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Experimental investigation of NO_x impact on ignition delay times for lean H₂ /Air mixtures using a rapid compression machine under ice conditions

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► **To cite this version:**

Nicolas Villenave, Guillaume Dayma, Pierre Brequigny, Fabrice Foucher. Experimental investigation of NO_x impact on ignition delay times for lean H₂ /Air mixtures using a rapid compression machine under ice conditions. 5th International RCM Workshop, Jul 2024, Milan, Italy. hal-04906713

HAL Id: hal-04906713

<https://hal.science/hal-04906713v1>

Submitted on 22 Jan 2025

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Introduction

- The transport sector is the second most polluting sector: CO₂ emissions = 7000 Mt in 2020.
- Replacing fossil fuels (gasoline and diesel) with green e-fuels: Hydrogen (H₂).
- Exhaust gas recirculation (EGR) in hydrogen spark ignition engines (H₂SIEs) → balance between lean-burn condition performance and low NO_x emissions.
- EGR/IGR can impact combustion → residual species such as nitric oxide (NO) and nitric dioxide (NO₂).
- Crucial to study the impact of NO_x on lean H₂/air ignition delays under H₂SIE conditions and validate kinetic mechanisms.

Experimental facility and methodology: Laser Gas Analyzer DURAG

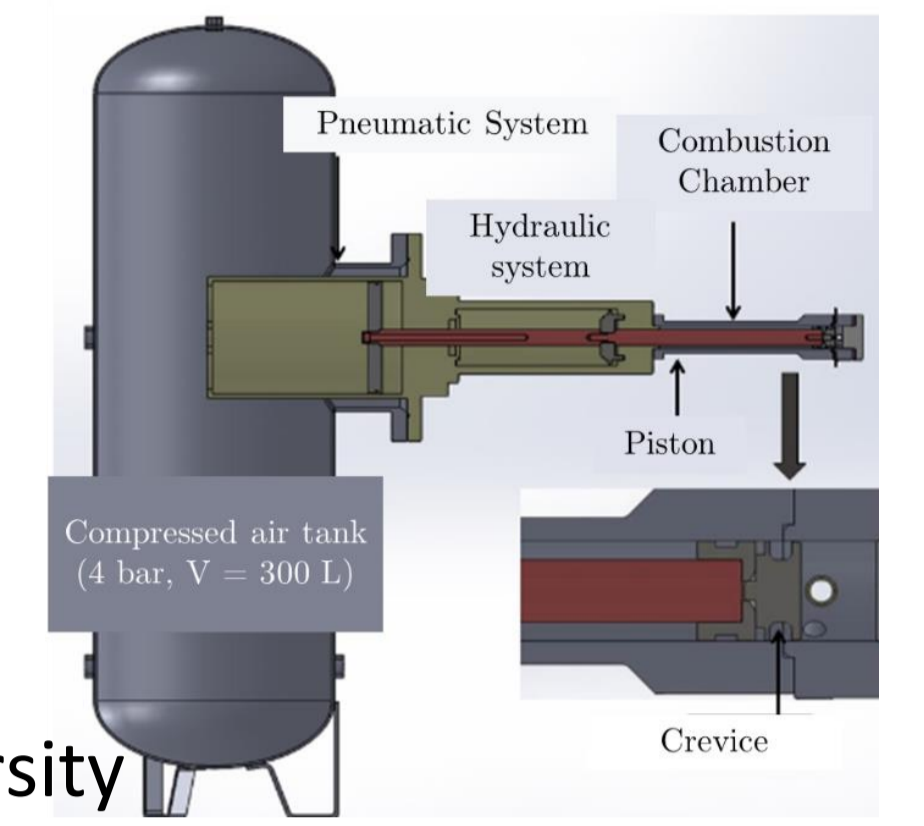
- Fast interconversion of NO into NO₂: 2 NO + O₂ = 2 NO₂ [2].
- Final mixture composition in the tank vessel measured using a precalibrated multi-compo laser infrared spectrometer LaserCEM.
- Measurement uncertainty for NO and NO₂ is ± 5 ppm.
- Experiment repeated three times for each mixtures : H₂/air/NO_x (= 50, 250 and 1250 ppm) at φ = 0.4.

Figure 1. Laser Gas Analyzer DURAG



Experimental rig and methodology: Rapid Compression Machine

- IDT = time difference between the time of the maximum pressure rise rate and the pressure at the end of the compression.
- Crevice to prevent vortex roll-up formation.
- Conditions: φ = 0.4 – p_c = 30 – 60 bar.
- NO_x addition: 50 ppm, 250 ppm and 1250 ppm.
- Non-reactive experiments conducted to consider the heat losses. Figure 2. RCM from Orléans university



Phase NO conversion

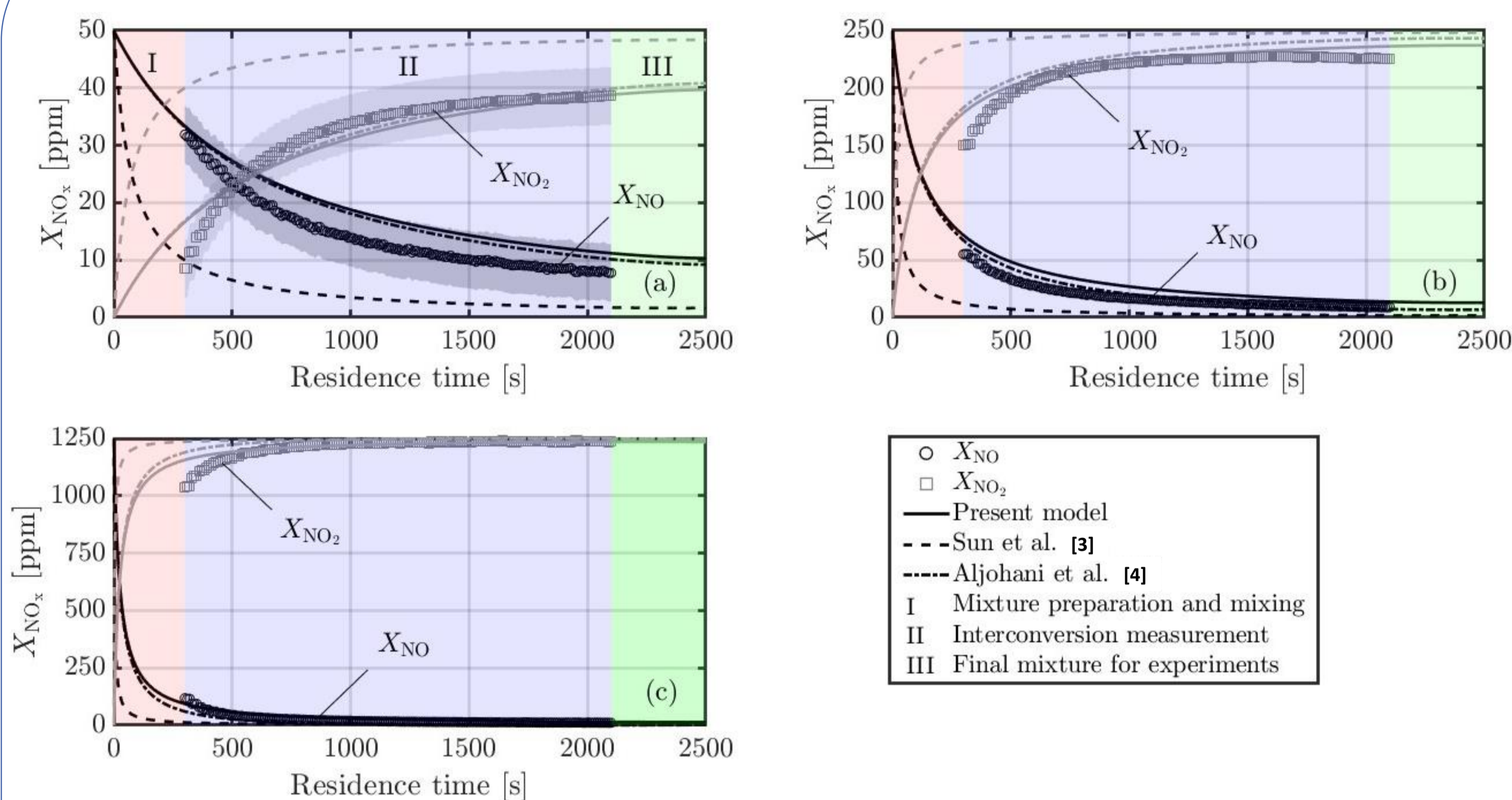


Figure 3. Comparison of NO and NO₂ mole fractions evolution during the mixing in the RCM tank vessel at p = 5 bar and T = 333 K.

- Kinetic mechanisms show a faster interconversion with initial NO concentration increases.
- A plateau is reached after 30 minutes.
- Three final mixtures:
 - (a) X_{NO} = 8 ppm et X_{NO2} = 42 ppm;
 - (b) X_{NO} = 9 ppm and X_{NO2} = 241 ppm;
 - (c) X_{NO} = 11 ppm and X_{NO2} = 1239 ppm

Ignition delay times measurement

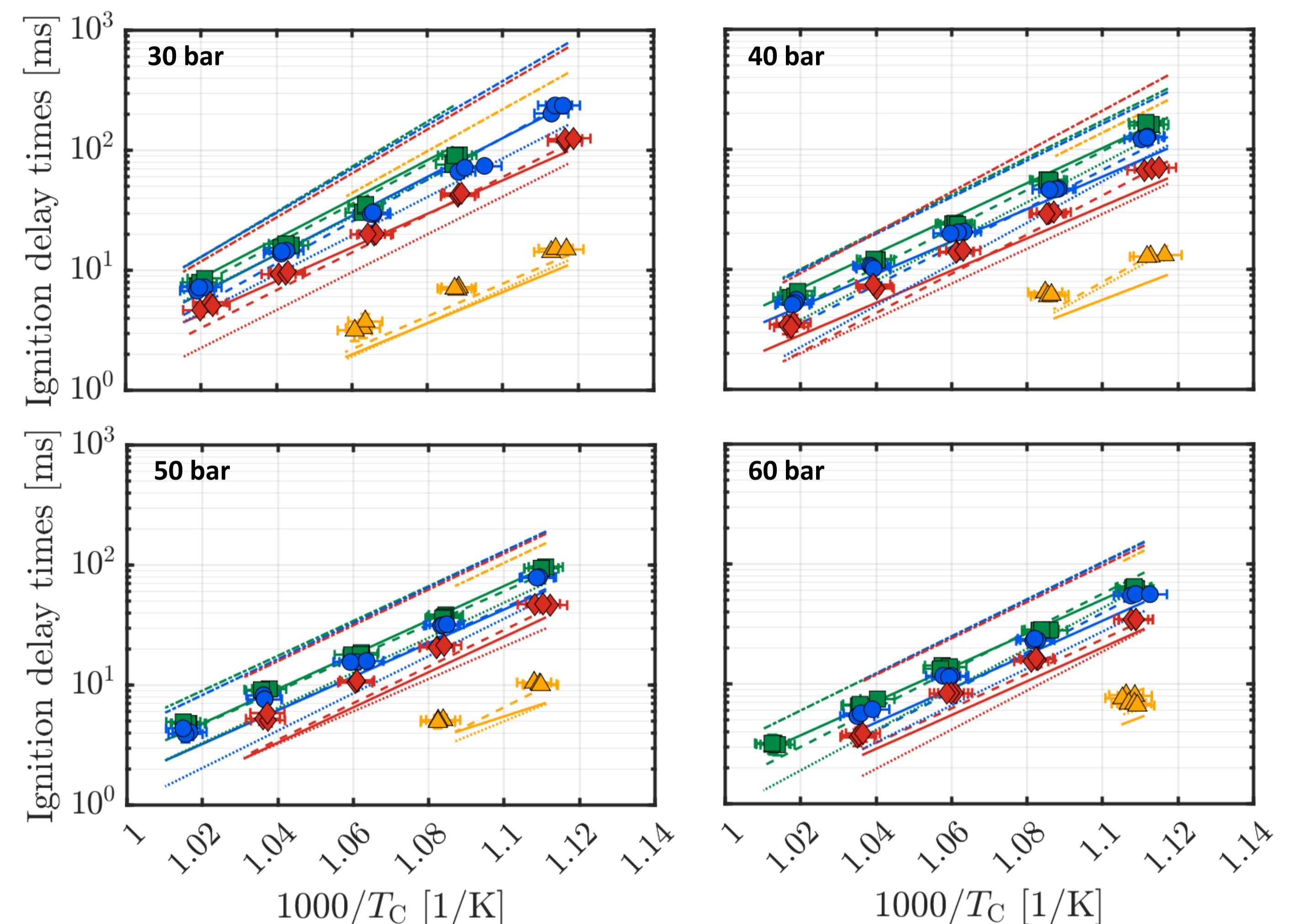
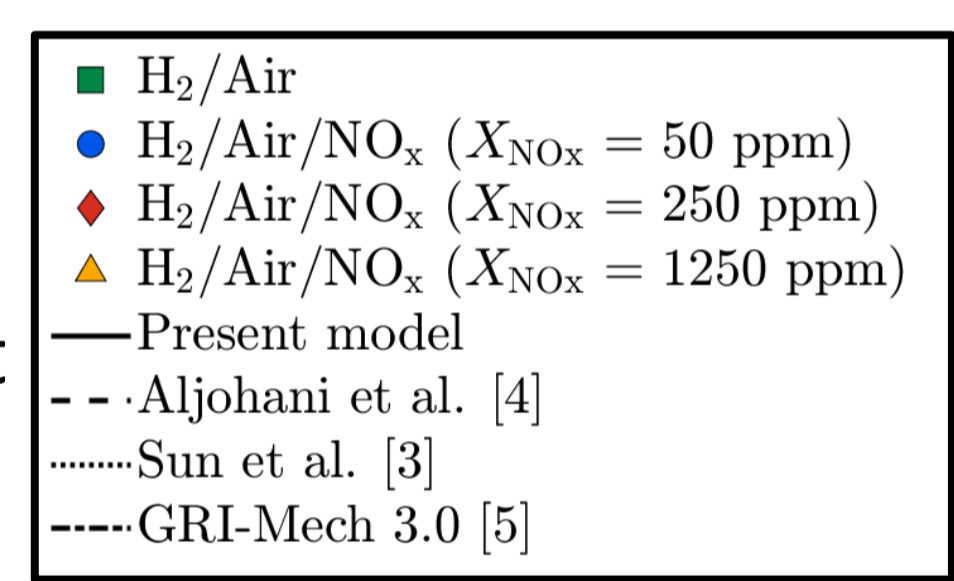


Figure 4. Ignition delay times of H₂/O₂/N₂/NO_x mixtures at φ = 0.4.

- Ignition delay times decrease with NO_x addition.
- The proposed model shows very good agreement for X_{NOx} = 50 ppm and X_{NOx} = 250 ppm. Discrepancies arise for the case X_{NOx} = 1250 ppm.



Sensitivity analysis

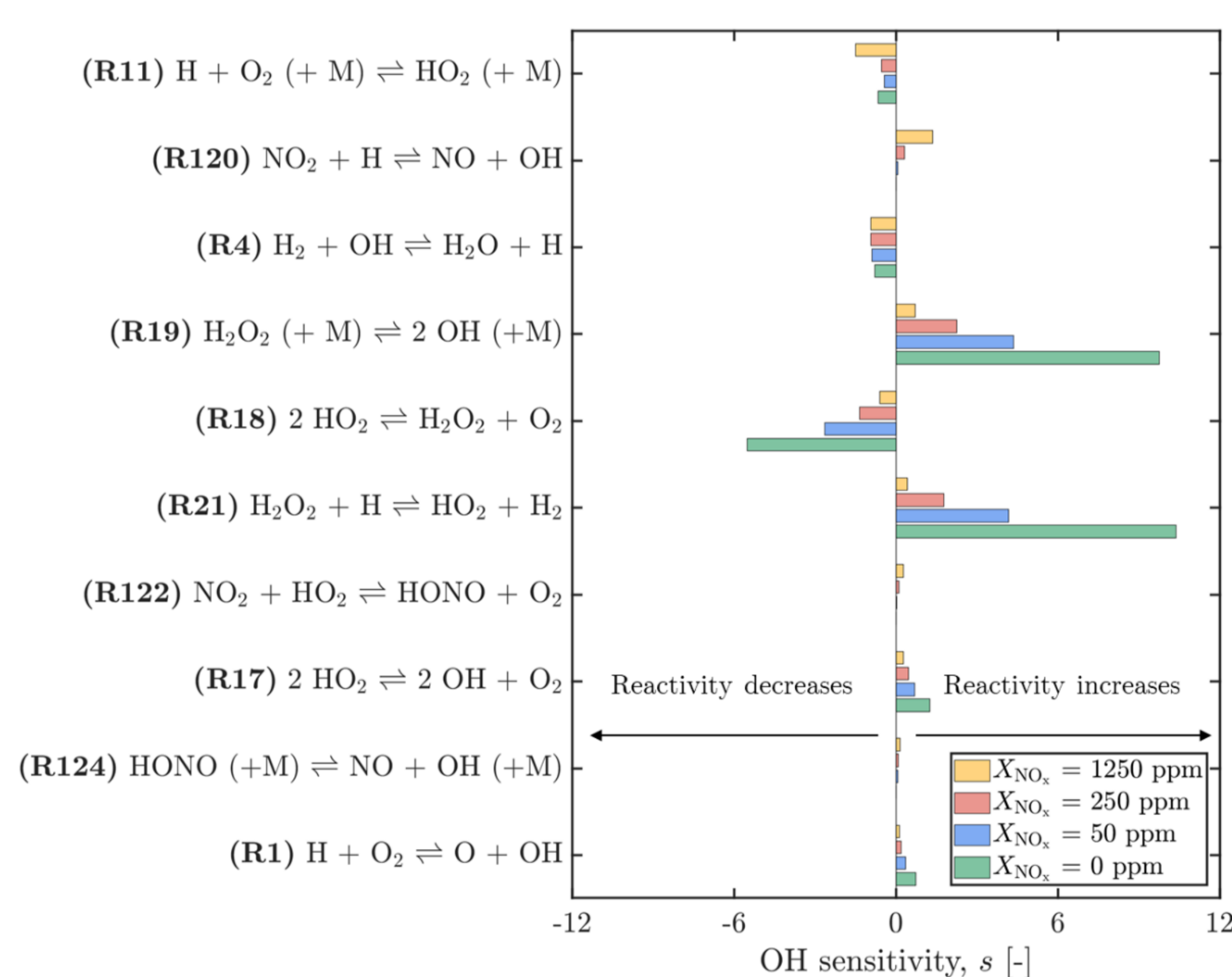


Figure 5. Sensitive reactions on OH radical for H₂/air/NO_x mixtures for X_{NOx} = 0 ppm, 50 ppm, 250 ppm, 1250 ppm at p_c = 50 bar, and T_c = 908 K.

- The HO₂/H₂O₂ sequence is not the exclusive contributor to OH production.
- Recycling loop between NO and NO₂ contributing to a more important production of OH.
- Reactivity enhancement and this ignition delay times decrease.

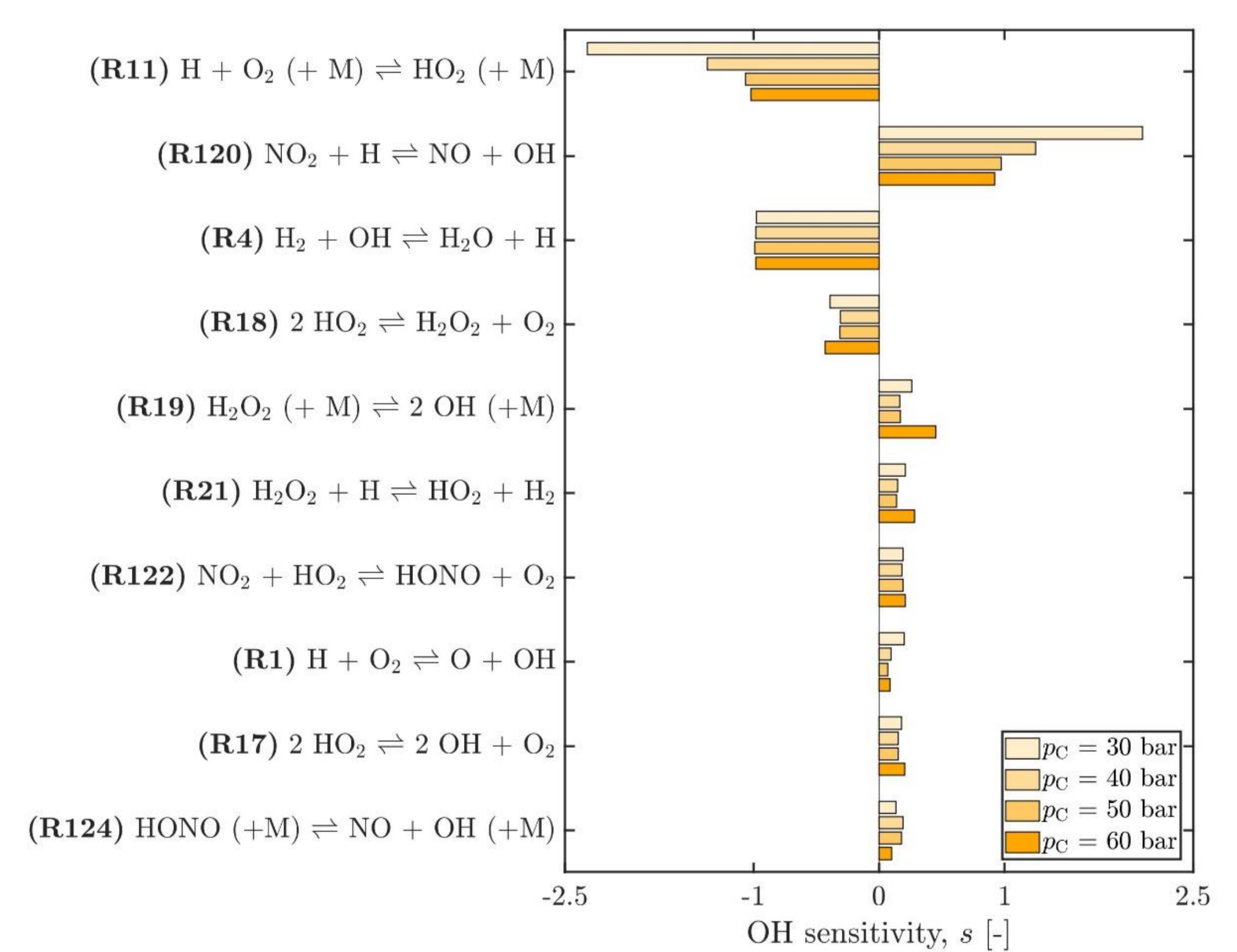


Figure 6. Sensitive reactions on OH radical for H₂/air/NO_x mixtures for X_{NOx} = 0 ppm, 50 ppm, 250 ppm, 1250 ppm at p_c = 50 bar, and T_c = 908 K.

- Dissociation reaction 2HO₂ = 2OH + O₂ [6] → enhance the reactivity of the mixture.
- Recent NO_x sub-mechanism has to be revisited by considering (R17).

Conclusion and perspectives

- Ignition delay times for lean H₂/O₂/N₂/NO_x mixtures under H₂SIEs condition measured using a RCM.
- The NO interconversion into NO₂ measured using a laser gas analyser DURAG and also estimated numerically using different kinetic mechanisms.
- This study shows that ignition delay times decrease with NO_x addition due to a recycling sequence between NO and NO₂, leading to enhanced reactivity → OH production.
- The proposed model displays very good agreement for low-to-moderate NO_x mole fractions.
- Recent NO_x sub-mechanism needs to be revisited by considering the reaction 2HO₂ = 2OH + O₂ [6] to reduce discrepancies at high NO_x mole fractions and high-pressure.