Response to Reviewer Comments 3 (Responses in blue)

The paper "Laboratory heat transport experiments reveal grain size and flow velocity dependent local thermal non-equilibrium effects" conducted laboratory experiments to clarify thermal non-equilibrium between solid and liquid phases in saturated porous media under forced convection. This study provides valuable laboratory experimental data on the effects of grain size and flow rates on thermal non-equilibrium between solid and fluid phases of saturated porous media. The authors measured not only the fluid temperature but also the temperature of solid phase by specifically designed probes, which only a few studies have reported before.

Regardless of the value of the experimental data, I have a few concerns regarding data analysis and interpretation of the experimental data. I believe the manuscript could be improved by re-analyzing the same data without additional experiments. Therefore, I recommend a major revision for potential publication of this manuscript.

Thank you for your detailed review which has brought up good questions. We will consider all of your comments carefully to improve our manuscript. Please find replies below each comment.

Major and minor points are summarized below (numbers indicate the line numbers).

Major points

Choice of LTNE model

While the authors used the LTNE model (Eq. 10 and Eq. 11), this LTNE model may not be applicable to the experimental data. The LTNE model with spatially uniform parameters (e.g., h_sf and lambda_s, eff) assumes that the physical property of solid phase is uniform in the spatial domain. However, in the experimental setup, glass spherical particles with varying sizes were embedded in finer glass spheres of 1 mm diameter. Although some of the parameters can be justified to be spatially uniform even in this setting (e.g., thermal conductivity of solid and porosity), this setting violates the assumption of the LTNE model. For example, the heat transfer coefficient and surface area are functions of grain sizes. The LTNE model with spatially uniform parameters is applicable when the porous media is made up of uniform grain sizes (could be non-uniform up to the validity of representative elementary volume).

If the authors (or the editor and other reviewers) want to include the analysis with an LTNE model, I would recommend a LTNE model presented in Wakao and Kaguei, 1982, where energy equation for a solid spherical particle is coupled with energy equation for fluid phase.

In this way, the authors can simulate LTNE of a spherical particle embedded in saturated porous media.

Wakao, N. and Kaguei, S. (1982): Heat and mass transfer in packed peds. Gordon and Breach Science Publishers, Inc, 364p.

Thank you for your suggestions regarding the LTNE model. We agree that the LTNE model in this study is limited to applications with uniform grain sizes. We will add the suggested model to our revised manuscript.

Calibration of temperature data

Regarding Line 225-229, it is more natural to normalize the measured temperature by the temperature difference between the initial and final temperature, as in Eq. 19, not by the final temperature. Doing a proper temperature calibration might provide temperature data, that is more compatible with the LTE model:

We will do this as suggested in our revised manuscript.

- In Figure 2, what caused the increase in the calibrated temperature at deeper depths before the arrival of the thermal front. This would not be affected by the replenishment of the water bath with tap water during the experiment. Is this affected by the laboratory air? In that case, why was the increase smaller for Figure (a), which was conducted for a longer time?

We will carefully check the experimental data, deduce an explanation and revise our manuscript accordingly.

Interpretation of inverse peaks

I am glad to see Figure 5, illustrating the difficulty of the experiments. In my unpublished data, I observed similar inverse peaks for smaller grains (dp = 3 mm). I attributed this to the placement of fluid temperature sensors. It is extremely hard to make sure the depth of solid and fluid temperature measurement is the same. Smaller the grains are, more difficult. When I failed to do this, I observed inverse peaks regardless of fluid flow rates. Non-uniform flow could also cause the inverse peaks, but I do not think we can eliminate the possibility of misplacement of fluid temperature sensors relative to the location of the solid temperature sensors in this experimental setup.

To fix the measurement position of the fluid and solid phase, a PVC frame was used as it is shown in Fig.1c. Although the LTNE probes were carefully embedded into the porous media composed by small glass beads, the possibility of small misplacement is inevitable. This influence could be evaluated by checking the same temperature measurement pair for fluid and solid phase, for example if they always produce the same inverse pulse. Considering this comment, the manuscript will be revised including an improved explanation of the possible influence by any inaccuracy in sensor placement.

Minor points

41: "at the same temperature at their interface": I believe this is true for LTNE approaches. The LTE approach assumes the temperature of the phases are the same within an REV, not just their interface.

Thank for your commenting on the LTE definition. As you suggested the LTE model could be described by stressing the difference from the LTNE model. This sentence will be updated on the revised manuscript.

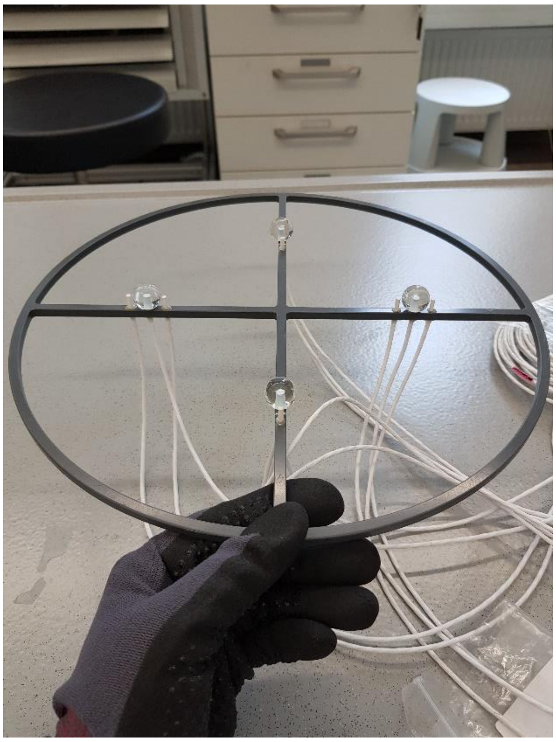
99: Could you provide the information on the glue used (e.g., the name of the product)? Also, what is the volumetric heat capacity of the glue?

Thermal Bonding System TBS20S, Electrolube was used, which is a two-part (Part A & Part B) thermally conductive epoxy system. Two parts were mixed with a ratio by volume (A:B) 3:1. According to the technical data sheet of the manufacture, specific heat capacity of Part A and Part B is 0.5 cal/g/°C at 30 °C and 0.35 cal/g/°C at 30 °C, respectively. And the cured glue density is 1.85 g/ml. We will add this to our revised manuscript.

100: How did you place temperature sensors next to the surface of the glass spheres? Accurately placing sensors for fluid temperatures is important to avoid the "inverse peaks".

PVC frames were designed to place the fluid and solid phase temperature sensors at the accurate positions. Through holes at the frame, PT100 sensor cables were inserted to be fixed aligning in a line. Please find a photo attached below the reply. And then the frame was placed at the depth of measurement inside the column, while the column was filled with small glass beads.

We believe that inverse peaks are a real phenomenon that cannot be avoided entirely. However, as mentioned previously, we will try to disentangle the effects of non-uniform flow from sensor placement by having a closer look at the dataset.



111: Could you describe how you achieved water saturation of the porous media? Also, did you use any thermal insulation for the column? Minimizing air in porous media and heat loss from the column is essential to get experimental data that is compatible with the LTE model.

Porous media was filled slowly with water from bottom to the top to avoid air bubble inside. The column was covered by an insulation layer. However, the laboratory was not equipped with climate control. Therefore, taking the air temperature into account, the initial water temperature was established close to the room temperature to minimize heat loss to the air. We will add this information to the revised manuscript.

131: 26-34: "C" is missing.

This will be corrected on the revised manuscript.

Equation 1: "x is spatial coordinate" is missing.

The definition of "x" will be added for the Eq. 1 on the manuscript.

Equation 6: This analytical solution is for normalized temperature, not actual temperature T.

The definition of T, T1 and T0 will be corrected.

183: The effective thermal conductivity of fluid includes the effect of thermal dispersion under advection. Bandai et al., 2023 was not accurate for this description. Line 206 is accurate.

Thank you for the specific comments. Line 180-182 will be revised considering the accurate definition of effective thermal dispersion.

200: 1.5 m (= L)?

Thank you for spotting the typo which will be corrected.

Figure 2: I would suggest using the same color for the temperatures measured at the same depths for both phases.

Thank you for your suggestion. We will consider the descriptive colour legend which can show intuitive colour code for measurement results from LTNE probes.

Figure 8: There is a discrepancy between the models and the data at the end of the thermal front (in addition to the end of the breakthrough curve) for q = 17.2 m d-1. What caused this discrepancy? Heat loss from the column can be one reason, but if this was the case, the discrepancy would have been larger for dp = 25 mm, which was located at a deeper depth. Or, the location of the sensors for dp = 5 mm was not far enough from the input? But, if this was the case, the discrepancy would have been larger for q = 22.8 m d-1. Another reason may be the artifact of the temperature calibration procedure.

We will conduct further data analysis to answer this question by thoroughly evaluating the cause of discrepancy between experimental data and model.

344: "limited to 0.04 K": This is not accurate. This value is maximum normalized temperature difference in Figure 8 in Bandai et al., 2023, which can be converted to approximately 0.6 K because the temperature difference was about 15 K.

Thank you for correcting the misunderstanding. This sentence will be revised considering the fact you stated.

Line 379: Could you describe how you fitted the models to the experimental data to estimate the heat transfer parameters? It would be better to define a minimization problem to be solved and specify optimization algorithms used to solve it.

We will evaluate the RMSE for each model (as was also raised by other reviewers) in our revised manuscript.