

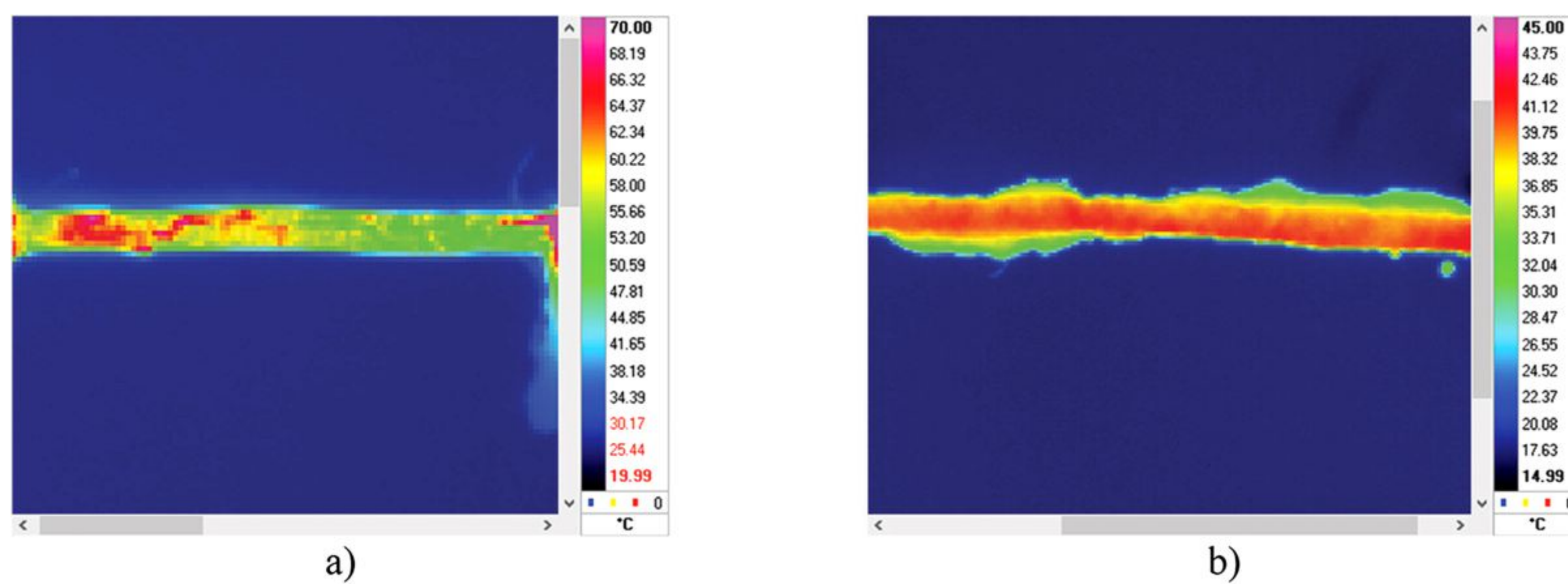
NON-FOURIER HEAT TRANSFER IN POROUS MATERIAL WITH EXPERIMENT USING PERIODIC POWER EXCITATIONS AND IR THERMOGRAPHY

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BACKGROUND AND OBJECTIVE

The Non-Fourier heat transfer model - Dual Phase Lag (DPL), is based on the assumption that heat transfer is influenced not only by the temperature gradient but also by the rate of temperature change itself. This model introduces a time lag between the application of heat (incident power) and the resulting temperature response of the material. Such phenomena typically occur in nanomaterials, porous materials, and biological tissues such as skin.

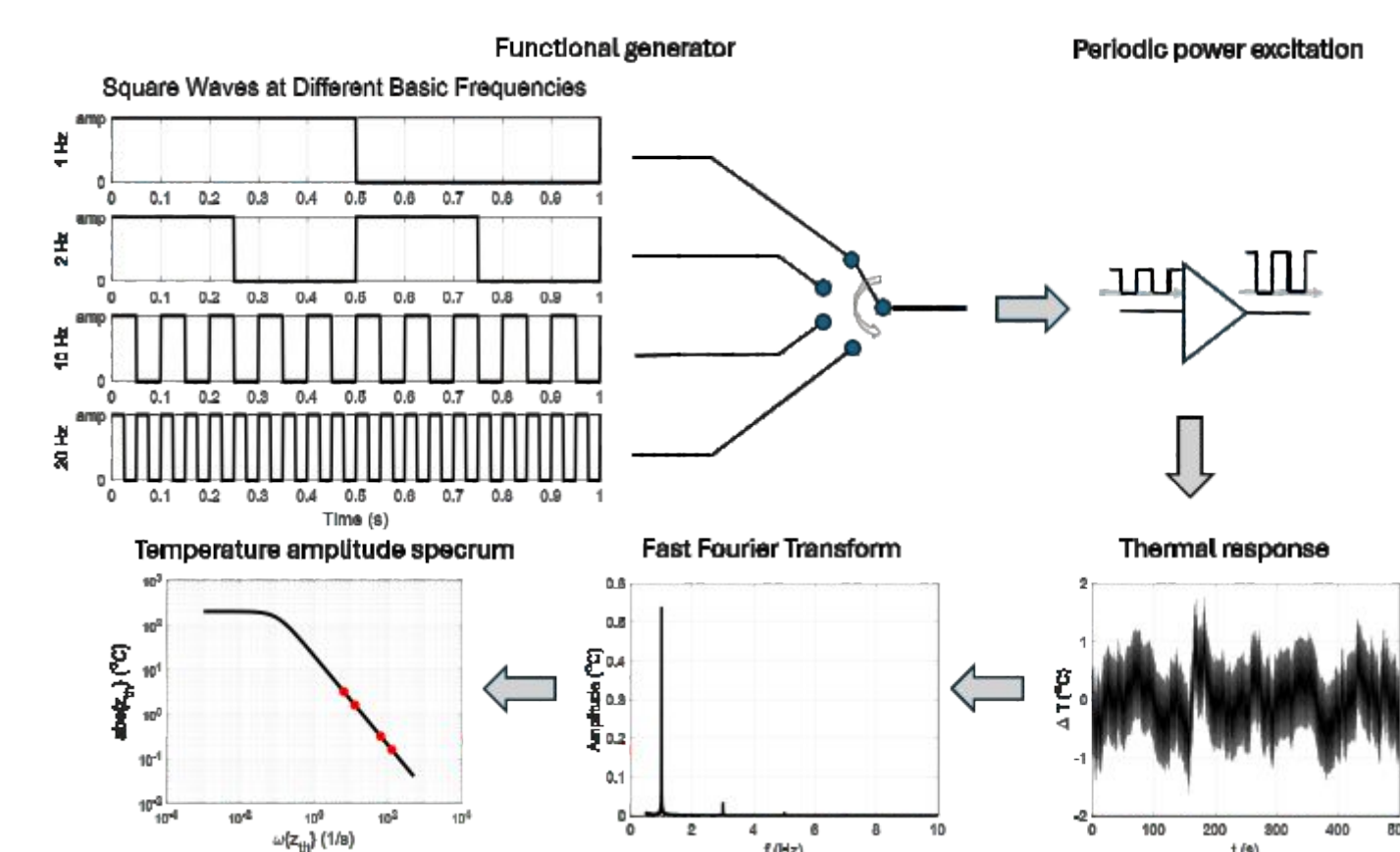
Although the DPL model has been extensively studied from a theoretical standpoint, experimental validation particularly using infrared (IR) thermography remains limited due to the small temperature variations involved. The objective of this work is to experimentally verify the Dual Phase Lag (DPL) heat conduction model in porous materials using infrared thermography under periodic power excitations.



Zoomed thermal images of the measured objects – naked wire without porous material (a), and wire with a porous material (b).

METHODS

A cylindrical model of a resistive constantan wire both with and without a surrounding wetted porous cotton layer was developed. The analytical thermal model was based on frequency-domain DPL equations, where the thermal conductivity is treated as a complex, frequency-dependent parameter. Experiments were carried out by periodically heating the wire using a square-wave electrical signal (1–20 Hz) and recording temperature responses with a high-sensitivity photon-cooled IR camera (NETD = 18 mK). Fast Fourier Transform (FFT) analysis was used to extract the fundamental harmonic of the temperature signal, allowing the estimation of thermal impedance and comparison with model predictions.



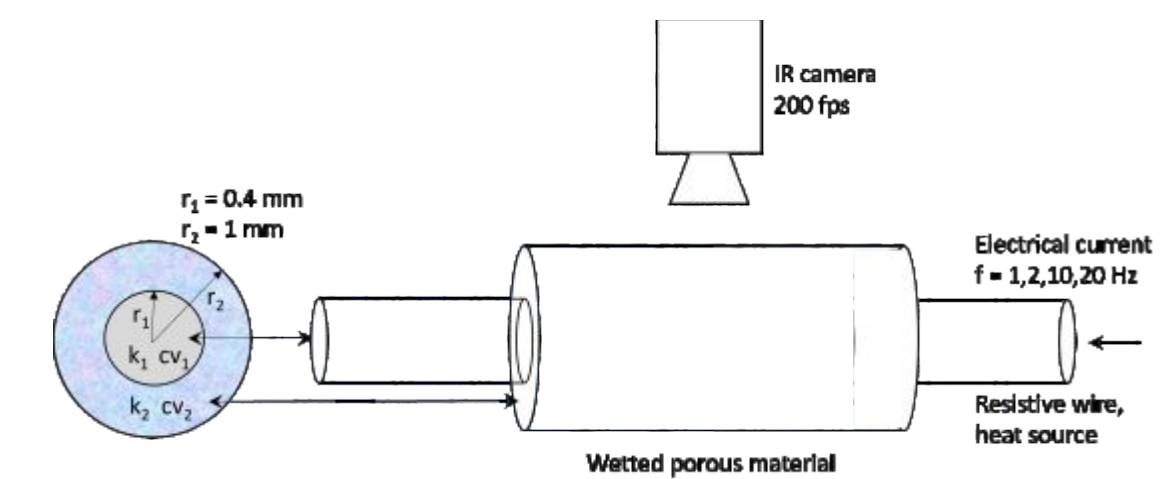
Scheme of measurement procedure for estimating temperature amplitude spectrum.

RESULTS

The experimental data closely matched the theoretical predictions of the DPL model.

- The thermal impedance and amplitude of temperature harmonics decreased with increasing excitation frequency, consistent with DPL-based frequency-dependent conductivity.
- For the porous sample, a clear deviation from the Fourier–Kirchhoff model appeared at higher frequencies, confirming the existence of phase lag effects between heat flux and temperature gradient.
- The estimated DPL time constants satisfied the diffusive regime condition ($\tau_T > \tau_q$).
- The coefficient of determination between model and experiment reached $R^2 = 0.9937$, confirming high agreement. Uncertainty remained below 10% for frequencies below 10 Hz, increasing slightly at 20 Hz due to noise.

Model of a thermographic measurement with an electrical constantan resistive wire wrapped in a porous material.



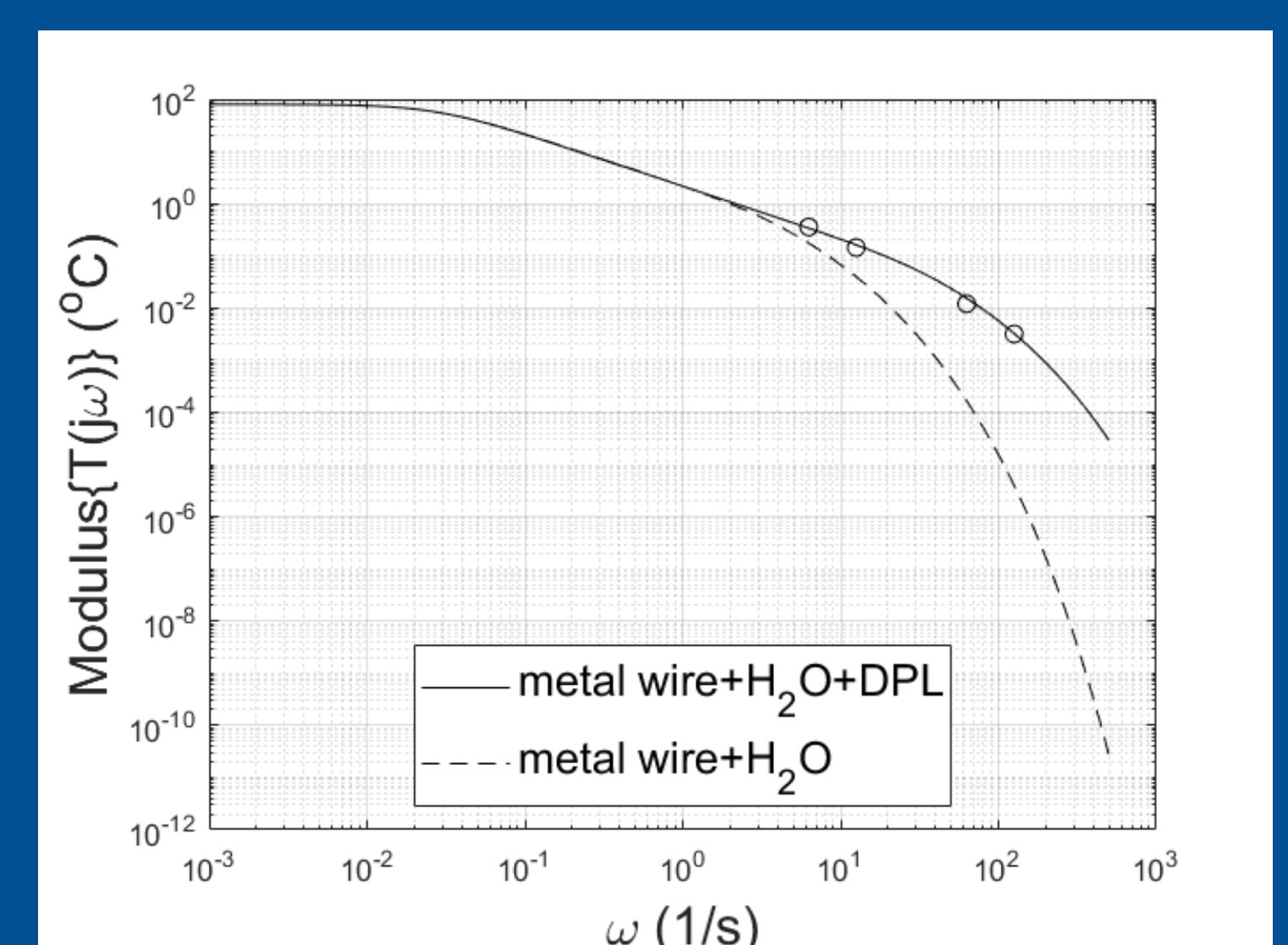
CONCLUSIONS

The study confirms that non-Fourier heat transfer, described by the dual-phase lag (DPL) model, can be experimentally observed in porous materials using periodic excitation and infrared (IR) thermography.

The proposed frequency-domain approach, based on analyzing the fundamental harmonic of the thermal response, enables the determination of complex thermal impedance.

The presented measurement approach demonstrates that it is possible to detect temperature harmonics with amplitudes below 10 mK at frequencies up to 20 Hz with an acceptable signal-to-noise ratio, using a standard cooled infrared system. This reveals new possibilities for applying lock-in IR thermography at higher frequencies and opens up a new area of application for radiative measurement methods, including modeling and quantitative assessment of non-Fourier heat transfer.

Although further improvements such as better synchronization between power and temperature signals and horizontal sample orientation could enhance measurement precision, the presented method successfully demonstrates a practical experimental validation of the DPL heat transfer model in porous media.



Modulus of temperature characteristics with and without DPL effect with overlapped measurement results for the 2-layer structure of an electrical wire wrapped in a porous material.



PUBLISHED ARTICLE

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