Hydrogen enrichment in gas turbines: A CFD study on NOx reduction for sustainable energy systems

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Abstract

Nitrogen oxides (NOx) emissions from gas turbines, resulting from high-temperature combustion, pose significant environmental and health challenges, needing innovative strategies for sustainable energy production. This computational fluid dynamics (CFD) study investigates the efficacy of hydrogen enrichment (0–30% by mass) and inlet air/fuel temperature variations in reducing NOx emissions in a single-can reverse-flow gas turbine combustor. Implemented in ANSYS Fluent 6.3.26 with the k-ω SST turbulence model and eddy-dissipation combustion, the model employs a 507,659-cell mesh, confirmed against experimental NOx data (15–25 ppm for natural gas, simulated 27.4 ppm). Hydrogen blending reduces peak flame temperatures from 999 °C (0% H_2) to 937 °C (30% H_2), achieving a 90% NOx reduction (below 1 ppm) at 30% hydrogen due to lean combustion (equivalence ratio 0.263). Inlet air temperature increases (630–680 K) elevate NOx by 51% (20.5–31 ppm), while fuel temperature rises (260–320 K) increase NOx by 11% (27–30 ppm). Inlet cooling enhances NOx abatement without added infrastructure. The novel synergy of hydrogen enrichment and inlet cooling outperforms conventional methods like selective catalytic reduction (SCR), offering a scalable, efficient solution for sustainable turbine operation. Future thermodynamic cycle analyses are recommended to perfect system-wide performance.

Keywords: Hydrogen enrichment, NOx reduction, CFD modeling, lean combustion, gas turbine sustainability