Hydrogen co-injection as a bridged technology for internal combustion engines

S. Molina-Ramírez[1]*, M. Cortés-Reyes[1], C. Herrera[1], M.A. Larrubia[1], J.A. Auñón[2], L.J. Alemany[1]*

[1]Departamento de Ingeniería Química, Facultad de Ciencias, Campus de Teatinos, Universidad de Málaga, Málaga, E-29071, Spain
[2]Departamento de Máquinas y Motores Térmicos, Escuela de Ingenierías, Campus de Teatinos, Universidad de Málaga, Málaga, E-29071, Spain
*smolina@uma.es; luijo@uma.es

☒	**Oral preferred**
☐	**Poster preferred**

Introduction

In order to survive at media-term, diesel engines need a new approach for the use of the new fuel portfolio and to control the exhaust gas emissions. Hydrogen has been proposed as an alternative due to its excellent combustion properties, which could improve the combustion performance and emissions of internal combustion engines [1, 2]. The main drawback is that the location of a hydrogen cylinder inside the vehicles implies space and risk problems. Therefore, it could be produced on board and released into the air-intake of any biofuels fed to diesel engines. For that, the required optimized amount of hydrogen must be known, studying all engine parameters and emission in different driving modes for the establishment of the engine regions of operation in which partial replacement of fuel by hydrogen is effective as a bridged technology.

Materials and Methods

This experimental study was performed in an engine test bench composed of a diesel engine (RHY DW10TD HDI, 4 cylinders – 2000cm^3, *common rail*) and a dynamometer TECNER E145. In addition, NO, NO_2, CO, CO_2 and O_2 concentration at the exhaust gas were measured directly to the manifold outlet by a PG-350E (HORIBA Inc.). The experiments were performed at different revolution conditions (2000-3000rpm) modifying the torque from 30 to 90N·m. Overall, Hydrogen was introduced through a nozzle to the intake manifold before entering the combustion chamber as it is represented in the engine setup scheme in Figure 1. H_2 co-injection was gradually increased from 5 until 15mL·min^{-1} reaching the stationary condition and, commercial diesel was used as a main fuel.

Results and Discussion

An increase in the loading (engine torque) implies an increase in consumption and power and, even with hydrogen co-fueled, the pre-injection disappeared and the pressure reached its maximum at 90N·m. Indeed, by increasing the H_2 flow rate under high load conditions, the increase of the maximum pressure (up to 80bar) became much more noticeable indicating a combustion improvement. At low loading (30N.m), a greater amount of hydrogen implied a lower fuel consumption to reach the same power, being necessary 15L·min^{-1} to be noticeable, whereas at higher loadings (90N.m), the improvement was already noticeable using 5L·min^{-1}. Therefore, depending on the engine conditions, it is necessary to variate the amount of co-injected H_2 to optimize engine performance. Hydrogen requires less energy to ignite than diesel and creates flames that spread through the combustion chamber faster than diesel, producing a faster and more complete combustion of the air-diesel mixture, making the use of fuel more efficient.

Regarding emissions, as the loading increases, NO_x and CO_2 production also increase, although CO decreases. The increase in H_2 content caused a considerable reduction of CO_2 and CO gaseous emissions and the maximum in-cylinder gas pressure and rate of heat release peak values raised with hydrogen fraction. An energy replacement by hydrogen of 8% allows an optimized direct injection timing improving the efficiency; by reducing consumption and hydrogen co-injection, it is possible to achieve the same energy efficiency, indeed, the formation of C-containing compounds decreases, thus achieving the decarbonization of the fuel and the reduction of CO_x emissions. In addition, the better combustion reduces the temperature of the chamber and the formation of thermal NO decreases. In Figure 2, the NO_x concentration values in the exhaust gas vs. Brake-Specific Fuel Consumption (BSFC) depending on torque were represented and, for all the fuel-mixtures tested, NO_x emissions decreased with the decrease of engine torque. The incorporation of H_2 also caused a decrease in NO_x formation and two regions can be distinguished depending on the BSFC value. Below 300 $g{\cdot}kWh^{-1}$, the effect of H_2 flow was noticeable, being necessary the use of $15L{\cdot}min^{-1}$ to reach a NO_x decrease of 52%, whereas for BSFC values above 300 $g{\cdot}kWh^{-1}$, the engine's NO_x emission remains at the lowest concentration, regardless of the amount of H_2 used.

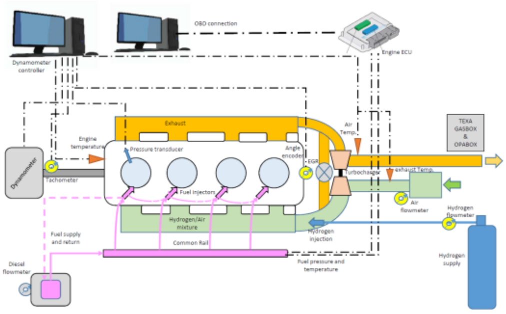

Figure 1. Scheme of dynamometer engine test bench and H_2-coinjection.

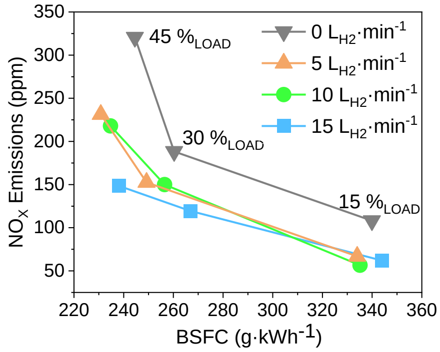

Figure 2. NO_x emissions for different H_2 inlet flows working at 2000 rpm and different loads (%).

Conclusions

H_2 co-injection flow should be adjusted to supply the appropriate amount of H_2 depending on the driving mode, since, at low loading, a hydrogen flow rate of $15L{\cdot}min^{-1}$ is necessary to observe an improvement in engine performance and emissions while at high loading, the co-injection of $5L{\cdot}min^{-1}$ makes the improvement noticeable. Thus, an on-board H_2 *in situ* production system can generate the H_2-enriched stream on demand while driving and inject it directly into the air-fuel mixture just before the combustion stage, modifying the engine's fuel map for optimal efficiency, being a bridge technology in the transition from conventional vehicles to fuel cell vehicles and electric vehicles.

References

1. Slcuk Sarikoc, Fuel 297 (2021) 120732
2. Hüseying. International Journal of Hydrogen Energy 45 (2020) 27969-27978