Synthesis, Characterization, and Application of Sustainable Ag Dopped ZnO Nanoparticles for Waxy Crude Flow Assurance

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Abstract

Wax deposition in crude oil pipelines is a critical flow assurance challenge, increasing operational costs and production risks. Conventional mitigation strategies rely on synthetic inhibitors, which raise concerns over toxicity, cost, and environmental impact. This study presents a sustainable alternative via Vitex doniana-assisted green synthesis of silver-doped zinc oxide (Ag–ZnO) nanoparticles (NPs) and evaluates their performance as wax inhibitors in waxy crude oil. Phytochemicals in Vitex doniana leaf extract acted as natural reducing and capping agents, producing stable Ag–ZnO nanocomposites. Characterization using FTIR, GC–MS, XRD, FESEM, EDS, and TGA confirmed functional phytochemicals, nanocrystalline sizes (≈51 nm ZnO, ≈66 nm Ag), with hexagonal wurtzite, face-centered cubic (fcc); heterogeneous morphologies, and excellent thermal stability. Elemental mapping revealed homogeneous Zn, O, and Ag distribution, with surface carbonaceous species enhancing hydrocarbon compatibility. Rheological testing on Dulang field crude oil demonstrated that incorporating only 0.04 wt% Ag–ZnO NPs reduced the flow activation energy from 213.6 to 207.6 kJ•mol^{-1}, lowering the energy barrier for molecular mobility. This reduction confirms the nanoparticles' role in weakening intermolecular associations and disrupting wax-crystal networks, thereby enhancing crude oil flowability. Overall, the findings highlight green-synthesized Ag–ZnO NPs as an environmentally benign and effective solution for wax mitigation in crude oil pipelines.

Keywords

Characterization, Flow Assurance, Green Synthesis, Nanoparticles, Sustainability, Vitex doniana, Ag-ZnO.