

Transisi menuju energi bersih menuntut sektor pembangkitan listrik untuk mengadopsi teknologi rendah karbon, termasuk menguji pemanfaatan hidrogen sebagai bahan bakar alternatif. *Co-firing* hidrogen pada *diesel gas engine* menjadi strategi yang menjanjikan karena mampu menurunkan emisi tanpa memerlukan modifikasi besar pada peralatan. Namun, pengujian fisik untuk mengevaluasi performa *co-firing* memerlukan biaya tinggi dan mengandung risiko operasional. Oleh karena itu, simulasi *Computational Fluid Dynamics (CFD)* menjadi pendekatan efektif untuk menguji berbagai skenario operasi.

Penelitian ini memodelkan proses *co-firing* hidrogen-LNG pada *diesel engine* Wärtsilä 50DF. Model *CFD* divalidasi menggunakan data eksperimen berupa diagram tekanan terhadap *crank angle*, dan emisi gas buang. Model *CFD* kemudian dilakukan simulasi untuk menganalisis pengaruh *equivalence ratio* pada rasio campuran hidrogen-LNG. Simulasi dilakukan dengan variasi fraksi mol hidrogen sebesar 0%, 10%, dan 20%, 30% serta variasi *equivalence ratio* dari ϕ 0,625 hingga ϕ 0,417 dengan total energi bahan bakar dijaga konstan. Parameter yang dikaji meliputi tekanan puncak silinder, temperatur puncak silinder, temperatur gas buang mesin, dan emisi gas buang.

Hasil penelitian menunjukkan bahwa penurunan *equivalence ratio* dari ϕ 0,625 ke ϕ 0,45 mampu meningkatkan kualitas pembakaran, sehingga tekanan puncak silinder dan efisiensi termal meningkat. Selain itu, penambahan fraksi mol hidrogen pada bahan bakar mampu memperpendek durasi pembakaran, meningkatkan efisiensi termal, serta menurunkan ISFC dan emisi CO. Namun, pada kondisi *equivalence ratio* (ϕ) 0,417, proses pembakaran menjadi lebih lambat sehingga tekanan puncak dan performa mesin menurun. Peningkatan fraksi hidrogen juga meningkatkan Maximum Pressure Rise Rate (MPRR) dan emisi NO_x. Kondisi operasi optimum diperoleh pada *equivalence ratio* ϕ 0,5–0,45 dengan fraksi mol hidrogen 20%. Pada kondisi tersebut, mesin menghasilkan efisiensi termal tertinggi, konsumsi bahan bakar yang lebih rendah, serta emisi yang relatif terkendali.

Kata kunci: Simulasi *CFD*, *diesel gas engine*, *co-firing* Hidrogen-LNG, *equivalence ratio*, Performa Pembakaran, emisi gas buang.

ABSTRACT

The transition toward clean energy requires the power generation sector to adopt low-carbon technologies, including the utilization of hydrogen as an alternative fuel. Hydrogen co-firing in diesel engines offers a promising pathway to reduce emissions with minimal hardware modification. However, physical testing of co-firing configurations is costly and poses operational risks, making Computational Fluid Dynamics (CFD) a practical approach for evaluating multiple operating scenarios.

This study investigates the co-firing process of hydrogen and LNG in a Wärtsilä 50DF diesel engine using Ansys Forte CFD simulations. The CFD model was validated using experimental data, including pressure–crank angle diagrams and exhaust emission measurements. After validation, the CFD model was used to investigate the effects of equivalence ratio and hydrogen–LNG fuel composition on engine performance and combustion characteristics. Simulations were conducted with hydrogen mole fractions of 0%, 10%, 20% and 30%, while the equivalence ratio varied from 0,625 to ϕ 0.417 under constant total fuel energy input. The investigated parameters included exhaust emissions, peak cylinder pressure and temperature, combustion characteristics, and exhaust gas temperature.

The results showed that reducing the equivalence ratio from ϕ 0,625 to ϕ 0,45 improved combustion quality, resulting in higher peak cylinder pressure and enhanced thermal efficiency. In addition, increasing the hydrogen mole fraction in the fuel shortened the combustion duration, improved thermal efficiency, and reduced indicated specific fuel consumption (ISFC) and CO emissions. However, at an equivalence ratio of ϕ 0,417, the combustion process became slower, leading to lower peak cylinder pressure and deteriorated engine performance. Increasing the hydrogen fraction also caused higher Maximum Pressure Rise Rate (MPRR) and NO_x emissions. The optimum operating condition was achieved at an equivalence ratio of ϕ 0,5–0,45 with a hydrogen mole fraction of 20%. Under these conditions, the engine produced the highest thermal efficiency, lower fuel consumption, and relatively controlled emissions.

Keywords: *CFD simulation, diesel gas engine, LNG–hydrogen co-firing, equivalence ratio, combustion performance, exhaust emissions.*