Comparative evaluation of ammonium carbamate and UWS based SCR system for diesel engine NO_X reduction under WHTC

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KIMM 한국기계연구원 Korea Institute of Machinery & materials

CLEERS Cross Cut Lean Exhaust Emissions Reduction Simulations

UST 과학기술연합대학원 UNIVERSITY OF SCIENCE & TECI

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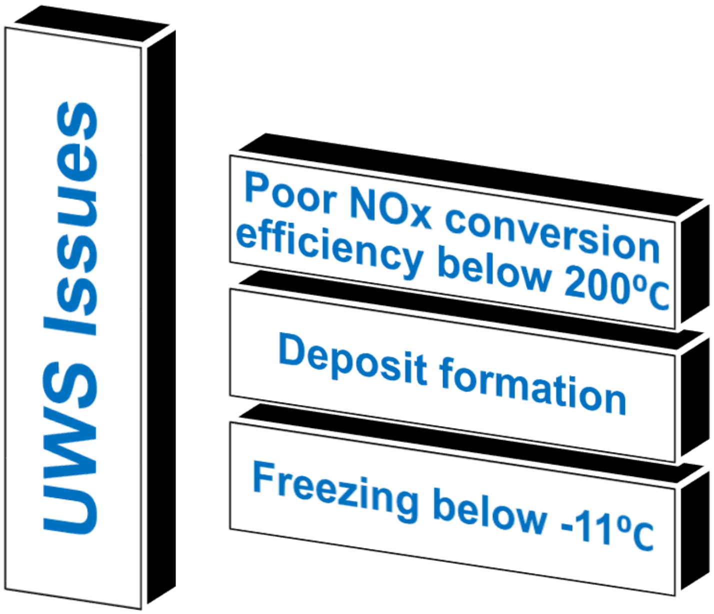
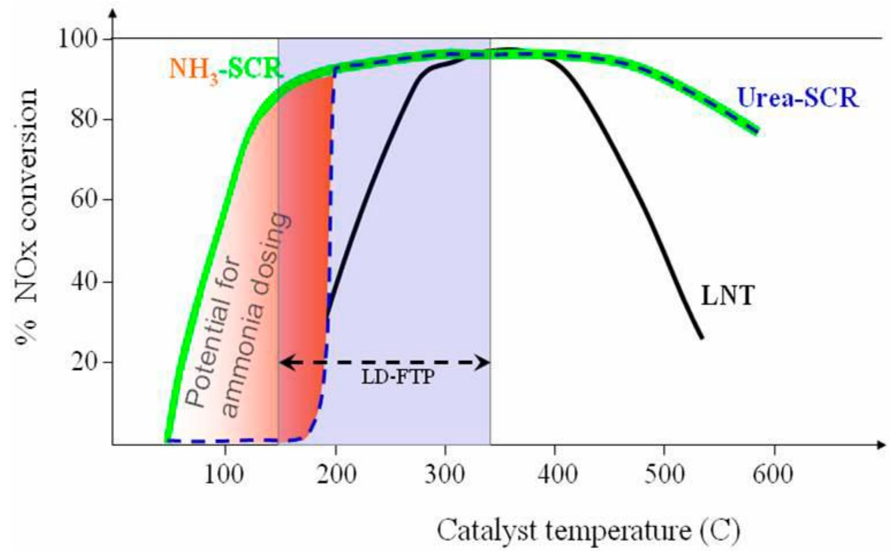
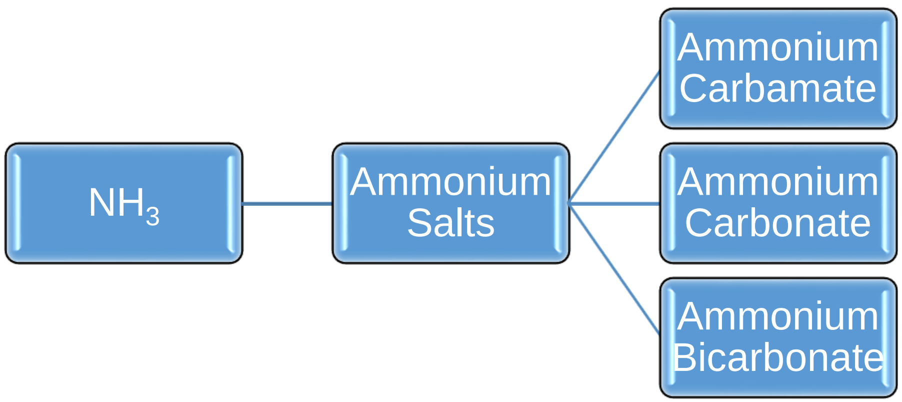
- Introduction
- Experimental setup
- Results and discussion
- Conclusion

1. Introduction

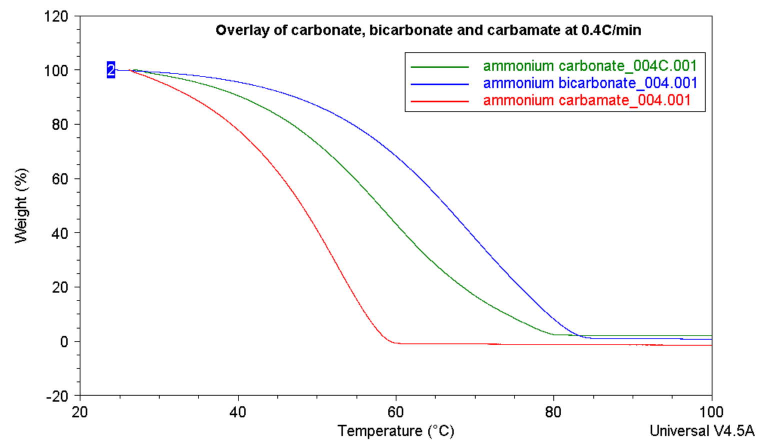




Effectiveness of NO_X conversion vs exhaust temperature [1]



Ammonia transport materials [2]



TGA analysis of ammonium salt decomposition [2]

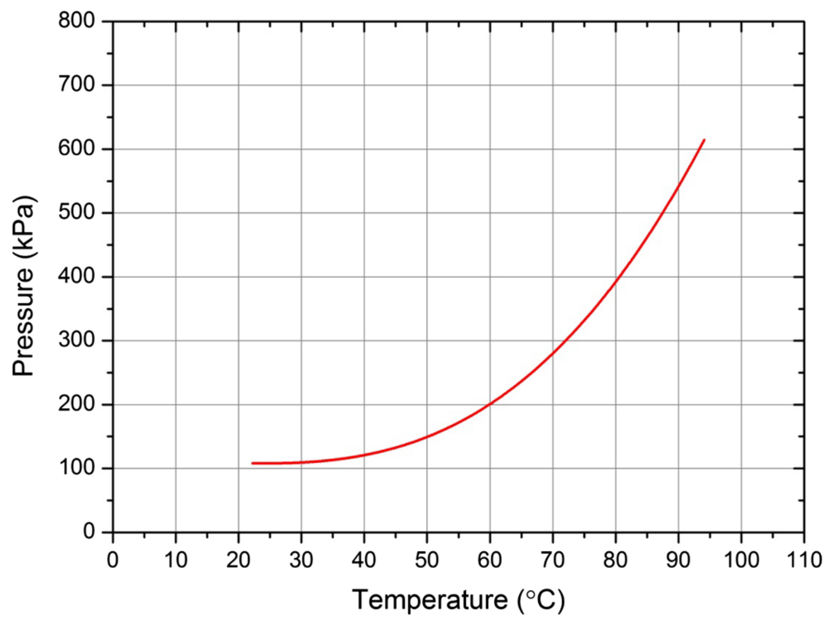
[1] T. Johannessen, H. Schmidt, J. Svagin, J. Johansen, J. Oechsle, R. Bradley, Ammonia storage and delivery systems for automotive NOx aftertreatment, SAE Tech. Pap. 2008 (2008). doi:10.4271/2008-01-1027
[2] G. Fulks, G.B. Fisher, K. Rahmoeller, M.C. Wu, E. D'Herde, J. Tan, A review of solid materials as alternative ammonia sources for lean NOx reduction with SCR, SAE Tech. Pap. (2009). doi:10.4271/2009-01-0907

1. Introduction

- Advantages of Ammonium carbamate based SCR system
  - ✓ Greater ammonia density than UWS
  - ✓ Opportunity to inject gaseous ammonia at low exhaust gas temperature
  - ✓ Increases NO_X reduction performance at low exhaust gas temperature
  - ✓ Eliminates deposition problem
  - ✓ Low decomposition temperature compared with other ammonium salts
  - ✓ The system size is more compact

Property	UWS	Ammonium Carbamate
Chemical Formula	$(NH_2)_2CO+H_2O$	NH_2COONH_4
Molar weight (g/mol)	N/A	78.07
Density (g/cm^3)	1.086	1.6
Moles of NH_3 per mole	2	2
Moles of NH_3 per kg	10.8	25.6
Decomposition Temp (ºC)	--	60
Volume Factor (Norm to AdBlue)	1	0.29

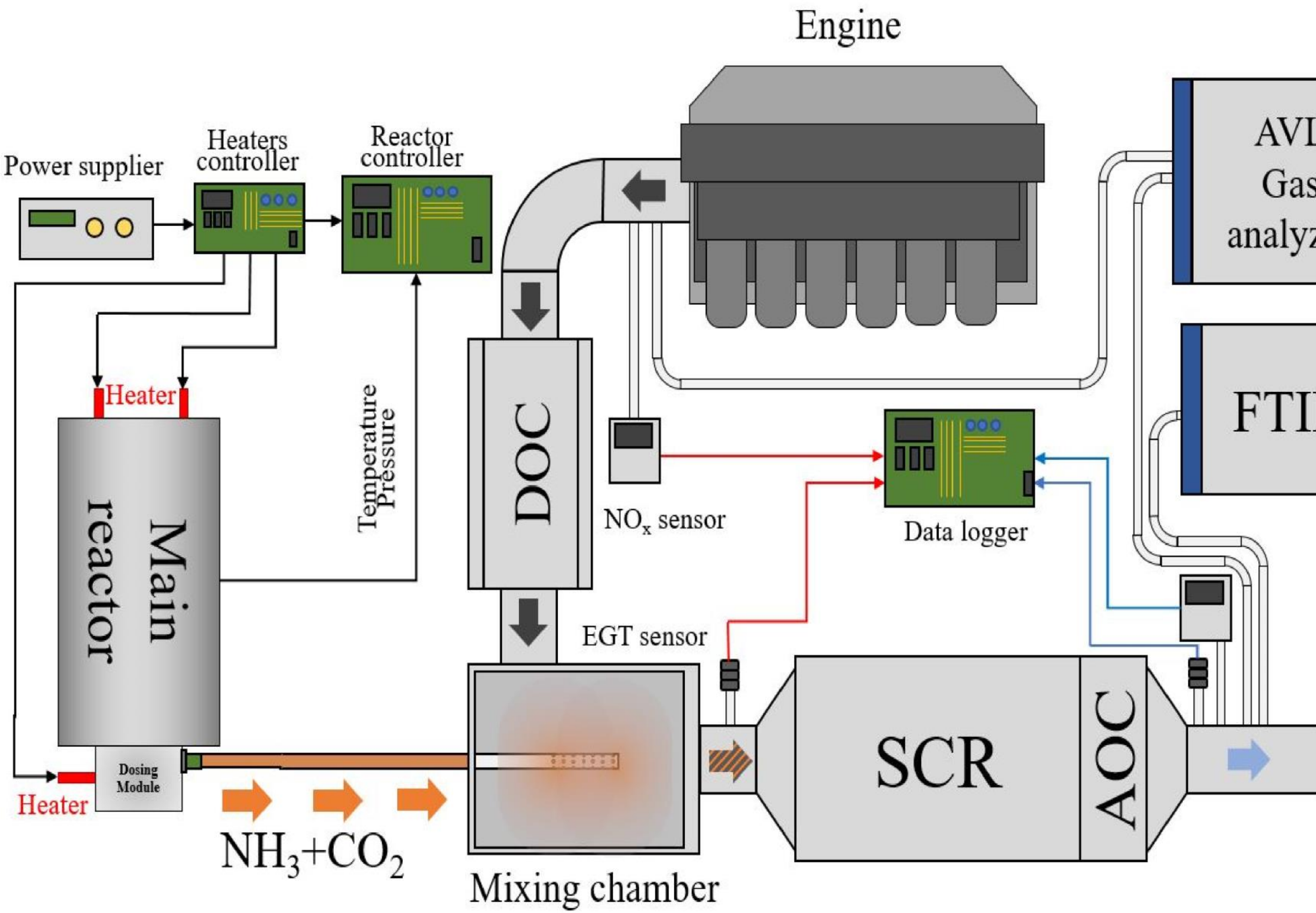
Comparison of UWS and ammonium carbamate properties



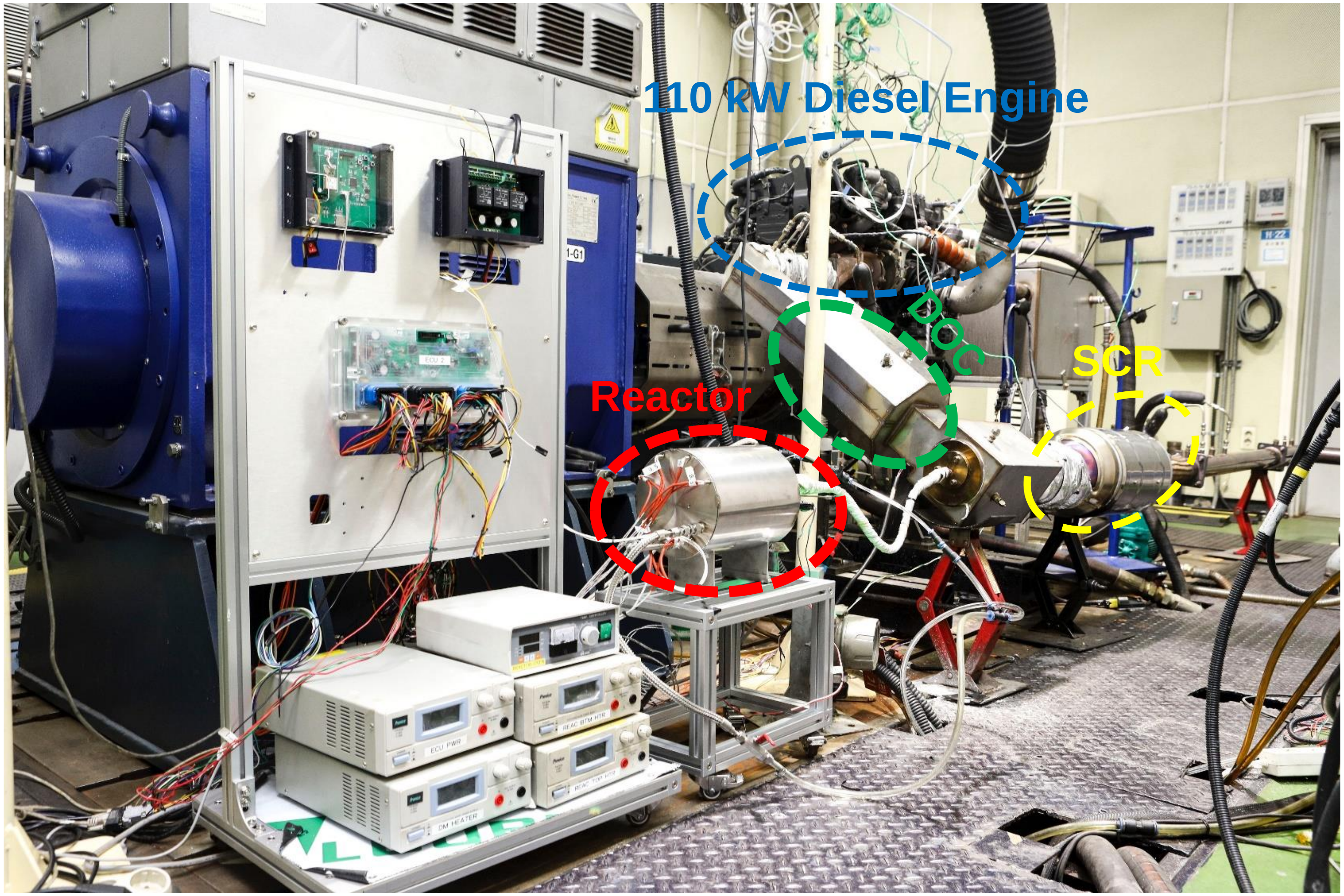
Equilibrium pressure of AC with respect to temperature measured in a closed chamber [3]

[3]Kim Y, Raza H, Lee S, Kim H. Study on the thermal decomposition rate of ammonium carbamate for a diesel NOx reducing agent-generating system. Fuel 2020;267. https://doi.org/10.1016/j.fuel.2020.117306

2. Experimental setup



2. Experimental setup

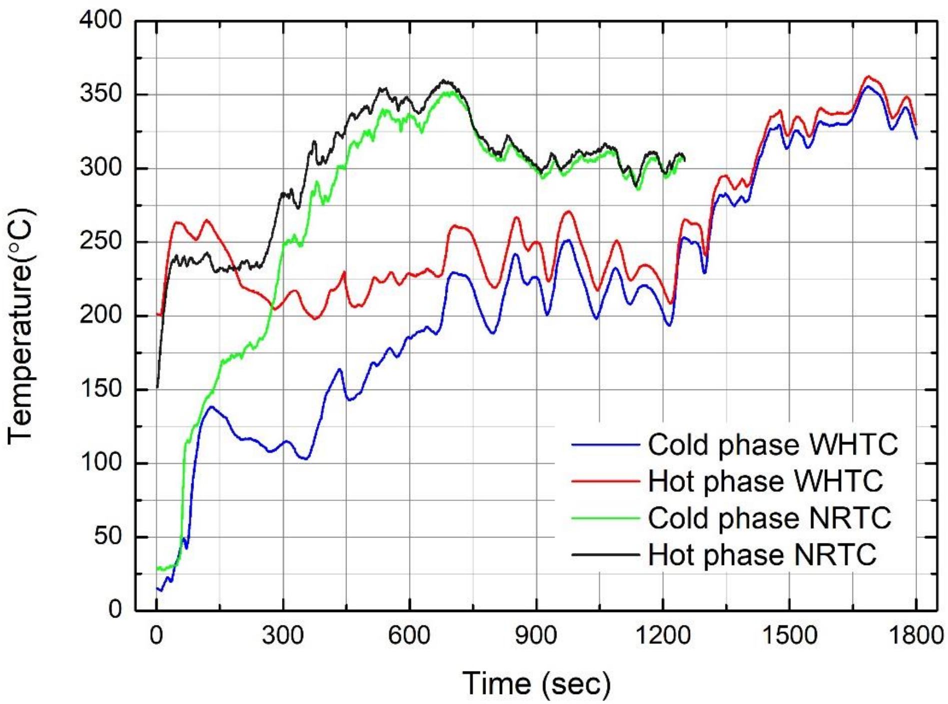


Engine specification	
Engine Displacement(L)	3.9
Compression ratio	17
Max. power(kW/rpm)	110/2500
Emissions standard	EURO-4

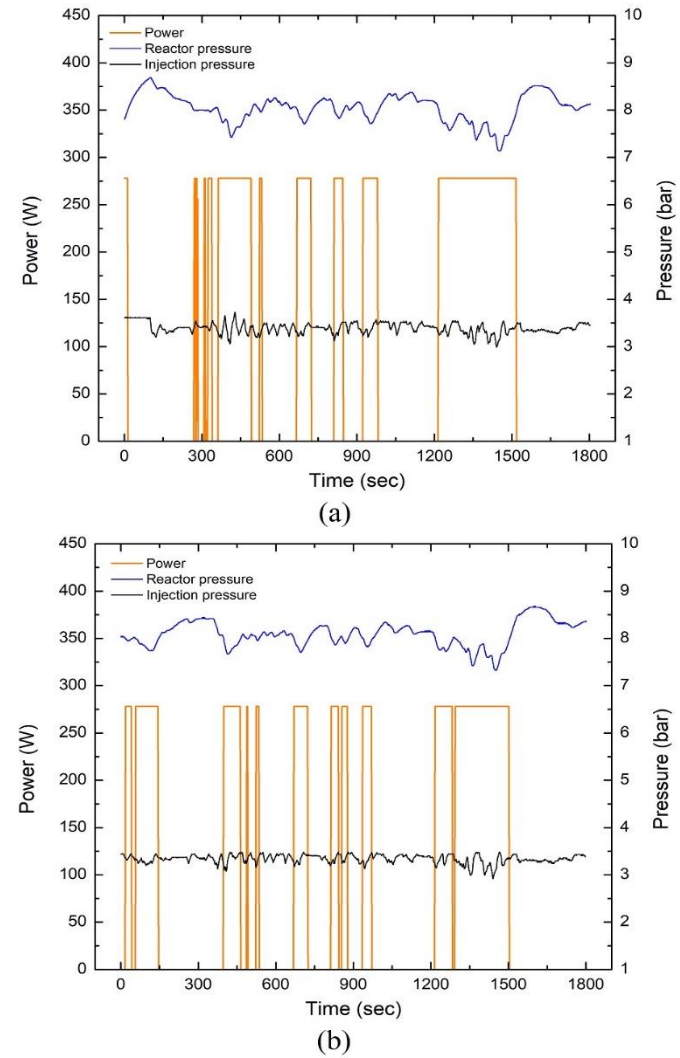
Catalyst specification	
DOC (Diesel Oxidation Catalyst)	Pt/Pd (D191mm, L152mm, Vol. 4.3L)
SCR (Selective Catalytic Reaction)	Cu-Zeolite (D203mm, L356mm, Vol. 11.5L)
AOC	Pt (D203mm, L5.1mm, Vol. 1.6L)

3. Results and discussion

Comparison of UWS and AC based system under WHTC and NRTC



- Ammonia gas and UWS injection commenced after 92 seconds and 678 seconds during the cold phase of WHTC, respectively
- For NRTC test, ammonia gas and UWS injection commenced after 80 seconds and 290 seconds during the cold phase, respectively
- The reactor and injection pressure was well maintained at about 8 bar and 3 bar respectively during the WHTC test

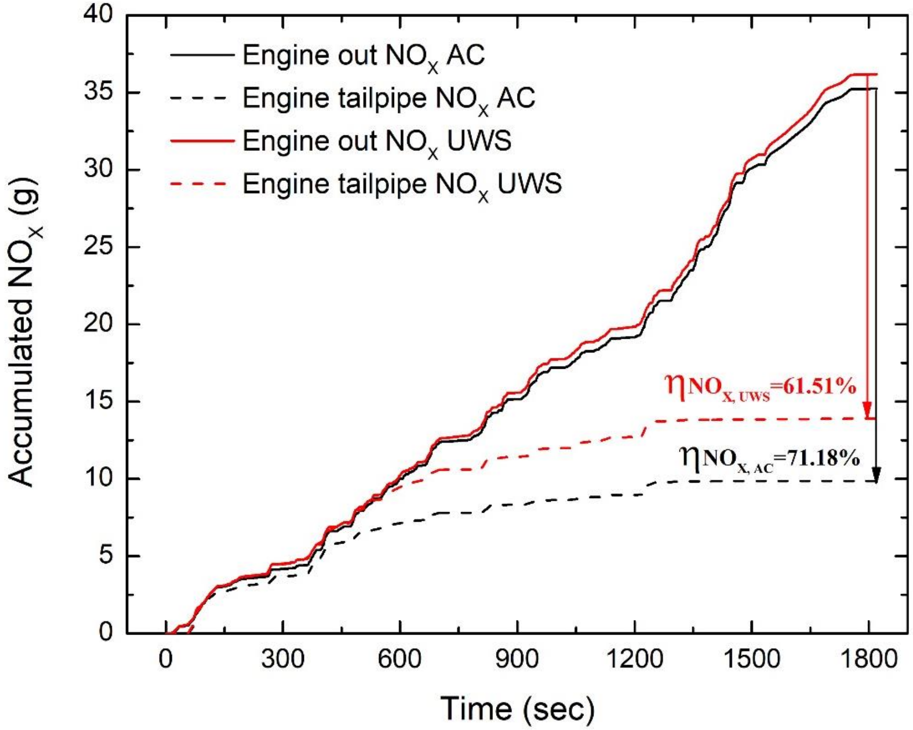


(a) Cold phase and (b) hot phase of WHTC

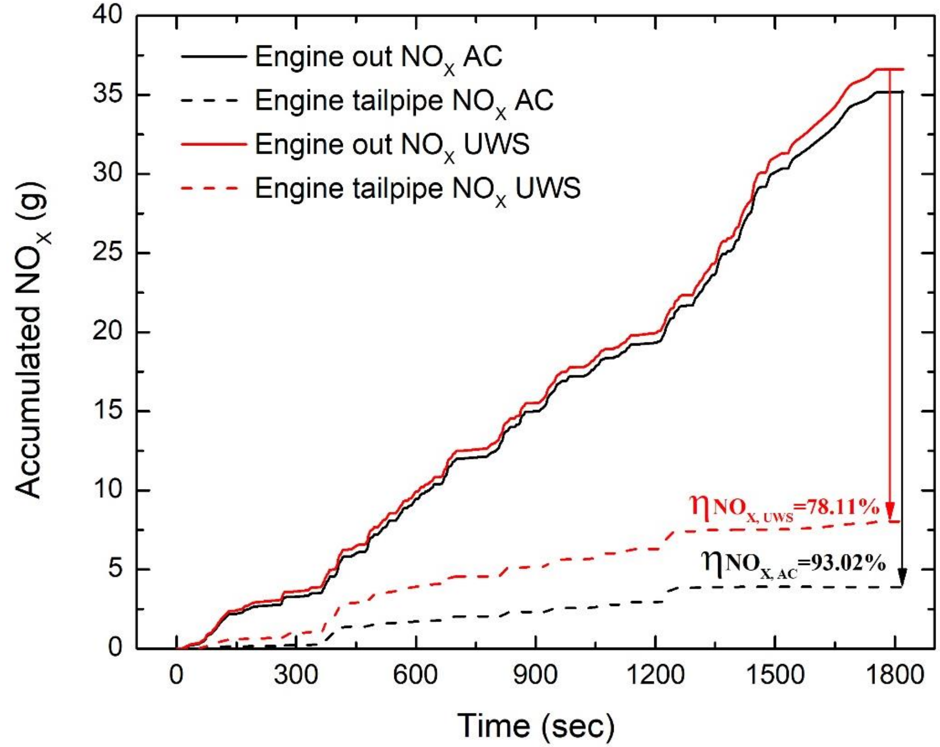
DeNO$_X$ performance comparison of AC and UWS under WHTC

Test Conditions: Cold phase time = 30 min, Soaking time = 10 min, Hot phase = 30 min, NH_3/NO_X = 1.0

UWS injection threshold temperature = 200ºC, Ammonia gas injection threshold temperature = 100 ºC



Cold phase



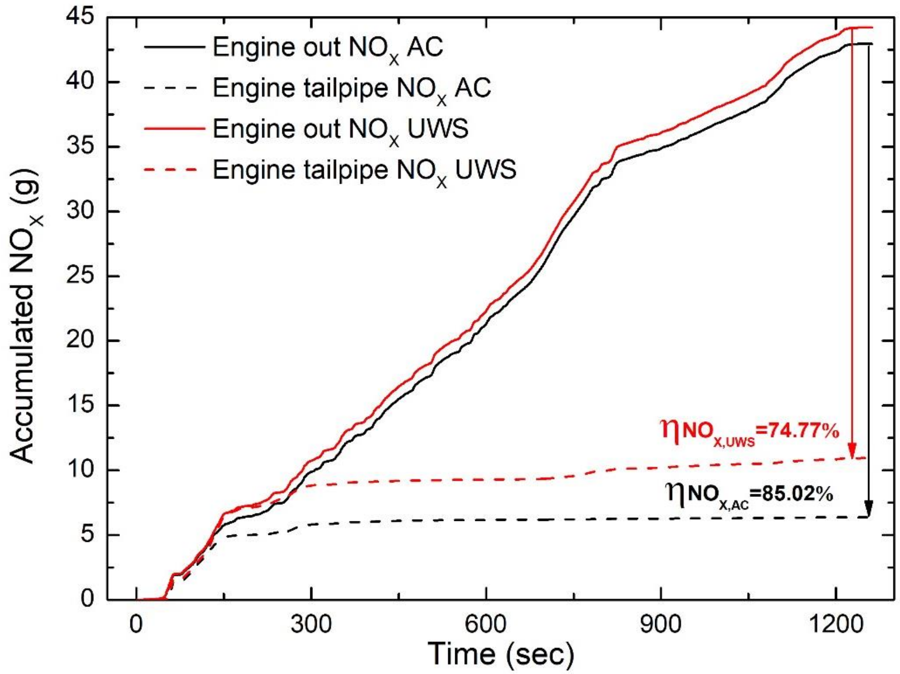
Hot phase

- Ammonia gas injection showed better deNO$_X$ efficiency than UWS
- Early injection and superior adsorption of gaseous ammonia leads to an increase the NO$_X$ conversion efficiency compared with UWS

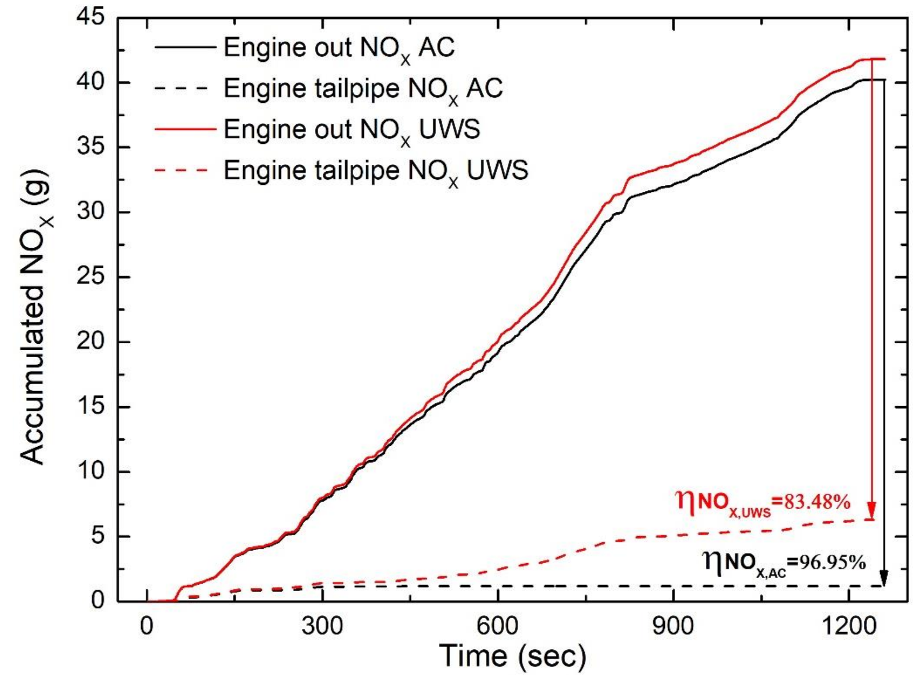
DeNO$_X$ performance comparison of AC and UWS under NRTC

Test Conditions: Cold phase time = 20min 38sec, Soaking time = 20 min, Hot phase = 20min 38sec, NH_3/NO_X = 1.0

UWS injection threshold temperature = 200°C, Ammonia gas injection threshold temperature = 100 °C



Cold phase

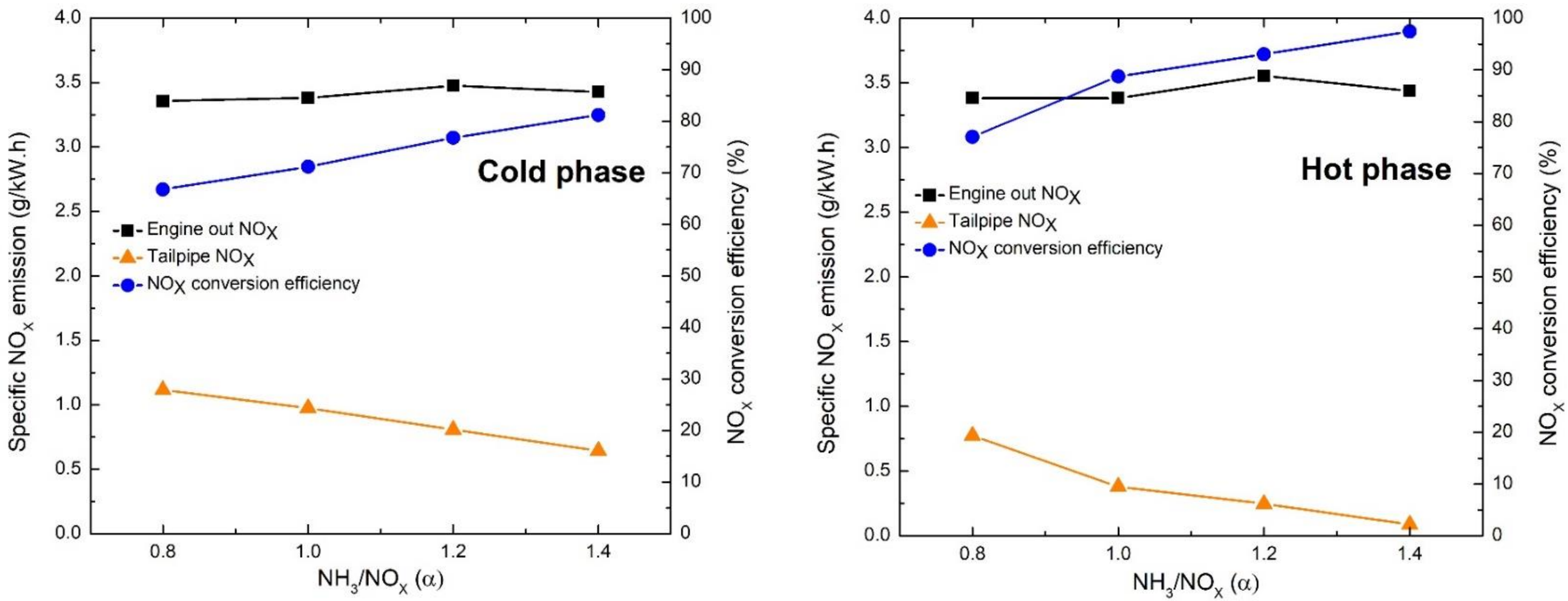


Hot phase

- The deNO$_X$ efficiencies of AC improve 8.71% and 11.93% than UWS during the cold and hot phase, respectively
- Compared with WHTC, the deNO$_X$ efficiency under NRTC tests was higher under both phases for each reducing agent, owing to the rapid heat-up of SCR, higher exhaust gas temperature, and early injection

The effect of $NH_3/NO_X(\alpha)$ ratio on the $deNO_X$ performance

Test Conditions: Cold phase time = 30 min, Soaking time = 10 min, Hot phase = 30 min , Ammonia gas injection threshold temperature = 100 ºC



- The $deNO_X$ performance of AC based system increases as the NH_3/NO_X (α) ratio increases
- At NH_3/NO_X=1.4, maximum of 81% and 97% NO_X conversion efficiency was observed during the cold and hot phase, respectively

Ammonia adsorption-desorption model based injection

The NH_3 adsorption and desorption rate expressions are given by equations (1) & (2) [4]

$$r_{ads} = A_{ads} c_{NH_3} (1-\theta) \qquad (1)$$

$$r_{des} = A_{des} e^{-\frac{E_{des}(1-\gamma\theta)}{RT}} \theta \qquad (2)$$

Where θ is fractional NH_3 storage in the catalyst, which can be represented by the following equation (3)

$$\theta = \frac{\Omega}{\Omega^*} \qquad (3)$$

The NH_3 adsorption and desorption rates from equation (1) & (2) are used to calculate the instantaneous fractional NH_3 storage with time by the following equation (4)

$$\frac{d\theta}{dt} = r_{ads} - r_{des} \qquad (4)$$

The rate of adsorption and desorption were then used to calculate the NH_3 release amount by the following equation (5)

$$NH_{3,release} = \Omega^*(r_{des} - r_{ads}) \qquad (5)$$

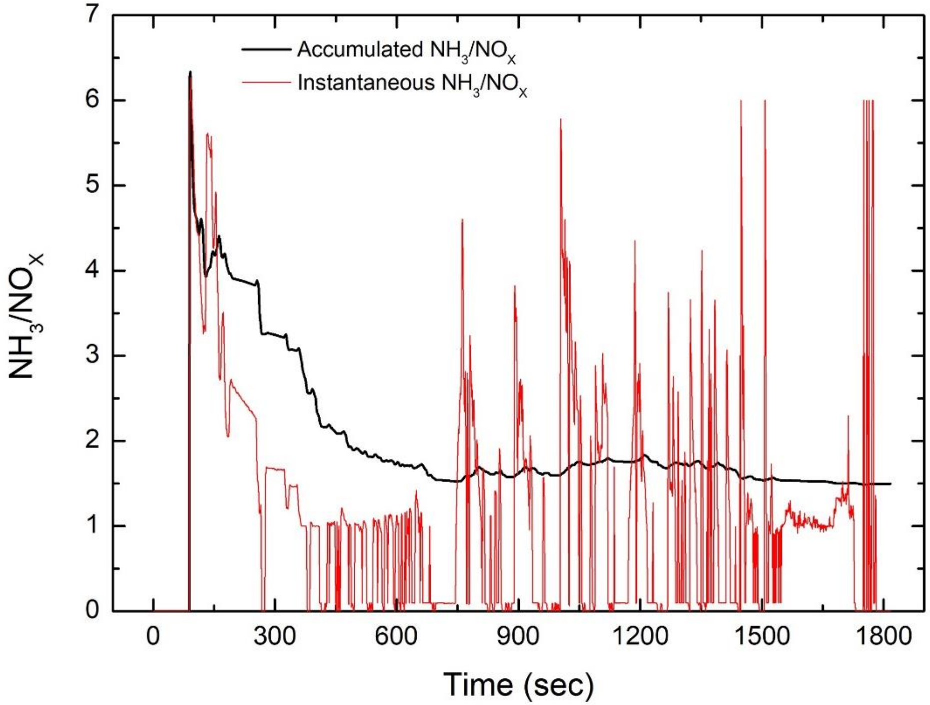
Parameter	Unit	Value
A_{ads}	$m^3/mol/s$	1
A_{des}	1/s	1.0E07
E_{des}	kJ/mol	107
Ω^*	mol/m^3	20
R	J/mol-K	8.314

NH_3 storage parameters used in the storage model

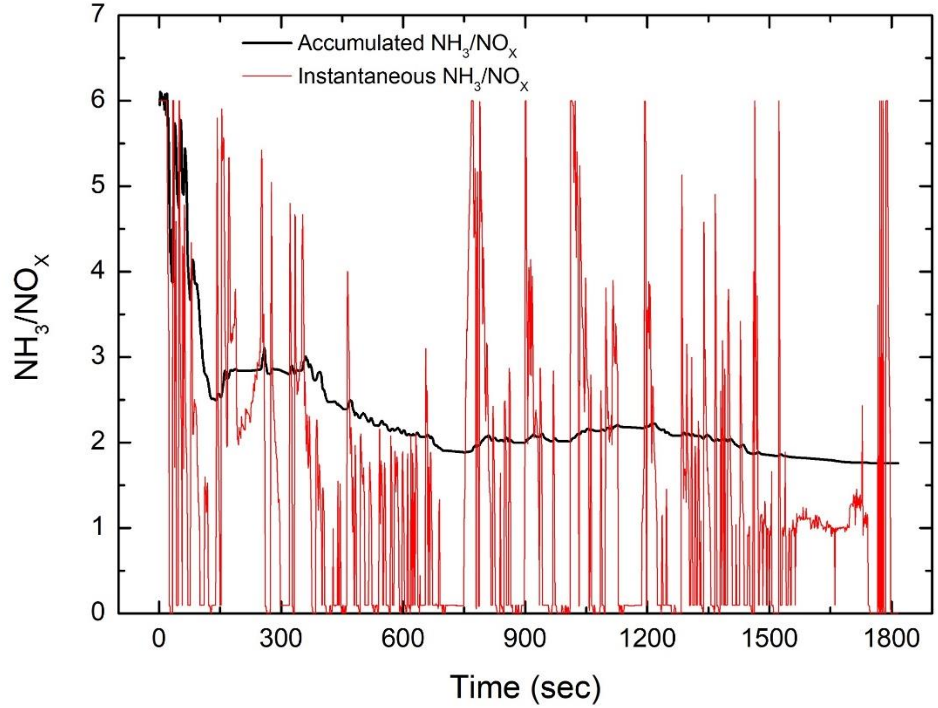
[4] Devarakonda M, Lee J, Muntean G, Pihl J, Daw S. 1D model of a copper exchanged small pore zeolite catalyst based on transient SCR protocol. SAE Tech Pap 2013;2. https://doi.org/10.4271/2013-01-1578

Ammonia adsorption-desorption model based injection

Test Conditions: WHTC cold phase time = 30 min, Soaking time = 10 min, Hot phase = 30 min , Ammonia gas injection threshold temperature = 100 ºC



Cold phase

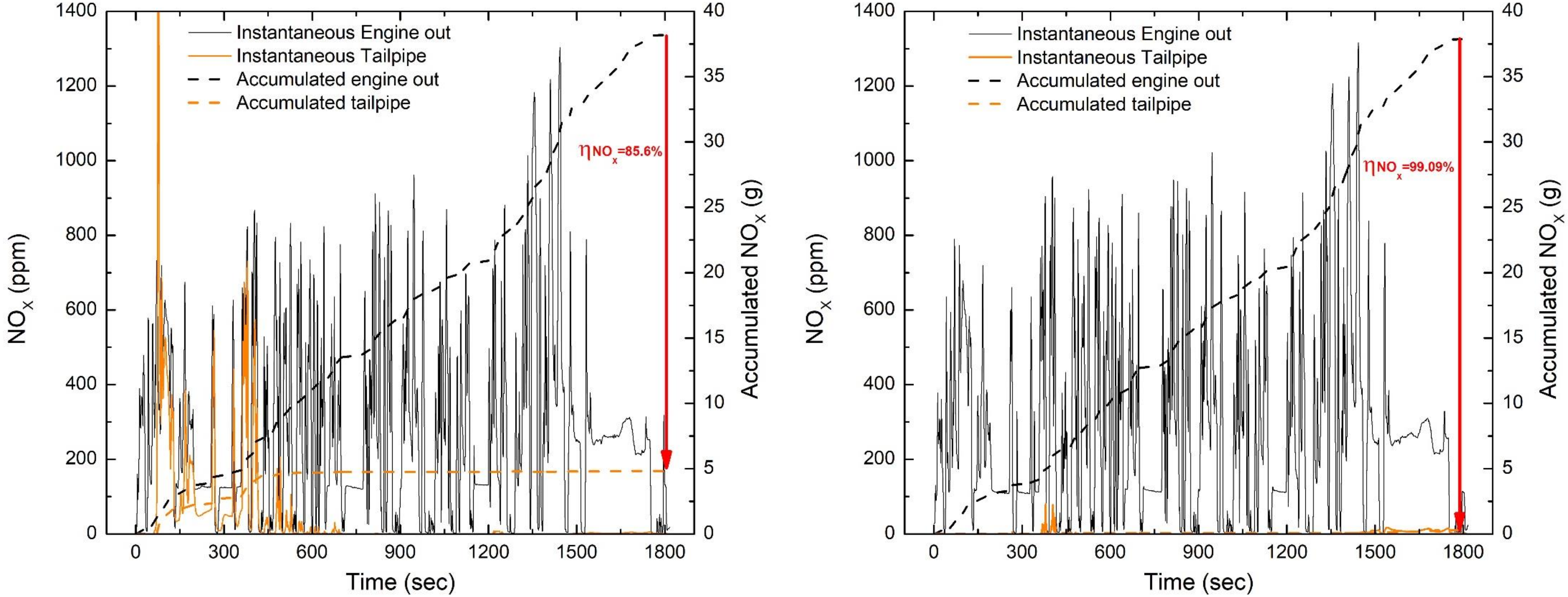


Hot phase

- NH_3/NO_X (α) ratio fluctuated according to the injected NH_3 demand depending upon adsorption-desorption rates
- Overall accumulated injected amount during the cold and hot phase of WHTC was equivalent to NH_3/NO_X ratio of 1.5 and 1.7, respectively

Effect of model based injection on the deNO$_X$ performance

Test Conditions: WHTC cold phase time = 30 min, Soaking time = 10 min, Hot phase = 30 min , Ammonia gas injection threshold temperature = 100 ºC

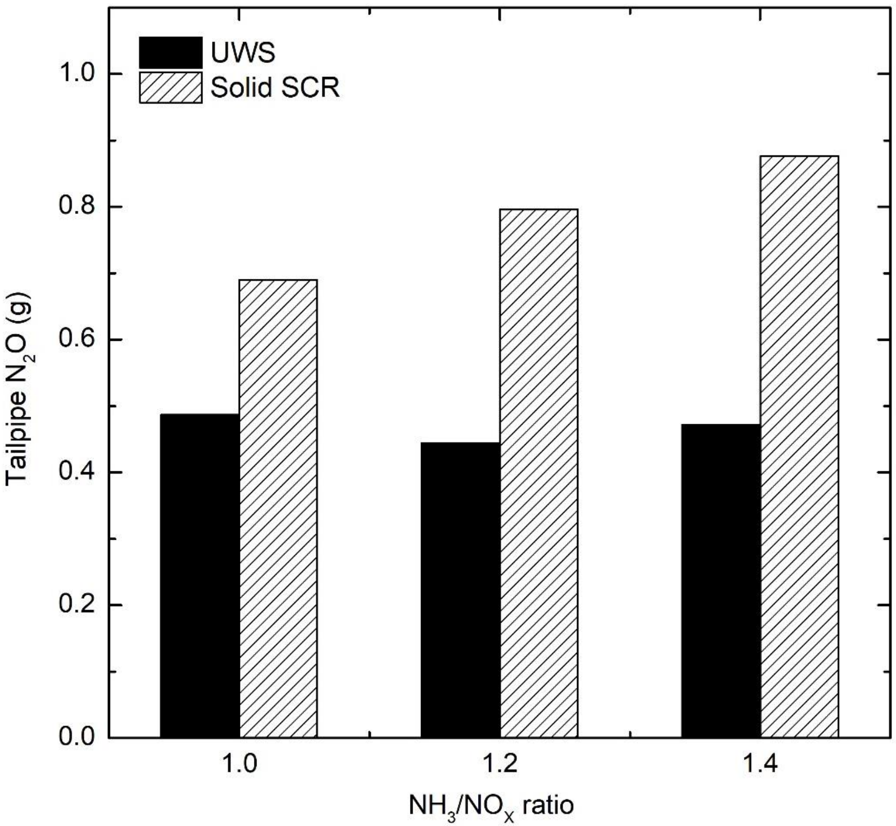


- NO$_X$ conversion efficiency of 85.6% and 99.09% was achieved during the cold and hot phase of WHTC, respectively
- Model based injection seems effective to increase the deNO$_X$ performance, especially during the cold phase of WHTC

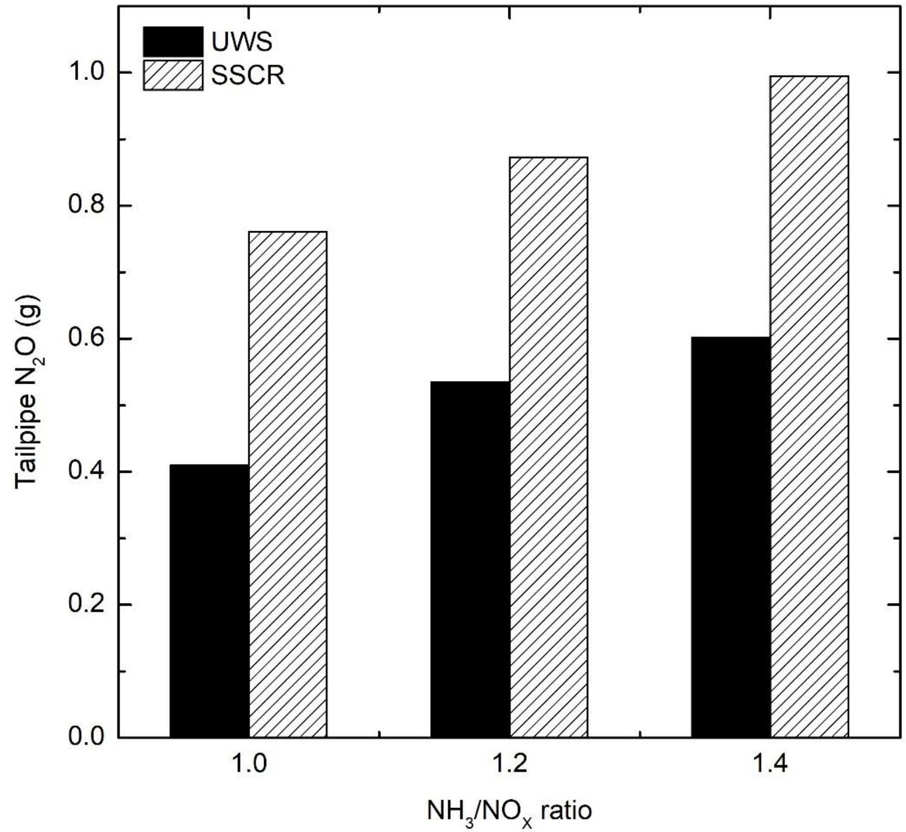
Effect of ammonia and UWS injection on N_2O emissions

Test Conditions: Cold phase time = 30min, Soaking time = 10 min, Hot phase = 30min,

UWS injection threshold temperature = 200ºC, Ammonia gas injection threshold temperature = 100 ºC



Cold phase



Hot phase

- Injection of gaseous ammonia using AC leads to more N_2O emissions than UWS
- N_2O emissions are sensitive to the ammonia injection amount

Conclusion

- SCR system using ammonium carbamate as NH_3 source can be injected at an exhaust temperature of below 200°C and reduce more NO_X under transient conditions compared with UWS
- SCR System using ammonium carbamate is preferable to increase the NO_X conversion efficiency than UWS under WHTC and NRTC tests because of early injection and better adsorption-desorption capability
- Increasing Alpha ratio is effective to increase the deNO_X performance of AC based SCR system
- Gaseous ammonia injection leads to more N_2O emissions because of injection at low temperature compared with UWS
- Ammonia adsorption-desorption model is favorable to increase the NO_X conversion efficiency
- In future work, the system will be developed to be used for on-road vehicle tests

THANK YOU

ANY QUESTIONS?