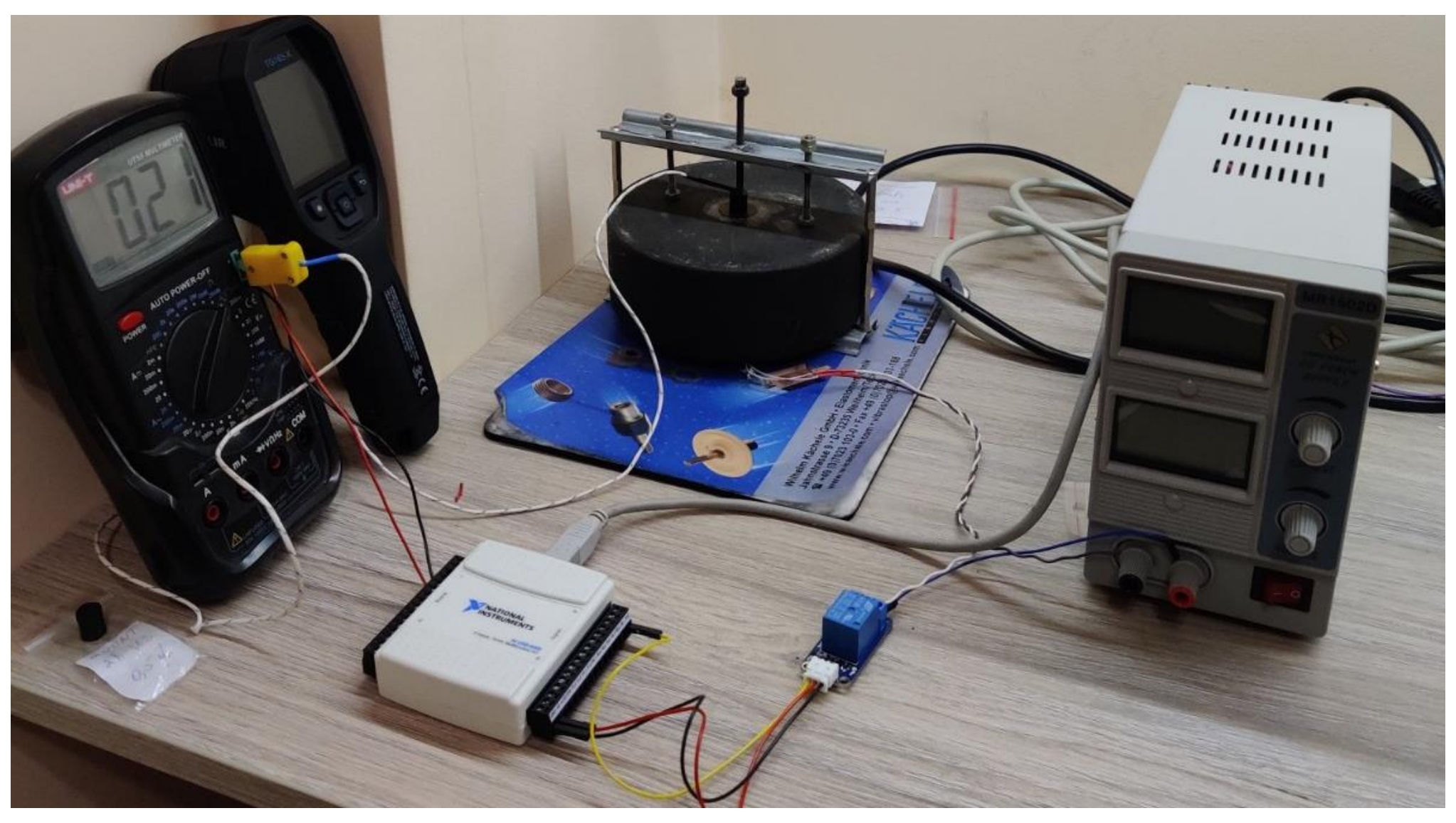
Enhancing the thermo-physical characteristics of epoxy resin through single- and multi-walled carbon nanotube reinforcement

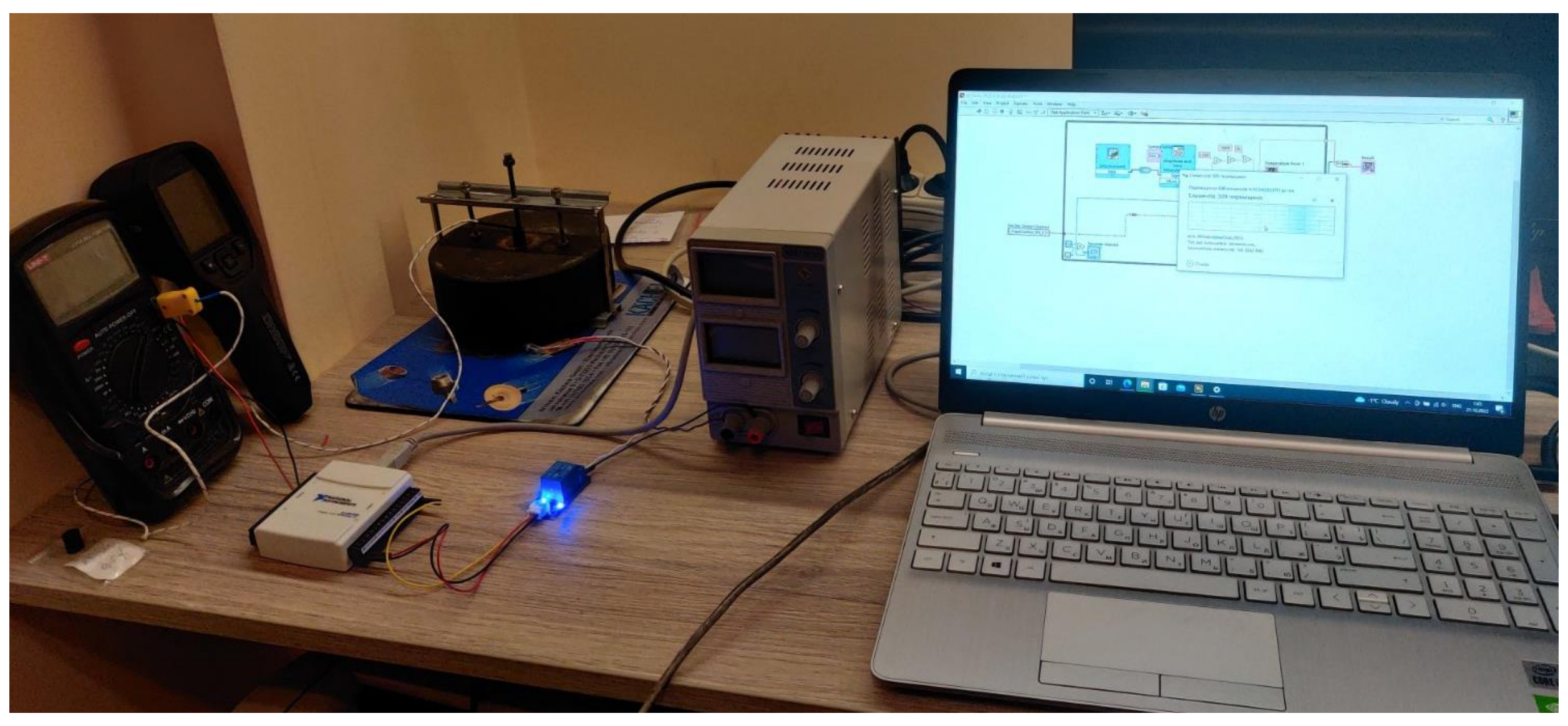
I. Zhydenko[1,2], H. Klym[2,3*], I. Karbovnyk[3], D. Chalyy[1]

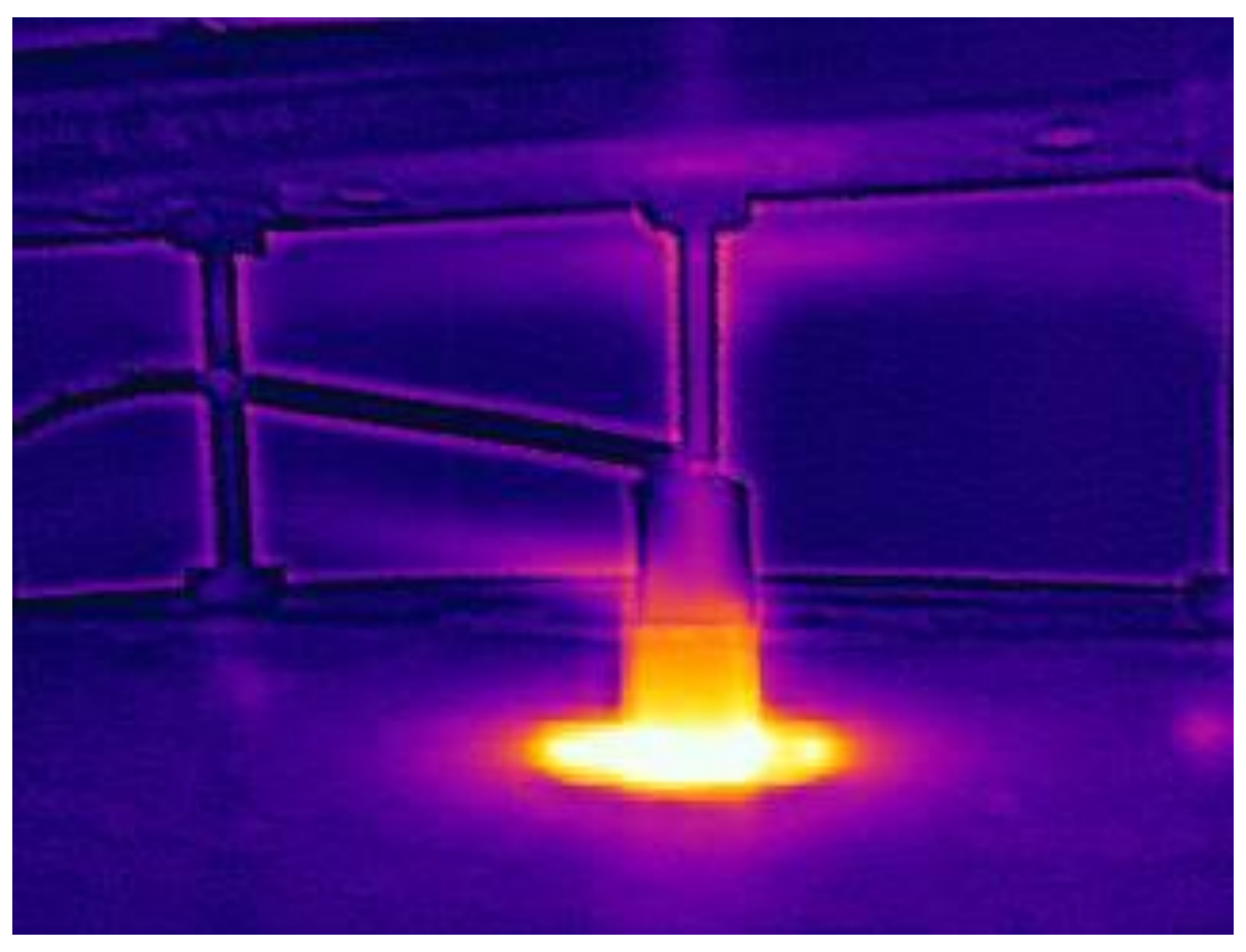
[1]Lviv State University of Life Safety, Lviv, Ukraine
[2]Lviv Polytechnic National University, Ukraine, Lviv, Ukraine
[3]Ivan Franko National University of Lviv, Lviv, Ukraine
*e-mail: klymha@yahoo.com; halyna.i.klym@lpnu.ua

Polymer nanocomposites are recognized for their exceptional thermo-physical properties. However, the widespread production of polymer composites reinforced with carbon nanotubes (CNTs) on a commercial scale heavily relies on stringent technological process standards. Therefore, it necessitates experimental approaches to regulate the impact of manufacturing conditions, with a key focus on achieving uniform dispersion of nanofillers. Our research concentrates on empirically investigating the thermal conductivity of engineered polymer nanocomposites by incorporating varying amounts of single-walled and multiwalled carbon nanotubes (CNTs) into the epoxy matrix structure.

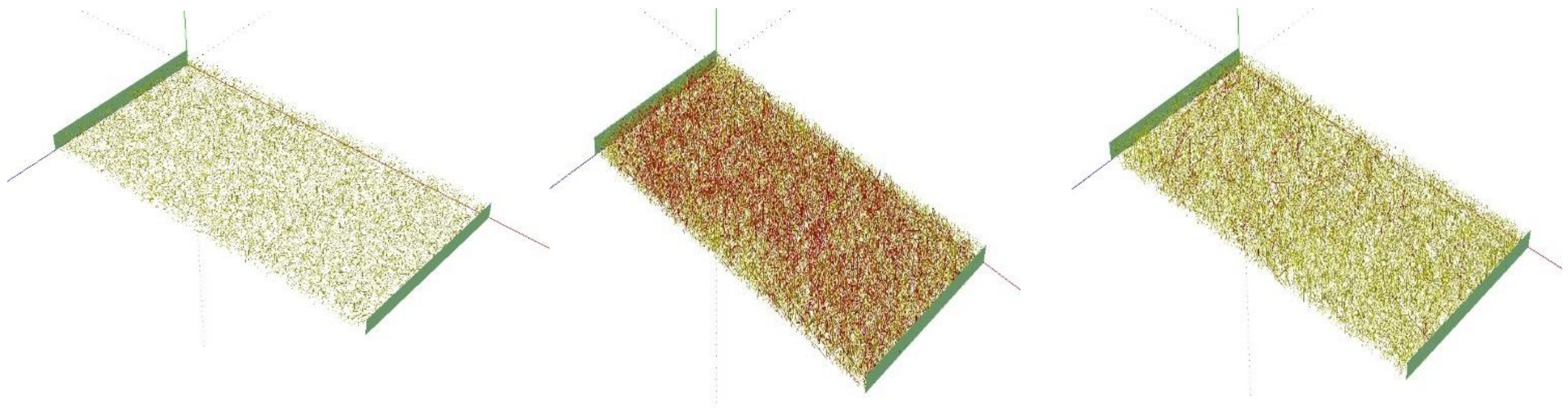
In this particular study, we emphasize the examination of how increased loading levels and/or dispersion quality influence the overall thermosetting characteristics of the composite material. To gather relevant data and gain insights into the peculiarities of nanofiller incorporation into the host polymer matrix, visual thermographic analysis and direct thermal response measurements were employed. The experimental setup involved a NI USB-6009 DAQ unit that controlled a 5V/1A electrical furnace with a flat heated surface on which the cylindrical samples were placed. The temperature at the opposite edge of the samples was measured using a thermocouple. The thermocouple signal was acquired through one of the analog channels of the DAQ module, which provided a 14-Bit resolution and 48 kS/s sample rate, ensuring the collection of reliable temperature versus time plots during both heating and cooling phases. The entire experiment was managed through custom-developed NI LabVIEW software.





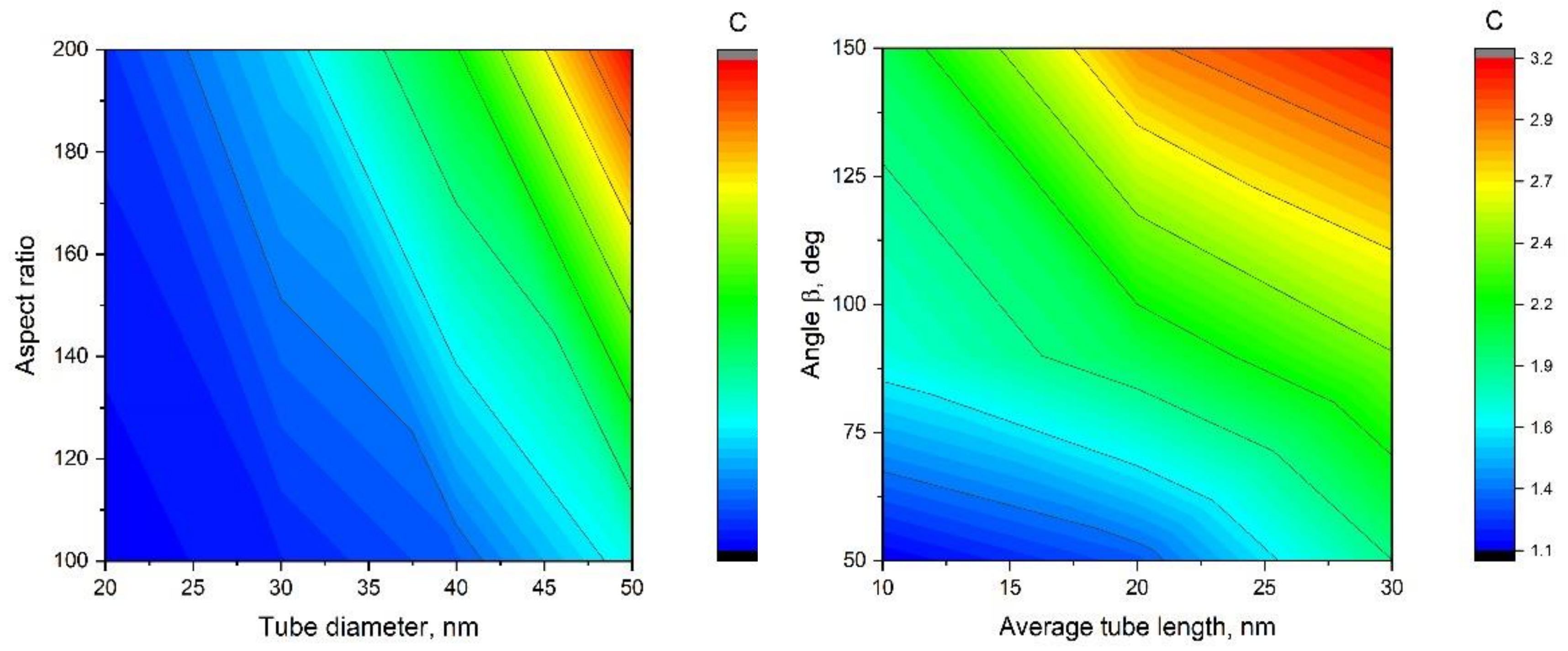


Visualizations of the results of computer experiments that yielded three distinctive outcomes related to percolation behavior of the model nanocomposite



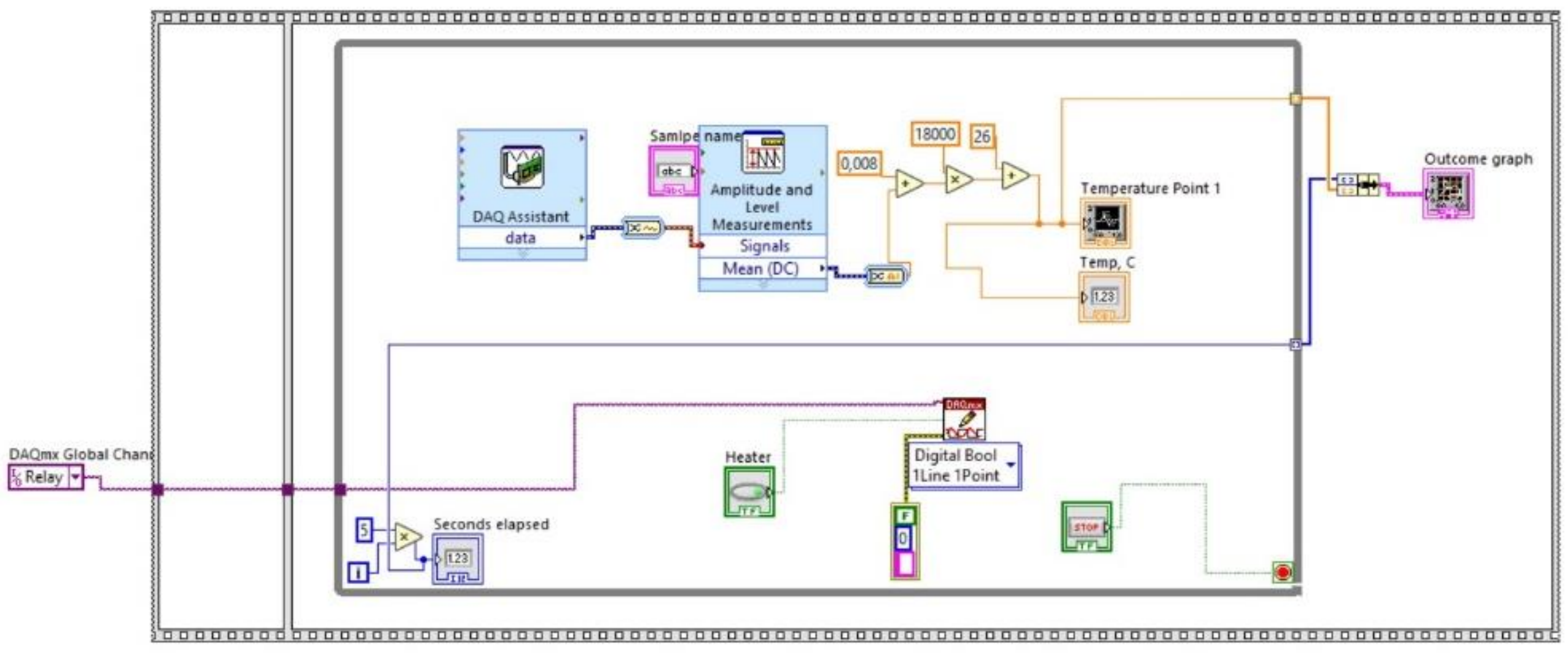
In the first scenario, no percolation was observed, indicating that the conductive elements within the nanocomposite did not form interconnected pathways. As a result, the layer is expected to be dielectric. In the second scenario, a clear percolation phenomenon was observed, with approximately 30% of the filler elements participating in the formation of conductive paths. This configuration is expected to facilitated the efficient transfer of charges along the layer, making it electrically conductive. The ultimate scenario depicts the marginal percolation or a situation just above the percolation threshold, where only a few conductive paths were created with about 4% of network elements participating.

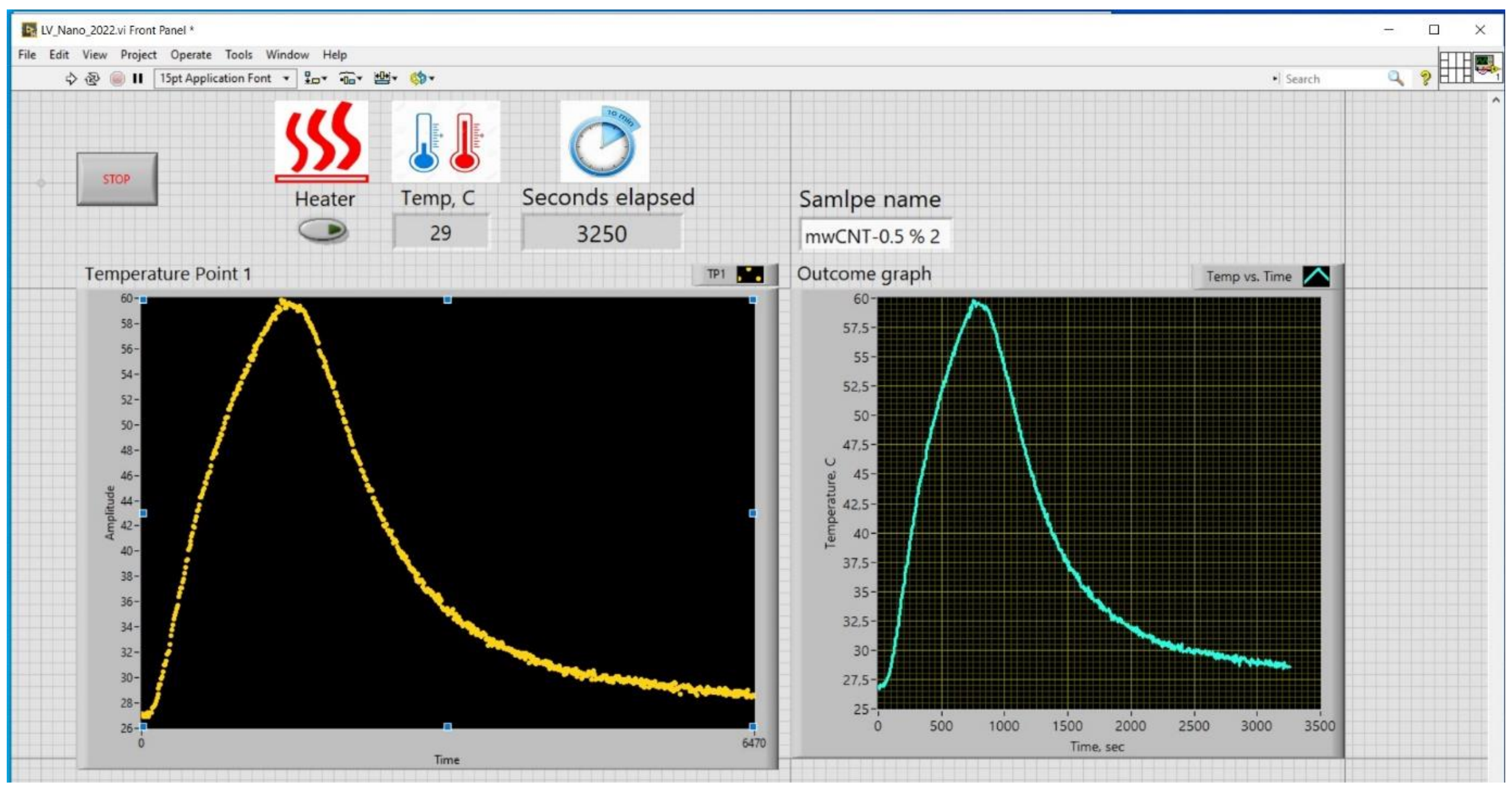
2D plots showcasing the dual parameter variations effect on critical volume fraction: interrelation between average nanotube diameter and aspect ratio (left) and between average nanotube length and orientation angle



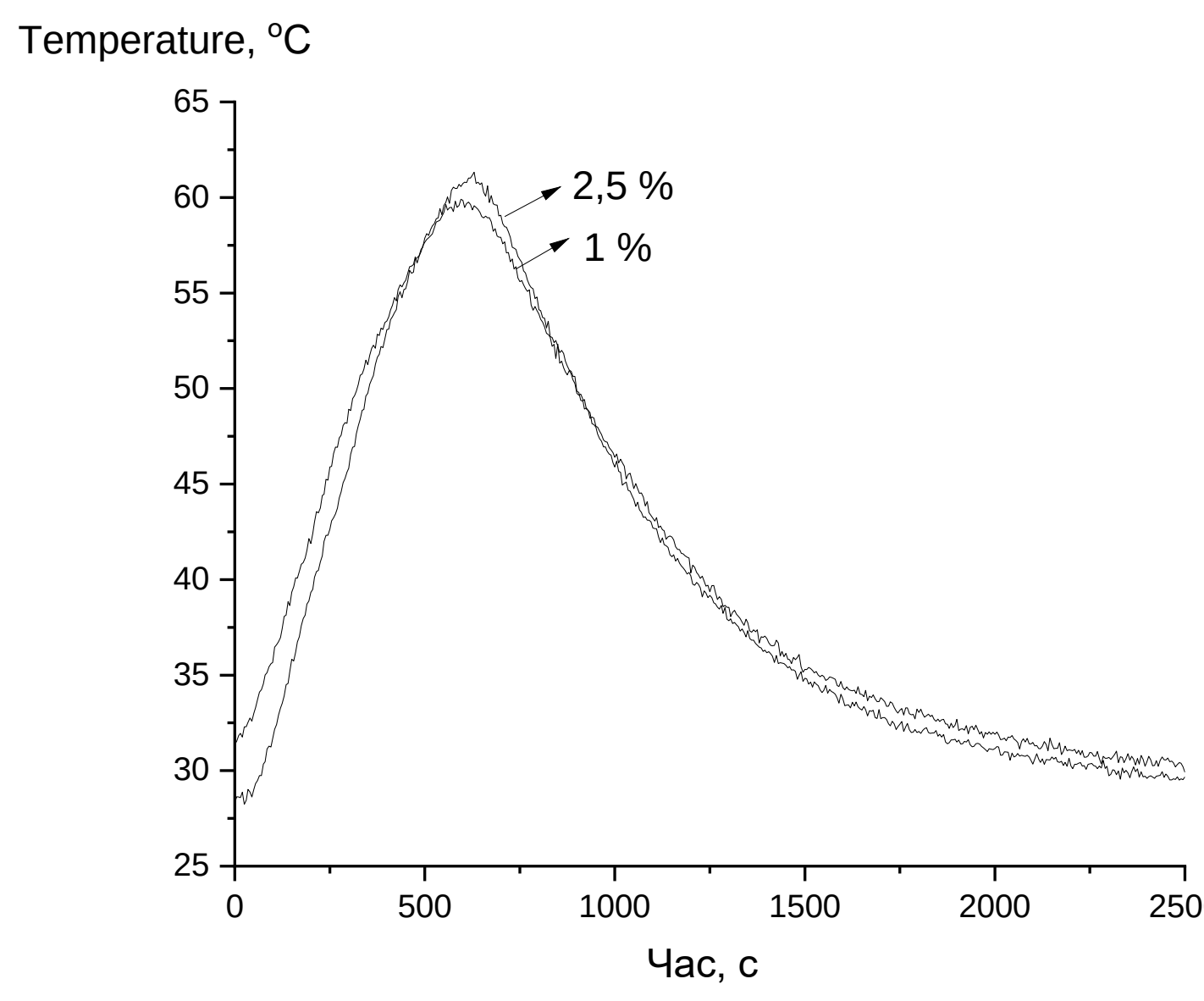
One of the critical considerations when employing a software-based approach to simulate nanotube distributions in nanocomposites is the assumption of an ideal random distribution. In practice, the reality can be more complex, and the actual distribution of nanotubes more often than not deviates from the idealized representation. In real-world nanocomposite systems, nanotubes can exhibit agglomeration, leading to the formation of bundles or clusters, which results in an inhomogeneous distribution across the bulk material.

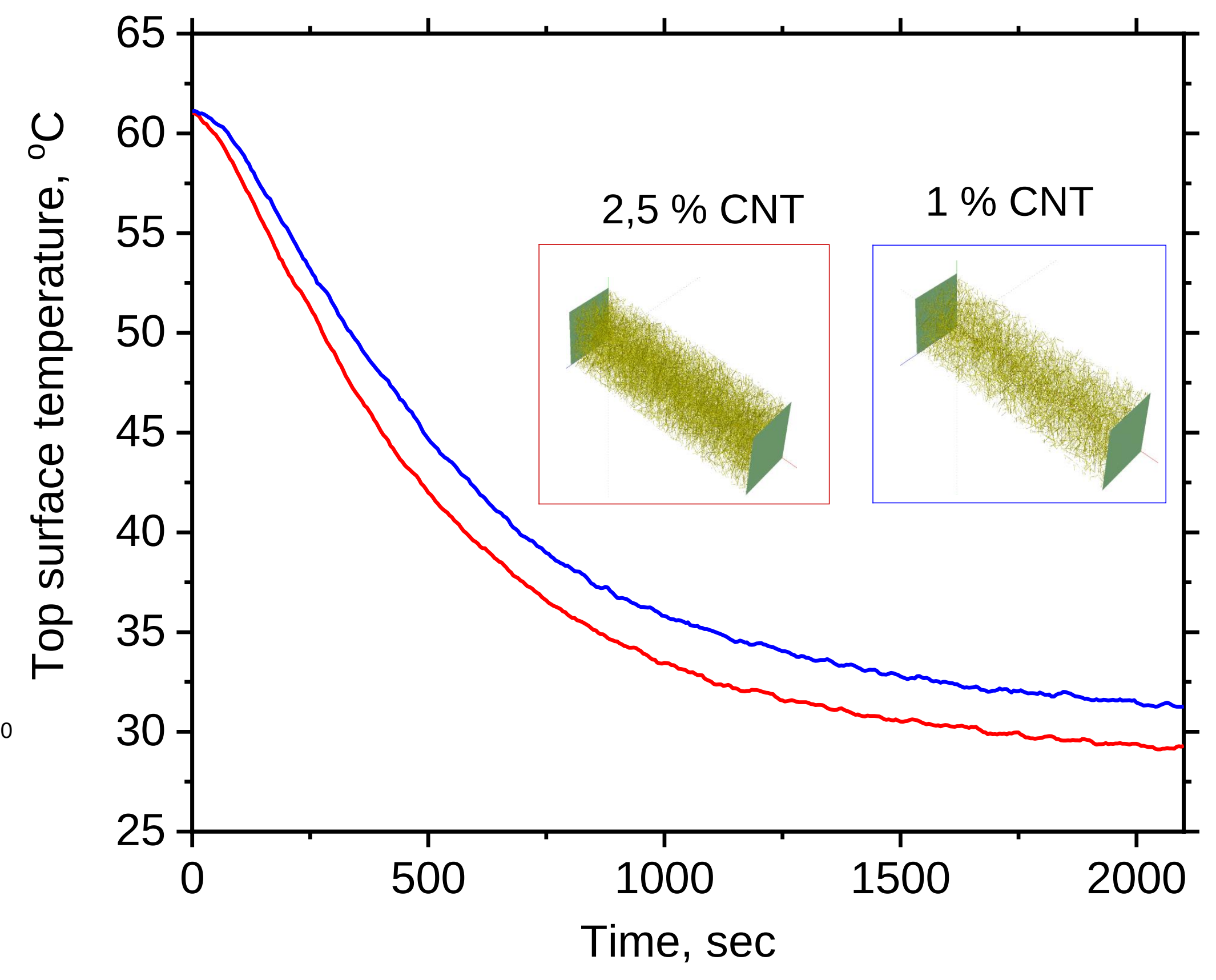
Experimental custom-developed NI LabVIEW software for thermal measurements





Heater
Temp, C: 29
Seconds elapsed: 3250
Samlpe name: mwCNT-0.5 % 2





Visual insights into the heat flow processes within the samples were obtained using a FLIR TG series thermal camera. The recorded thermal response data were utilized to discuss the mechanisms underlying the differences in thermo-physical behavior observed in epoxy composites reinforced with single-walled and multi-walled carbon nanotubes.