation (v_{therm}/v_a) on the flow velocity. With rising flow velocities the effective thermal retardation converges towards the retardation predicted by the thermal retardation factor. At flow velocities < 12 m/d the effective thermal conductivity significantly influences v_{therm} resulting in lower effective thermal retardation.

Conclusion and further investigations

- Effective thermal conductivity significantly influences the thermal peak velocity at flow velocities lower than ca. 12 m/d for the investigated porous medium
- At higher flow velocities (> 12 m/d for investigated porous medium) thermal retardation can be predicted by the thermal retardation factor and therefore be used to determine the involved parameters (e.g. heat capacity or effective flow velocity)

Next Steps:

- Evaluation of LTE assumption: first results show that LTE might be violated for typical conditions within an highly conductive aquifer

References

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