SPECO: A Novel Multiparametric Methane Forecasting and Mitigation System Using Quantum Long Short-Term Memory and Sonophotoelectrochemical Oxidation

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Anthropogenic methane (CH4) emissions cause roughly 700,000 premature deaths annually; moreover, CH4 is difficult to monitor and predict. Existing methods lack the predictive accuracy and real-time response necessary for effective mitigation, due to high predictive error (Khan et al., 2024). Further, few innovations currently exist to effectively reduce ambient CH4. The goal of this study is to enhance CH4 forecasting and mitigation efforts through SPECO, a multiparametric, dual-stage system using a Quantum Long Short-term Memory (QLSTM) neural network for accurate CH4 hotspot prediction and sonophotoelectrochemical oxidation (SPECO) for CH4 oxidation. The QLSTM neural networks were trained on 6 spatiotemporal datasets extracted from Google Earth Engine and the Emissions Database for Global Atmospheric Research, forecasting CH4 concentrations with hyperparameter tuning. QLSTM showed a 17.37% reduction in Root Mean Squared Error (RMSE) compared to the classical LSTM baseline. The SPECO was optimized using ANSYS multiphysics software, undergoing three phases of testing: laminar flow testing using Computational Fluid Dynamics (CFD) simulations, chemical optimization using Molecular Dynamics Simulation (MDS), and vibroacoustics simulations. A physical oxidation chamber prototype was engineered using an ultrasonic transducer, yielding a 40% decrease in CH4 as frequency increased. The novel introduction of ultrasonic cavitation was shown to enhance CH4 oxidation by increasing reactivity through uniform propagation – an emerging solution for future space energy. The multiparametric SPECO resulted in syngas and H2 products used for recurrent energy feedstock, supported by computational validation. SPECO is a promising dual-stage system to identify and reduce CH4 emissions.

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