# Contextualizing the Performance of Hydrogen LDI Fuel Nozzles

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## OVERVIEW

One of the primary ways industry has planned to decarbonize gas turbines has been to replace typical hydrocarbon fuels with alternative, carbon-free fuels, such as hydrogen. The combustion dynamics of hydrogen are extremely different than traditional natural gas, having higher autoignition and flashback risks, but greater overall stability. These differences encourage the development of a combustion system with an entirely new concept. Lean direction injection (LDI) combines micromixing concept and liquid fuel injection concepts to rapidly mix the hydrogen fuel with air to generate a flame that behaves like a premixed flame.

Previous studies focused on the imaging diagnostics and the Chemical Reactor Network (CRN) of a series of 16 injectors with vary geometries. These injectors were testing with varying pressure drops, preheat temperatures, fuel compositions (ranging from 100% natural gas up to 100% hydrogen), and flame temperatures. Recorded emissions were then compared to the CRN model developed to predict such emissions. However, to quantify the performance of LDI nozzles, an additional study comparing the $NO_x$ emissions performance of a traditional system to this new system is needed.

New, additional hardware was developed to simulate the performance of a traditional premixed system. Initial development such hardware and initial results are discussed here.

## GOALS

1. Develop Experimental Hardware to compare Premixed NOx Emissions to LDI
    1. Use the same Test Stand
        1. Airbox
        2. Air and Fuel Flows
        3. Preheat
        4. Imaging Diagnostics
        5. Emissions Measurements
    2. Same Effective Area as LDI Nozzles
    3. Have a Modular Design
2. Determine if LDI can achieve $NO_x$ emissions levels of a premixed system

## HARDWARE DEVELOPMENT

The initial studies used an airbox comprised of a piece of standard thick-walled size 6 stainless steel pipe. The additional hardware needed to be compatible with this airbox to use the flow metering, preheat, and diagnostic functionality built into the test stand. An entirely new dome plate and fuel injection system was developed. The premixed system uses a jet in cross-flow to premix the air and fuel prior to entering the combustor via a swirl plate. The previous test stand and the new hardware are picture below in Figure 1.

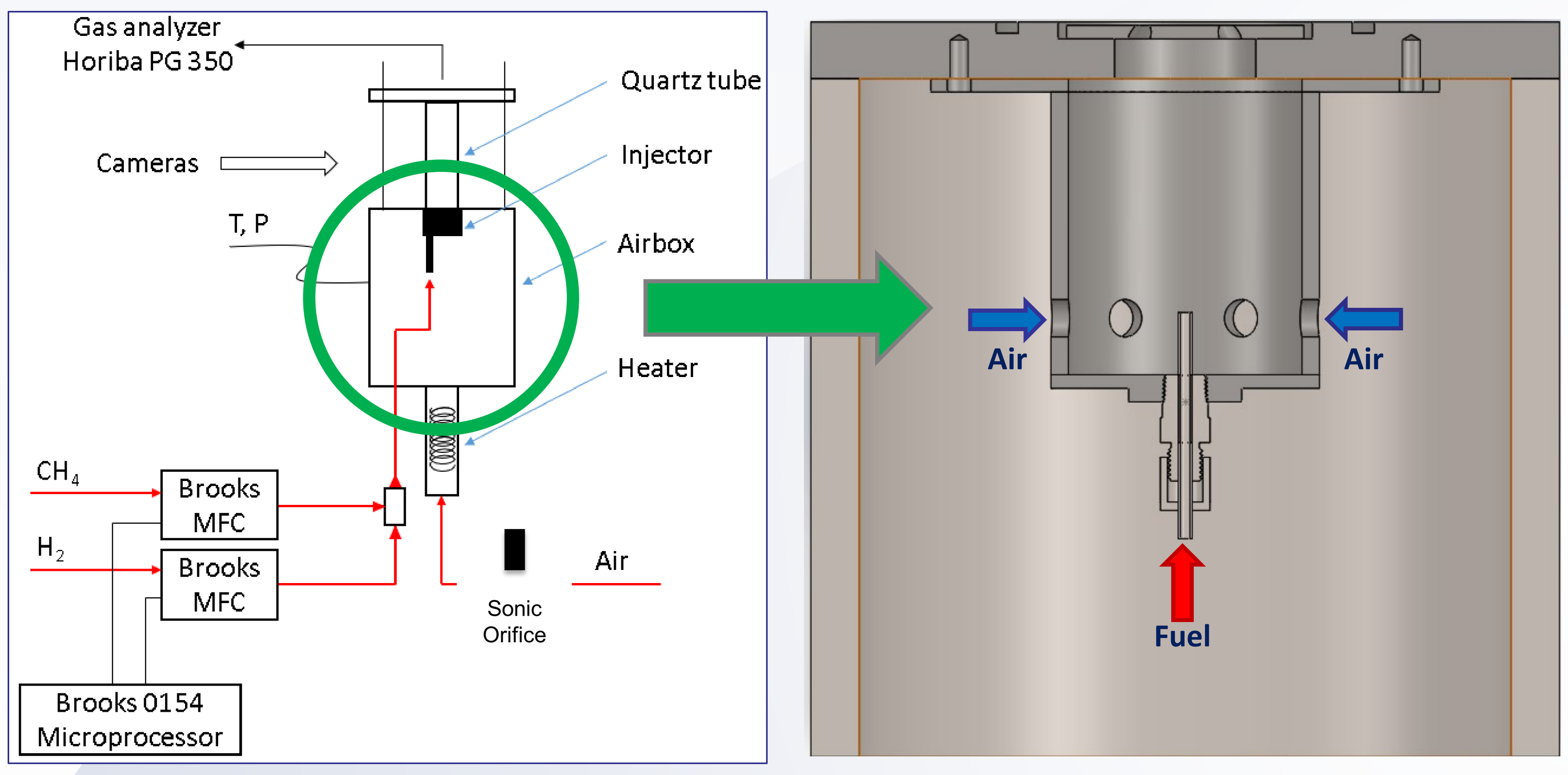


*Figure 1: The LDI Test Stand (Left) and the Premixed Hardware Developed for the same Airbox (Right)*

## HARDWARE VALIDATION

Solidworks Flow Simulations (SFS) were used to validate the level of mixing between the air and fuel streams prior to entering the combustion chamber. A mixing index of 0.975 was achieve at the plane 2mm upstream of the swirl plate, seen in Figure 2.

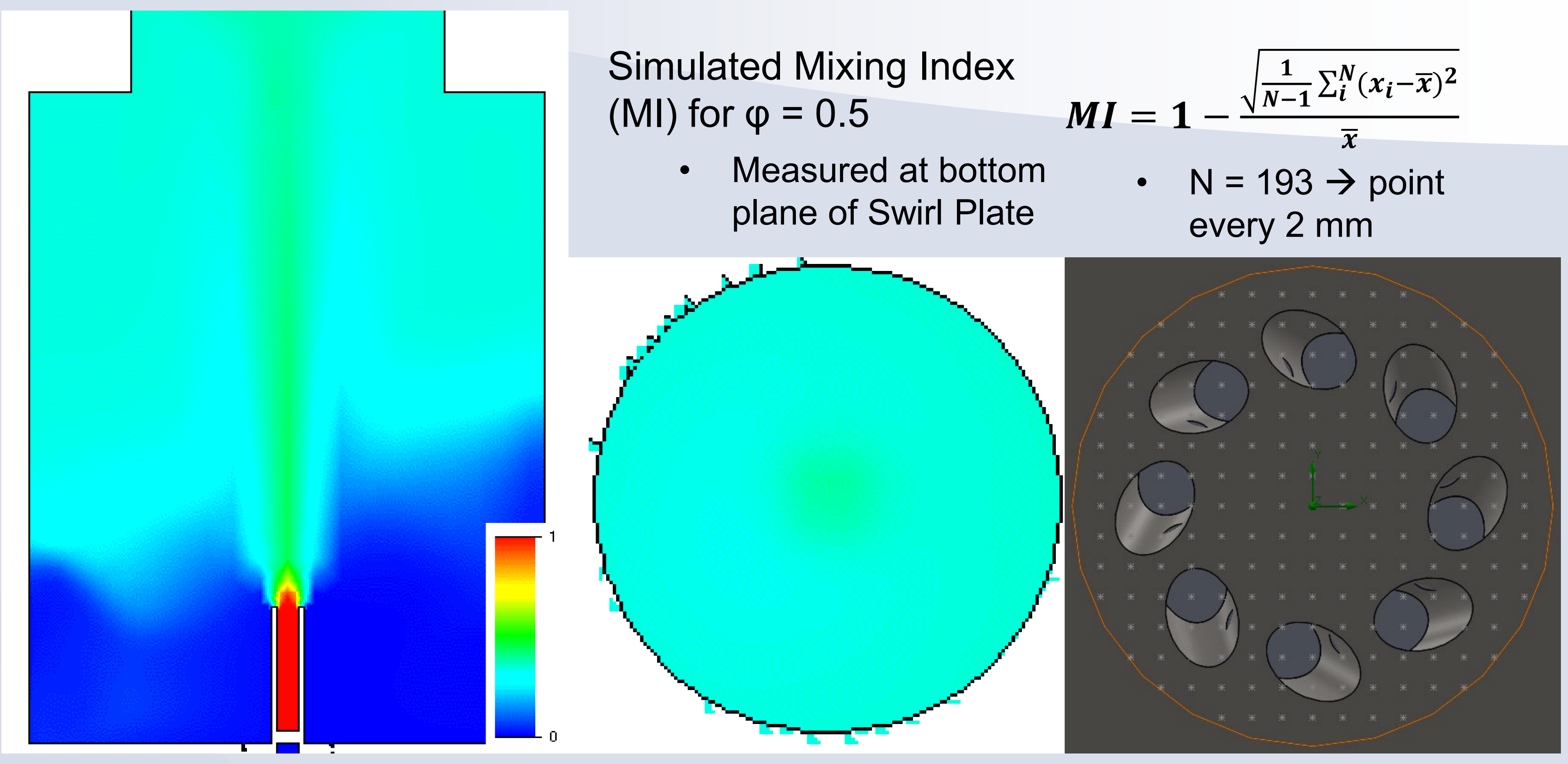


*Figure 2: SFS of %-Vol Methane Side View (L), Top View (C), Sample Point Mesh (R)*

## EMISSIONS RESULTS

Emissions data for pure natural gas was obtained at various pressure drops (2%, 4%, 6%), various preheat temperatures, and at various equivalence ratios. Data was collected between the lean blowoff point until the CO amount was over 100 ppm. Recorded emissions were converted from ppmvd to ng/J using an F-Factor Method. Adiabatic Flame Temperatures were estimated using Chemkin. Initial results are plotted below in Figure 3.

$$NO_x\left[\frac{ng}{J}\right] = X * C * F * \left(\frac{20.95}{20.95 - \%O_2}\right)$$

- C = Concentration of NOx in PPMVD, uncorrected
- F = Fuel Specific Factor for various H2/CH4 mixes
- X = Conversion Factor (mL/SCM to ng/SCM)
- $\%O_2$ = Percent Volume of Oxygen, Dry

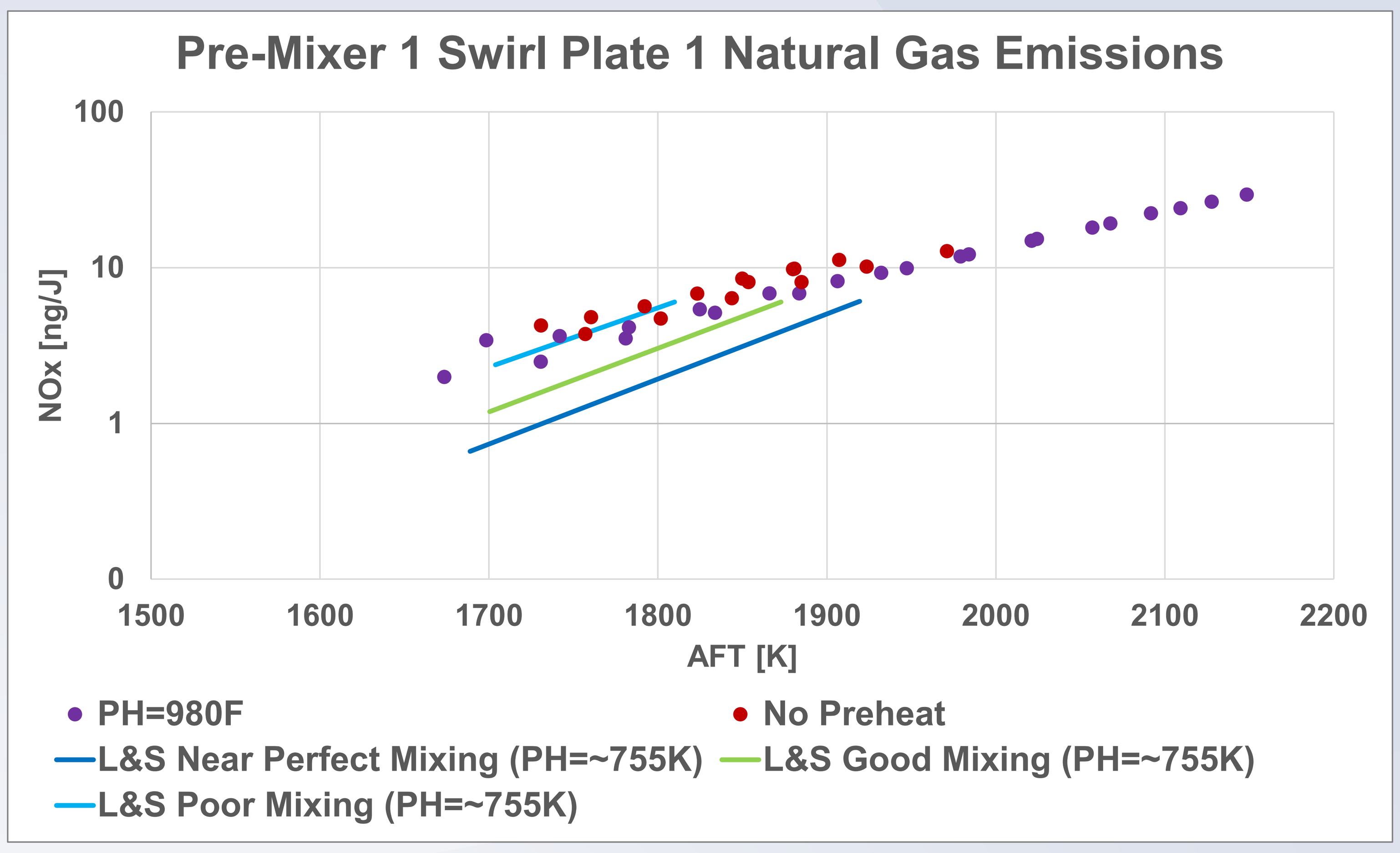


*Figure 3: Recorded $NO_x$ Emissions Plotted Against Inferred Leonard and Stegmaeir Mixing Curves*

As seen in Figure 4, the brightness of the flame was not observed to be symmetric, which could be an indicator of their being imperfect mixing of the fuel and air streams. This would explain the relatively poor $NO_x$ emissions performance.

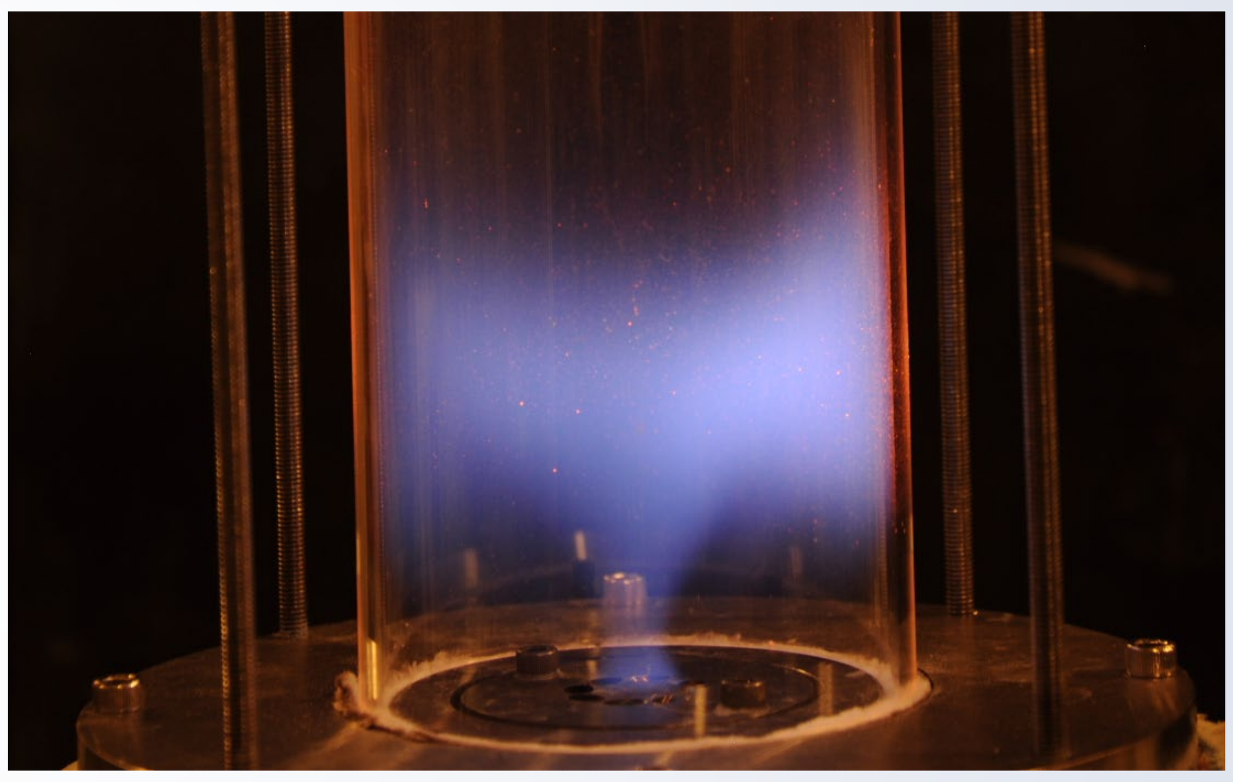

*Figure 4: Natural Gas Flame with Premixer 1, Swirl Plate 1 Configuration*

## FUTURE WORK

Further development of the premix hardware is necessary to achieve the required levels of mixing for low $NO_x$ emissions. Additional LDI nozzles will be tested alongside the new premixed hardware at the same conditions to provide direct comparisons between the two systems.

To determine if design trends translate between atmospheric and elevated pressures, the best performing injectors and premixed configurations will undergo testing at high pressures (up to 10 atm).

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