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Quantum computing of nonlinear reacting flows via probability density function

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Quantum computing offers the promise of exponential speedups in scientific computing tasks, particularly those involving large-scale linear systems [1]. However, its application to reacting flows remains challenging due to the nonlinear source terms and the need for time-dependent solutions [2]. In this work, we address these issues by employing a probability density function (PDF) formulation [3] to transform the nonlinear reacting-flow partial differential equations (PDEs) into linear ones. The evolution process is then solved by the history state [4], namely space-time coupling, in which all time steps are stored as a superposition state. This approach avoids repeated quantum state measurement and preparation at intermediate steps, fully leveraging the advantage of the quantum linear systems algorithm. By encoding the distributions in a quantum state, we can efficiently measure the PDF's statistical moments through carefully designed quantum algorithms. This advances the practical value of the algorithm, allowing for an end-to-end application of quantum computing on nonlinear reacting flows. Our computational complexity analysis indicates a near-exponential speedup over classical algorithms. To validate the proposed framework, we perform a series of test cases simulating reacting flows with various conditions. The results highlight the potential of quantum computing for solving reacting flows with nonlinear source terms and extracting statistics efficiently.

References

[1] Meng ZY et al. Advances in quantum computing for fluid dynamics. *Advances in Mechanics*. 2025.

[2] Lu Z and Yang Y. Quantum computing of reacting flows via Hamiltonian simulation. *Proceedings of the Combustion Institute*. 2024;40:105440.

[3] Pope SB. *Turbulent Flows*. (Cambridge, Cambridge University Press, 2000).

[4] Berry DW. High-order quantum algorithm for solving linear differential equations. *Journal of Physics A: Mathematical and Theoretical*. 2014;47:105301.