

Cover Letter

To

The Editor-in-Chief

Discovery Artificial Intelligence

Dear Editor,

On behalf of my co-authors, I am pleased to submit our manuscript entitled:

"Physics-Informed AI Surrogate Modelling of Thermal and Hydraulic Losses in Omani Crude Oil Pipelines Using RHLI-Based Analysis, Uncertainty Quantification, and Explainable AI" for consideration for publication in *Discovery Artificial Intelligence*.

This study presents a novel Physics-Informed Artificial Intelligence (PIAI) framework that integrates high-fidelity Computational Fluid Dynamics (CFD), machine learning, uncertainty quantification, and Explainable Artificial Intelligence (XAI) for rapid prediction of thermal and hydraulic losses in non-Newtonian crude oil pipeline systems. The framework was developed using a comprehensive dataset generated from **962 COMSOL Multiphysics simulations** representing realistic thermo-rheological operating conditions for Omani crude oil pipelines.

The principal contributions of this work are:

- Development of an accurate AI surrogate capable of simultaneously predicting **Heat Loss, Head Loss, and Power Loss** in multi-segment crude oil pipelines.
- Introduction of the **Rheological Heat-Loss Index (RHLI)**, a novel physics-informed feature that links rheological behaviour with thermal energy dissipation.
- Comprehensive comparison of multiple machine-learning and ensemble-learning algorithms, demonstrating near-perfect predictive performance.
- Integration of **uncertainty quantification** through quantile regression, conformal prediction, and calibration analysis to provide reliable confidence estimates.
- Application of **SHAP-based explainable AI** to identify the dominant physical parameters governing pipeline energy losses.

- Demonstration of the potential for real-time surrogate modelling to replace computationally expensive CFD simulations, supporting future digital-twin deployment, intelligent pipeline monitoring, predictive maintenance, and energy-efficient pipeline operation.

The manuscript fits well within the scope of ***Discovery Artificial Intelligence*** because it combines computational modelling, petroleum engineering, artificial intelligence, uncertainty-aware prediction, and digital energy technologies to address challenges in sustainable pipeline transportation. We believe the proposed framework will be of broad interest to researchers and practitioners working in geoenergy systems, petroleum engineering, computational mechanics, and AI-driven energy applications.

We confirm that:

- This manuscript is original and has not been published previously.
- The manuscript is not under consideration for publication elsewhere.
- All authors have read and approved the submitted manuscript.
- There are no conflicts of interest related to this work.
- Any funding sources and ethical declarations are fully disclosed in the manuscript.

Thank you for considering our manuscript for publication in ***Discovery Artificial Intelligence***. We appreciate your time and consideration and look forward to your response.

Yours sincerely,

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