**Hybrid CNC–MXene nanolubricant for tribological application: characterization, prediction, and optimization of thermophysical properties evaluation**

**ABSTRACT**

In the present work, hybrid Cellulose Nanocrystal–MXene (CNC–MXene) nanolubricants were prepared via a two-step method and investigated as potential heat-transfer hybrid nanofluids for the first time. CNC–MXene nanolubricants were synthesized via a two-step method by varying the weight percentage of CNC–MXene nanoparticles (ranging from 0.01 to 0.05 wt%) and characterized using Fourier-Transform Infrared Spectroscopy and TGA (Thermogravimetric Analysis). Response surface methodology (RSM) was used in conjunction with the miscellaneous design model to identify prediction models for the thermophysical properties of the hybrid CNC–MXene nanolubricant. Minitab 18 statistical analysis software and Response Surface Methodology (RSM) based on Central Composite Design (CCD) were utilized to generate an empirical mathematical model investigating the effect of concentration and temperature. The analysis of variance (ANOVA) results indicated significant contributions from the type of nanolubricant ($p < 0.001$) and the quadratic effect of temperature ($p < 0.001$), highlighting non-linear interactions that affect viscosity and thermal conductivity. The findings showed that the predicted values closely matched the experimental results, with a percentage of absolute error below 9%, confirming the reliability of the optimization models. Additionally, the models could predict more than 85% of the nanolubricant output variations, indicating high model accuracy. The optimization analysis identified optimal conditions for maximizing both dynamic viscosity and thermal conductivity. The predicted optimal values (17.0685 for dynamic viscosity and 0.3317 for thermal conductivity) were achieved at 30 ◦C and a 0.01% concentration, with a composite desirability of 1. The findings of the percentage of absolute error (POAE) reveal that the model can precisely predict the optimum experimental parameters. This study contributes to the growing field of advanced nanolubricants by providing insights into the synergistic effects of CNC and MXene in enhancing thermophysical properties. The developed models and optimization techniques offer valuable tools for tailoring nanolubricant formulations to specific tribological applications, potentially leading to improved efficiency and durability in various industrial settings.