

Influence of Water Content on NO_x Conversion in the SCR Catalyst for Hydrogen Engines

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Problem and Purpose

Hydrogen Internal Combustion Engine (H₂ICE) powered vehicles can reduce carbon emissions by >95% compared to diesel vehicles [1]. However, H₂ICE exhaust gas contains nitrogen oxides (NO_x).

An ammonia (NH₃) Selective Catalytic Reduction (SCR) effectively converts NO_x into harmless nitrogen. H₂ICE's exhaust gas contains higher water content (xH₂O), affecting SCR performance in NO_x conversion (deNO_x) [2].

Hence, this study aims to determine how the water concentration (xH₂O) in the exhaust affects deNO_x independently of gas space velocity, NO_x, and SCR temperature.

Experimental setup

H₂ICE setup used in this study is shown in Figure 1. A water injection system, an electric heating (EH) monolith, urea dosing and a Cu-zeolite SCR were used. SCR had a volume of 0.8 litres to ensure deNO_x conversion. Table 1 shows the test engine operating conditions. AVL i60 measures upstream emissions. FTIR measures upstream (P1) or downstream (P2) emissions.

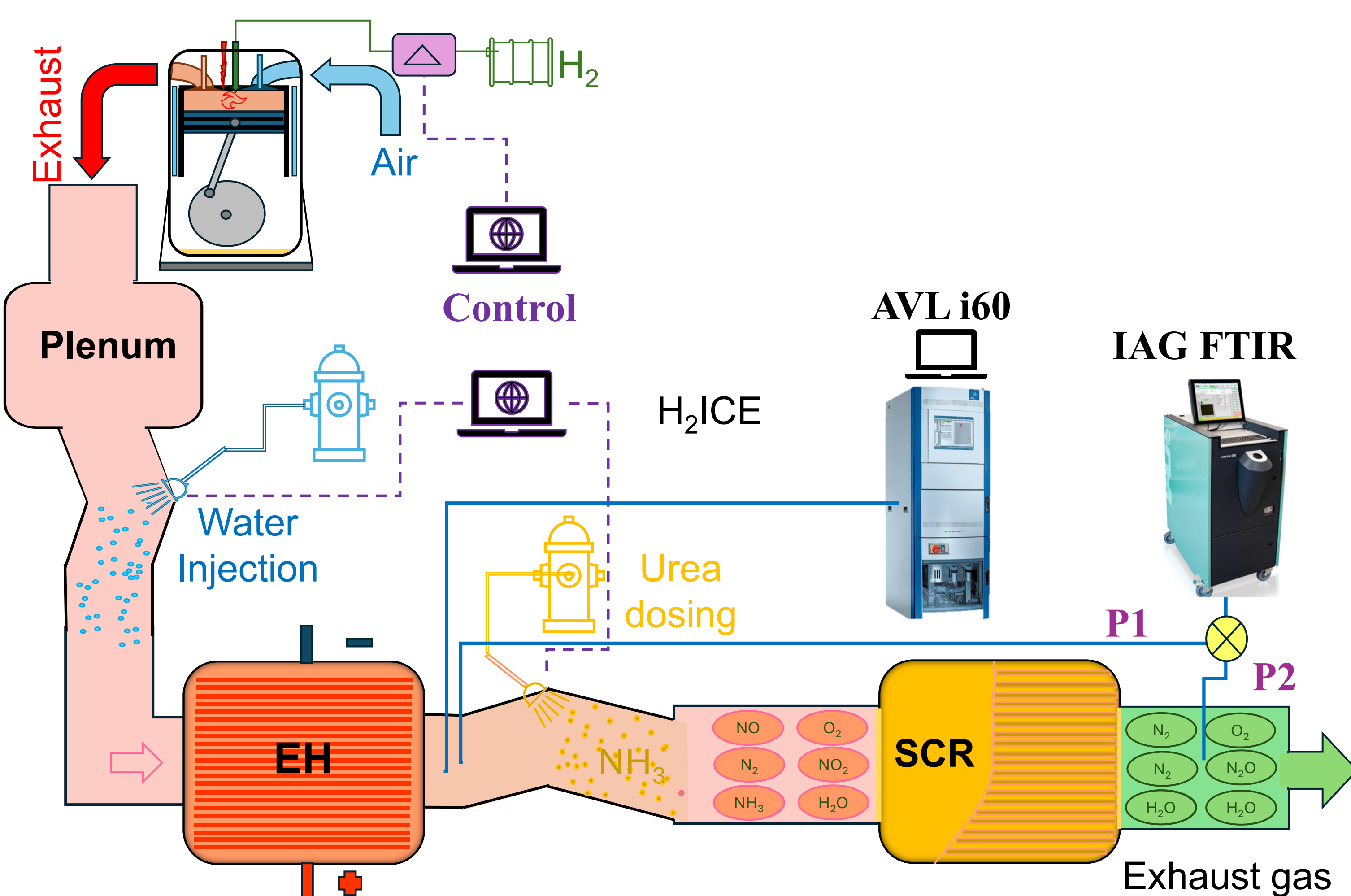


Figure 1. Hydrogen engines and the SCR system setup

Table 1. Engine operating conditions

Load (bar)	Speed (rpm)	Lambda	xH ₂ O (%)	xO ₂ (%)	Gas Temp.
5.5 imep	1200	2.25	17 v/v	12 v/v	200 °C

The water content in the exhaust gas was increased by adding water injection. An electric heater (4 kW) was used to heat the SCR. The ammonia-to-NO_x (ANR) ratio was varied. Test cases are given in Table 2.

Table 2. Test conditions based on a typical H₂ICE run for the SCR.

Case	xH ₂ O	SCR Temp.	ANR	NO _x	HSV
1	17 % v/v	300, 200 °C	0.8 -1 & 1-1.2	500 ppm	~ 68000 hr ⁻¹
2	20 % v/v	300, 200 °C	0.8 -1 & 1-1.2	500 ppm	~ 70000 hr ⁻¹
3	23 % v/v	300, 200 °C	0.8 -1 & 1-1.2	500 ppm	~ 73000 hr ⁻¹

Results and Discussion

NO_x comprises NO and NO₂ species. The upstream (before SCR) gas contains ~95% NO and ~5% NO₂ in the NO_x composition.

High-temperature combustion produces NO, whereas lower cooler post-flame conditions produce lower NO₂.

NO_x concentration in the exhaust varies with time due to cycle-to-cycle variations of the engine.

Figure 2 shows the NO and NO₂ emissions upstream and downstream of the SCR catalyst at a water content of 17% v/v and a 300 °C SCR temperature.

NO and NO₂ decrease after the AdBlue injection begins. The amount of NO_x conversion in the SCR depends on the ANR ratio. An ANR slightly above one maximises NO conversion into N₂.

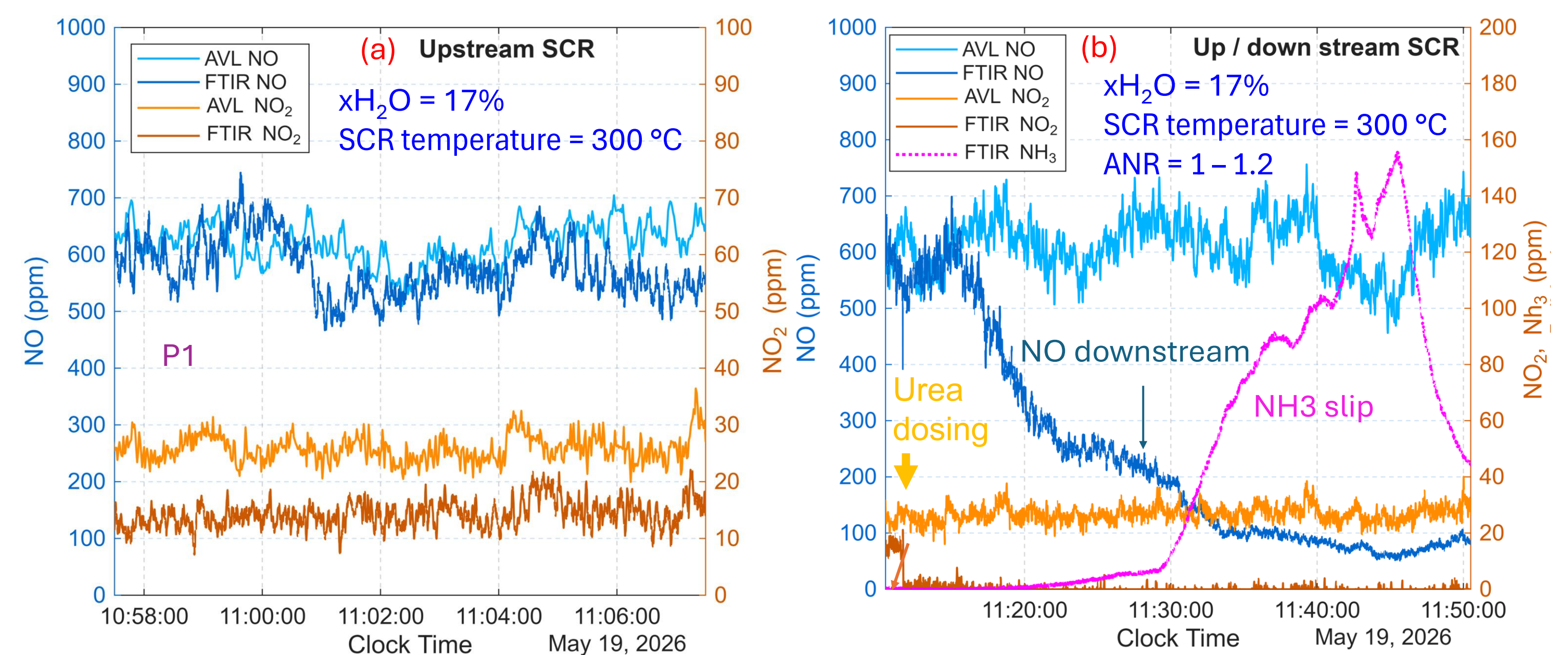


Figure 2. NO and NO₂ emissions before and after the SCR catalyst

At 17% xH₂O, NH₃ slip was observed for 1-1.2 ANR. At 23% xH₂O, higher NH₃ slip was observed for ANR cases in Figures 2b and 3b.

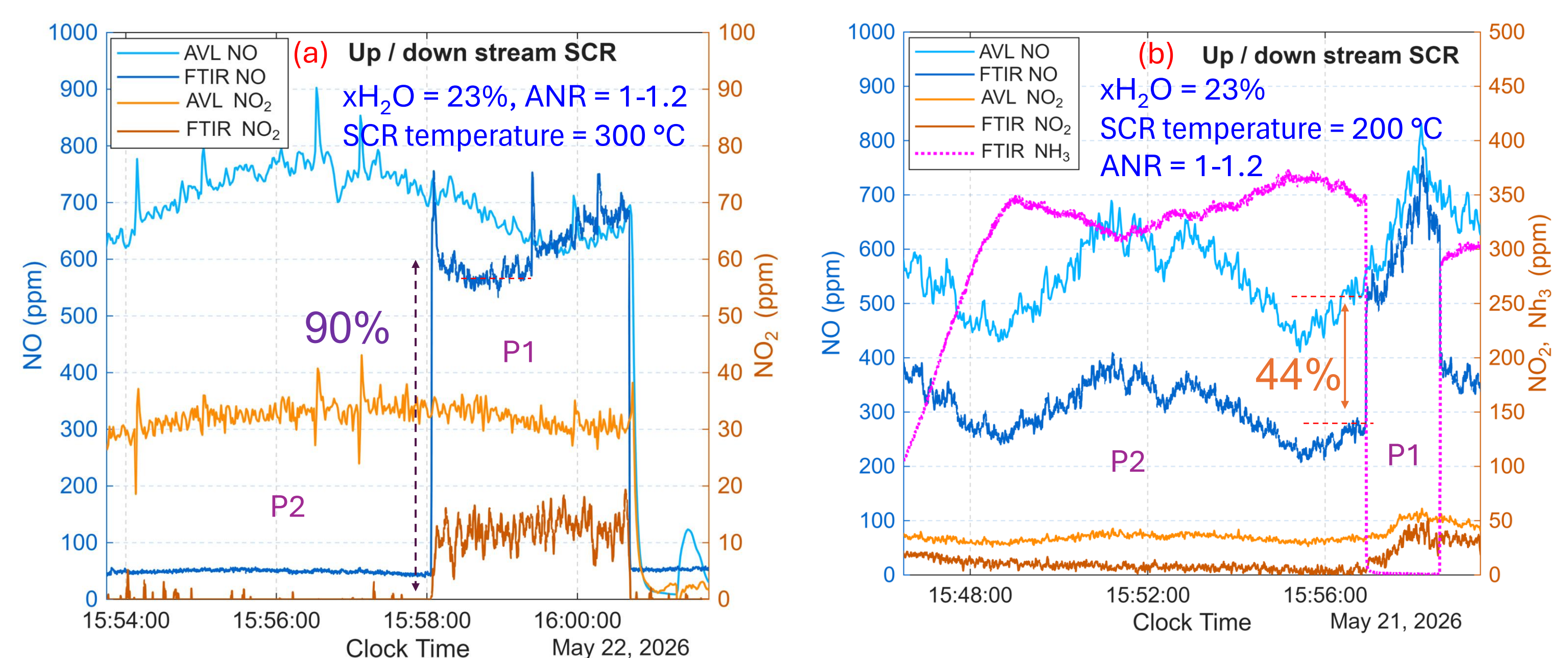


Figure 3. NO and NO₂ emissions in 23% water concentration cases

At 17% xH₂O, the NO_x conversion efficiency was 95% at 300 °C SCR temperature. When the xH₂O was 23%, the NO_x conversion dropped to 90%.

NO_x conversion efficiency dropped to 44% when the 23% xH₂O and the SCR 200 °C temperature, as shown in Figure 4.

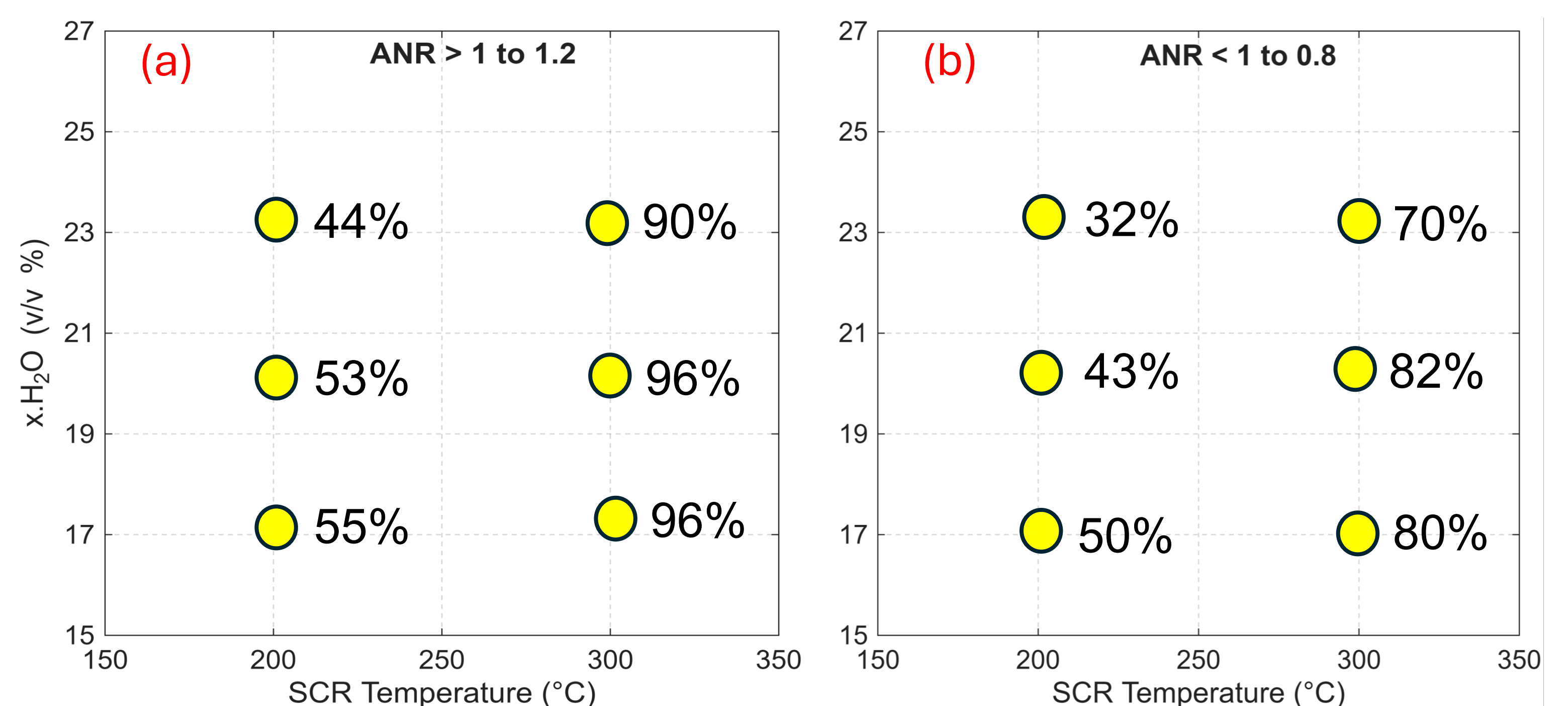


Figure 4. deNO_x efficiency at different xH₂O content cases

Summary

- Decreasing catalyst temperature reduces the NO_x-to-N₂ conversion.
- NO_x-to-N₂ conversion decreases further as water content increases.
- Higher ammonia slip was seen in cases with higher water concentration.

References

- [1] A global comparison of the life-cycle greenhouse gas emissions of combustion engine and electric passenger cars. ICCT 2021. White Paper.
- [2] Lee et al. Water effects on NH₃-SCR over Cu-based small-pore zeolite catalysts: A review. Applied Catalysis A Gen. 10.1016/j.apcata.2025.120491.