
**Ammonium Formate/Urea Based DEF
TerraCairPlus (TCP)**

*"Lower Freezing DEF For Higher NOx
Reduction Attainment"*

**Presented To
DEER Conference
Detroit, Michigan**

October 3-6, 2011

Presentation Agenda

- ❑ TerraCairPlus Chemistry
 - TerraCairPlus and DEF fluid compositions
 - Advantages of the New Compositions
 - ❑ Vehicle Testing
 - DEF Vehicle performance results
 - DEF Injector Tip Temperature
 - TerraCairPlus Vehicle Test – 500 Hours
 - DEF Injector PRE-Test Spray Characteristics
 - Injector Evaluation
 - ❑ Bench Testing
 - Photographs of Injector Hole Orifices
 - Summary of Injector Hole Orifices
 - ❑ Corrosion Testing
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TerraCairPlus Chemistry

- Traditional DEF is a binary mixture of Urea in Demineralized water at a concentration of 32.5%

 - TerraCairPlus is a tertiary mixture of Ammonium Formate, Urea and Water
 - 26% Ammonium Formate
 - 20% Urea
 - 54% Water

 - While there is no comparable ISO standard for TCP, all the trace element parameters are identical to DEF
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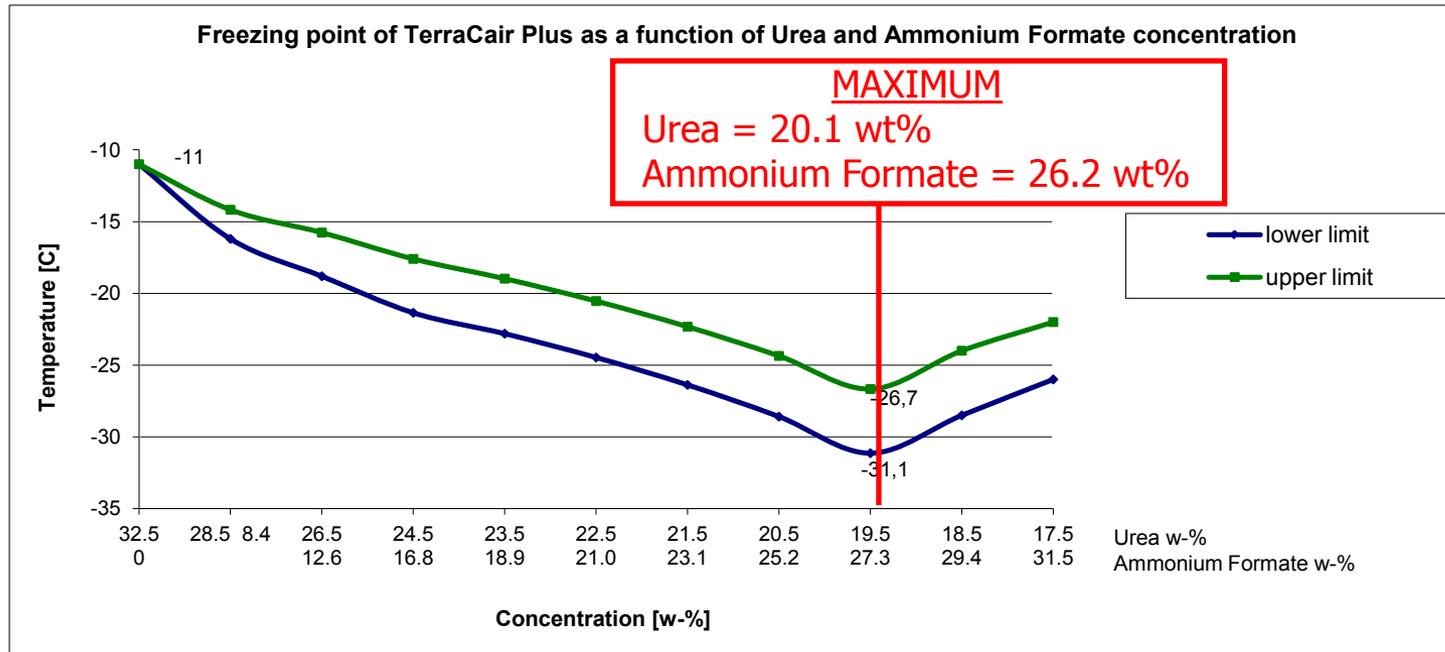
TerraCairPlus vs. DEF Specifications

DEF Spec	units	Spec Min	Spec Max	Typical TerraCairPlus
ISO 22241-1				
Refractive Index	20C	1.3814	1.3843	
Urea	%	31.8	33.2	
Density	kg/m3	1087	1093	
Biuret	%	--	0.3	
Alkalinity	%	--	0.2	<0.45
Insoluble matter	mg/Kg	--	20	<10
Aldehydes	mg/Kg	--	5	ND
PO4	mg/Kg	--	0.5	ND
Ca	mg/Kg	--	0.5	ND
Fe	mg/Kg	--	0.5	ND
Cu	mg/Kg	--	0.2	ND
Zn	mg/Kg	--	0.2	ND
Cr	mg/Kg	--	0.2	ND
Ni	mg/Kg	--	0.2	ND
Al	mg/Kg	--	0.5	ND
Mg	mg/Kg	--	0.5	ND
Na	mg/Kg	--	0.5	ND
K	mg/Kg	--	0.5	ND
pH				8 - 9

TerraCairPlus is fully Neutralized with a pH of 8-9.

TerraCairPlus Freezing Point (-25 to -35 C)

Freezing Point of TerraCairPlus with Different Urea to Ammonium Formate Ratios



Fully substitutable! TerraCairPlus can be interchange with DEF systems and deliver the same ammonia requirements for NOx conversion

TerraCairPlus Advantages vs. DEF

- ❑ Better stability in high temperature when vehicles or tanks are exposed to sunshine or extreme high temperatures.
 - ❑ Expansion of volume during freezing is smaller than with water or urea resulting in less damage.
 - ❑ Interchangeable with DEF systems (no system draining needed).
 - ❑ Reduced heating systems needed in logistics chain or vehicle.
 - ❑ Ammonium formate does not polymerize like urea.
 - ❑ Broader temperature stability adds significant operating advantages across the supply chain up to and including the vehicle.
 - ❑ NOx reduction capacity of TerraCairPlus remains comparable to DEF at higher exhaust temperatures and potentially better NOx reduction at lower exhaust temperatures because of lower decomposition temperatures of TerraCairPlus.
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 - Objectives
 - TerraCairPlus and DEF fluid compositions
 - ❑ Vehicle Testing
 - Control : DEF Vehicle performance results
 - DEF Injector Tip Temperature
 - TerraCairPlus Vehicle Test – 500 Hours
 - DEF Injector PRE-Test Spray Characteristics
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 - Summary of Injector Hole Orifices
 - ❑ Corrosion Testing
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Vehicle Testing Objectives

- Demonstrate TerraCairPlus in on-road vehicle trial.
 - Demonstrate the NO_x conversion of TerraCairPlus.
 - Demonstrate TerraCairPlus is fully substitutable for DEF.
 - Report observations of Injector Performance..
 - Report observations of Materials Compatibility.
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TerraCairPlus Vehicle Test - Ford F-250, 6.7L Diesel Truck

Test Conditions

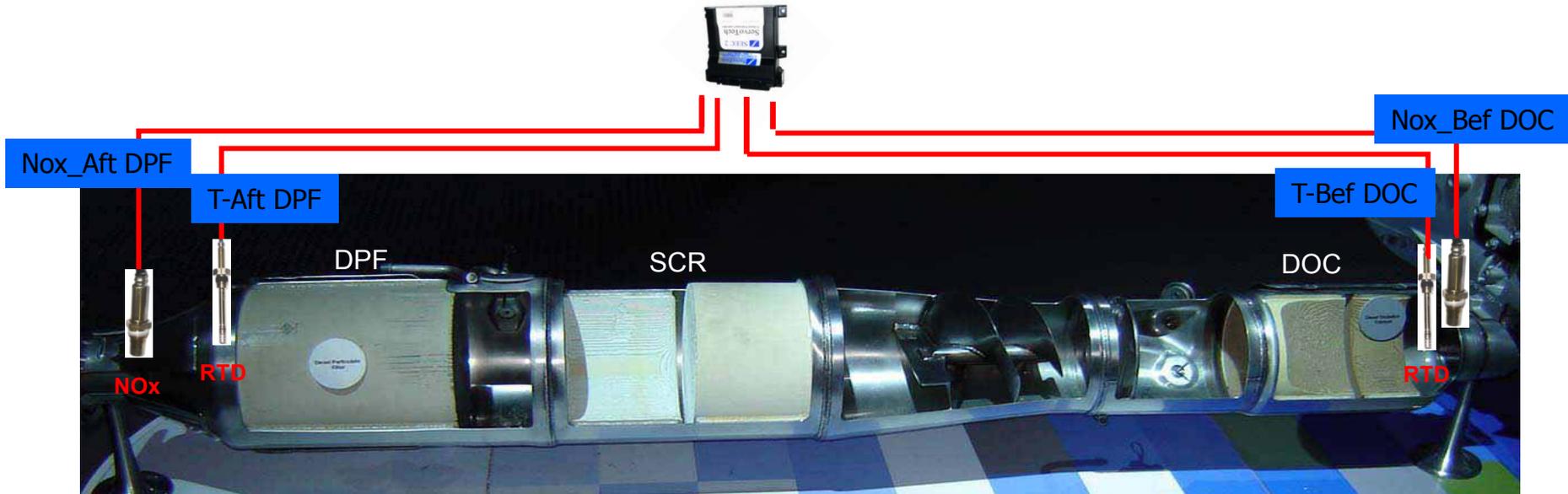
1. Vehicle testing with a new Ford F250, 6.7L diesel truck, instrumented with ServoTech NOx monitoring and data logging system to measure SCR system while using TerraCairPlus.
 2. Dosing Injector spray angles and patterns where characterized by Michigan Technological University (MTU).
 3. DEF reservoir tank was completely drained and filled with TerraCairPlus.
 4. 500 hours of 25/75 (city/highway) road testing using TerraCairPlus.
 5. NOx efficiency measured during the road test (Detroit, Michigan).
 6. DEF injectors were examined by microscopy and analysis of spray angles before and after road testing.
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TerraCairPlus Vehicle Test - Ford F-250, 6.7L Diesel Truck



Exhaust Platform Instrumentation

ServoTech Engineering Exhaust Monitoring System



Abrev.	Definition
T-Before DOC	Temperature Measurement Before DOC
T-Aft DPF	Temperature Measurement After DPF
NOx_Eff	NOX Efficiency
Injector TT	Dosing Injector Tip Temperature

Abrev.	Definition
IHT-SNK-T	Injector Heat Sink Temperature
Urea - T	DEF Fluid Inside Tank Temperature
Nox_Bef_DOC	NOx Measurement Before DOC
Nox_Aft_DPF	NOx Measurement After DPF

DEF Injector Tip Temperature

Temperature probe placed on the tip of the DEF injector to record TCP Fluid temp in injector throughout drive cycles.



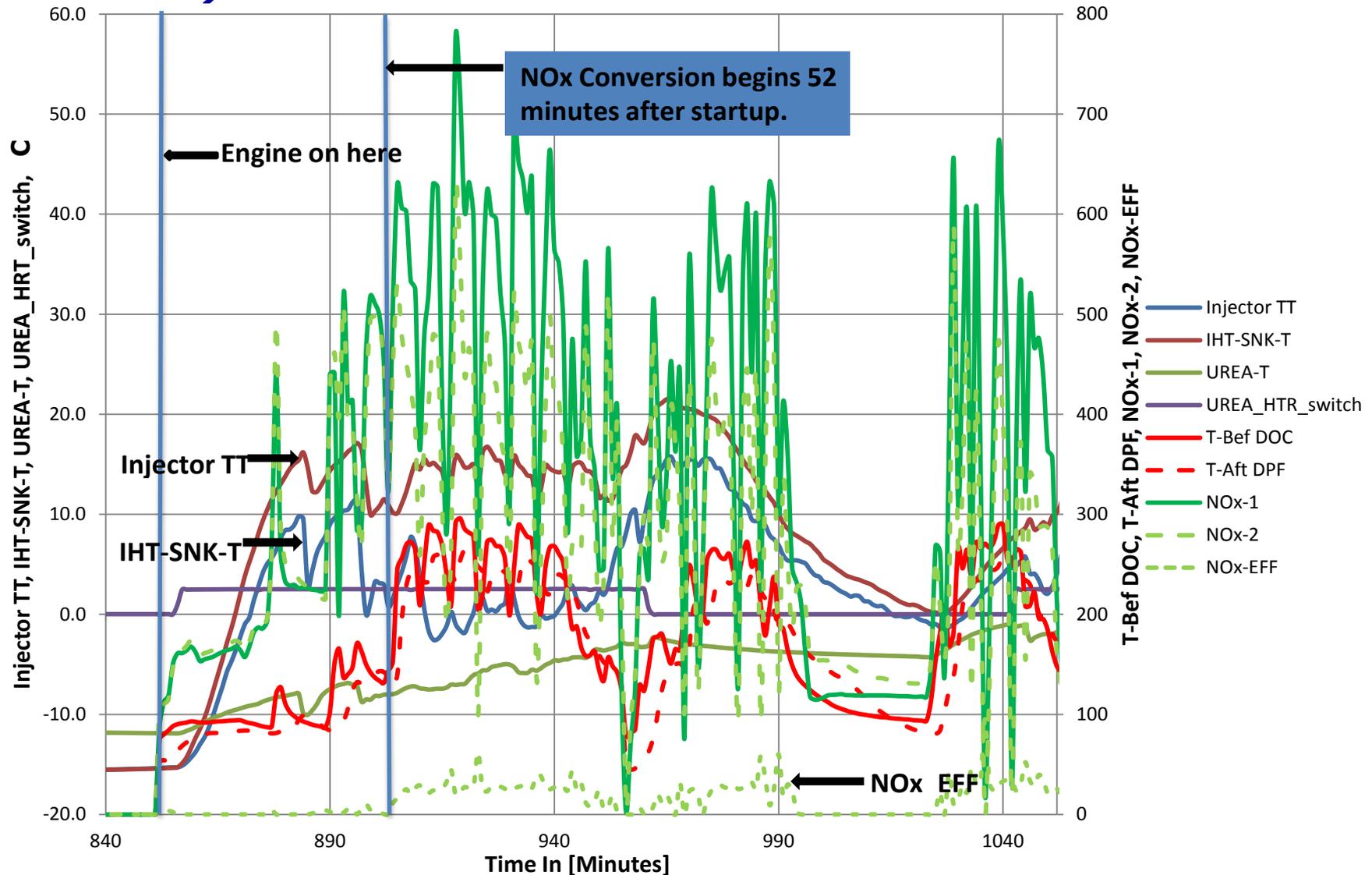
Control Vehicle Trial – On Road Cold Weather Performance Running DEF

Objective: Document Actual Performance of the SCR system on Test Vehicle using DEF during Cold Weather (not a Soak Temp Experiment).

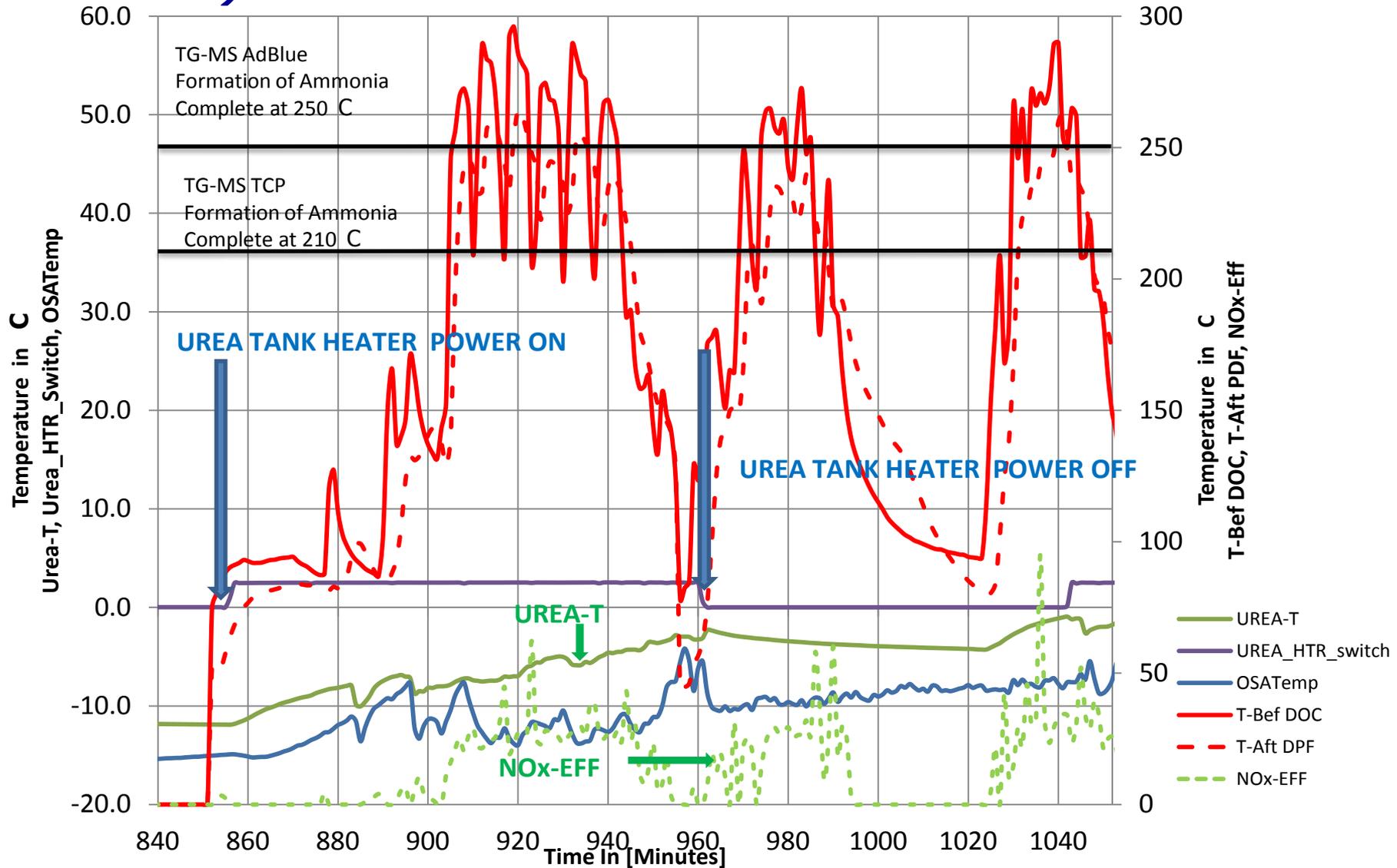
Parameters Recorded

1. Length of time before DEF fluid is injected into the exhaust as displayed by NOx removal efficiency.
 2. Length of time heating element with DEF fluid remained on.
 3. NOx efficiency during Cold Temperature Trial running DEF.
 4. Temperature of exhaust gas before DOC and after DPF.
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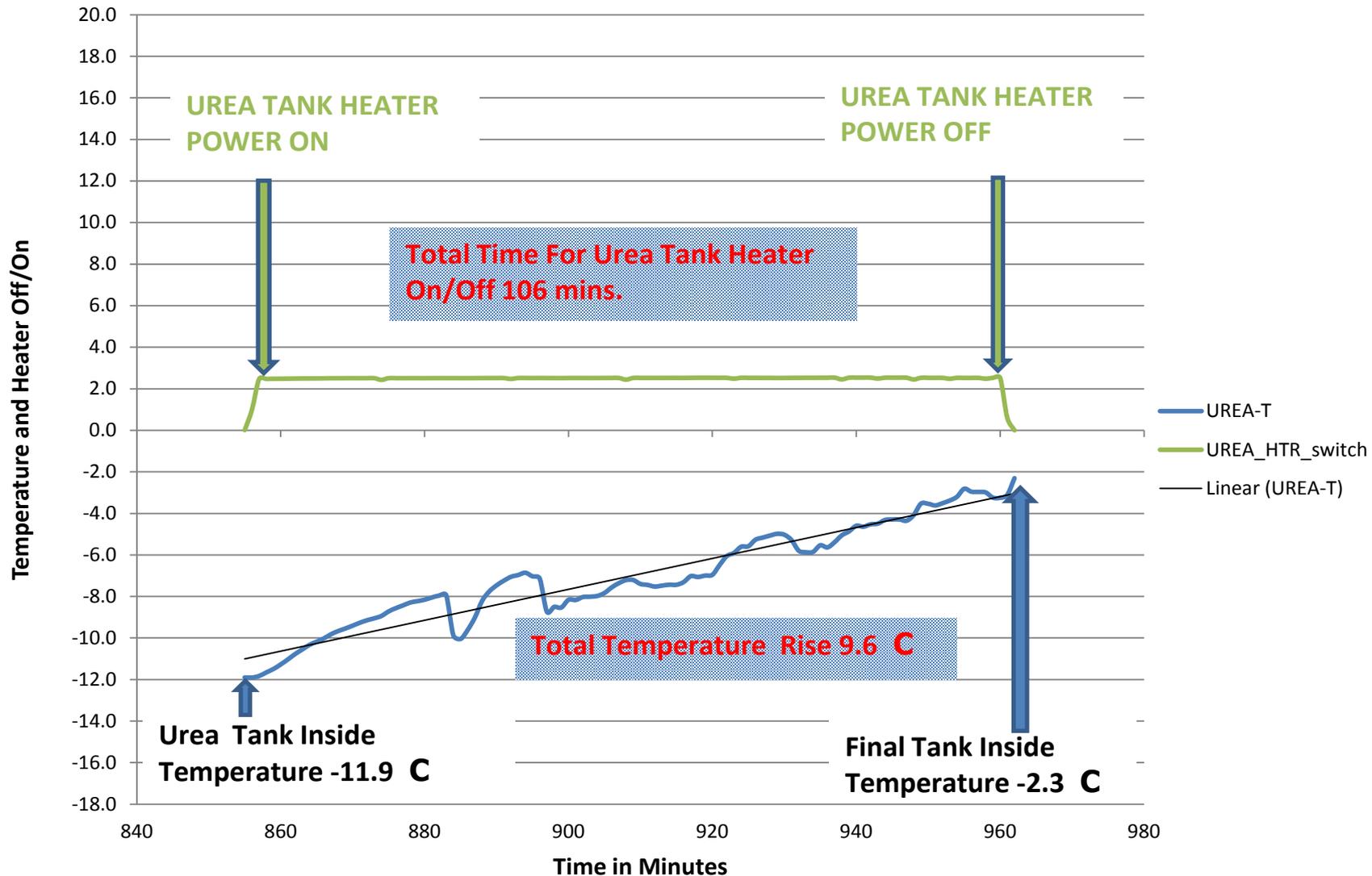
DEF Vehicle Test – Cold Weather (-15 to -5°C Ambient)



DEF Vehicle Test – Cold Weather (-15 to -5°C Ambient)



DEF Vehicle Test - DEF Tank Heater Operation



DEF Vehicle NOx Efficiency – Summary of Observations

1. Total vehicle operating time during cold weather trial; 201 minutes.
 2. 53 minutes elapsed before DEF Injection began.
 3. DEF tank heater element turned on 3 minutes after vehicle start-up. Heater element remained on for 106 minutes before shutting off. Temperature rise within the DEF tank was 9.6 C.
 4. Average NOx-EFF over 201 minutes of vehicle operation in this Control Trial was less than 20%.
 5. DEF Injector Tip Temperature operated between 10 and 40 C. No DPF regeneration occurred.
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TerraCairPlus Vehicle On Road (City/Hwy) Trial

Objective 1: Document Performance of the SCR system on Test Vehicle using TerraCairPlus Diesel Exhaust Fluid.

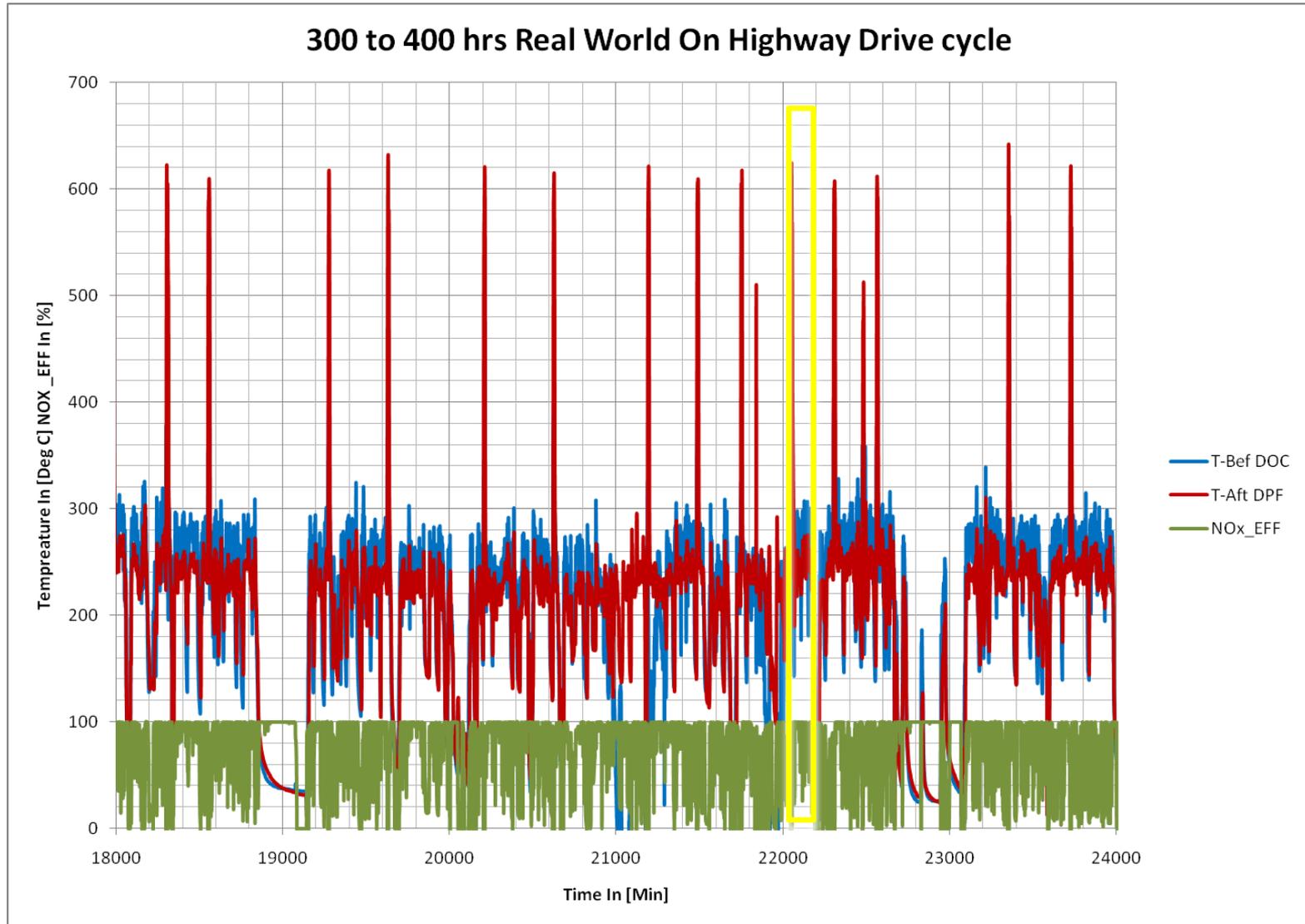
Parameters Recorded

1. NOx removal efficiency.
 2. Any Onboard Diagnostic Warnings.
 3. Evidence of Injector fouling.
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Vehicle Testing with a NEW Ford 250, 6.7L Diesel Truck Using TerraCairPlus DEF.

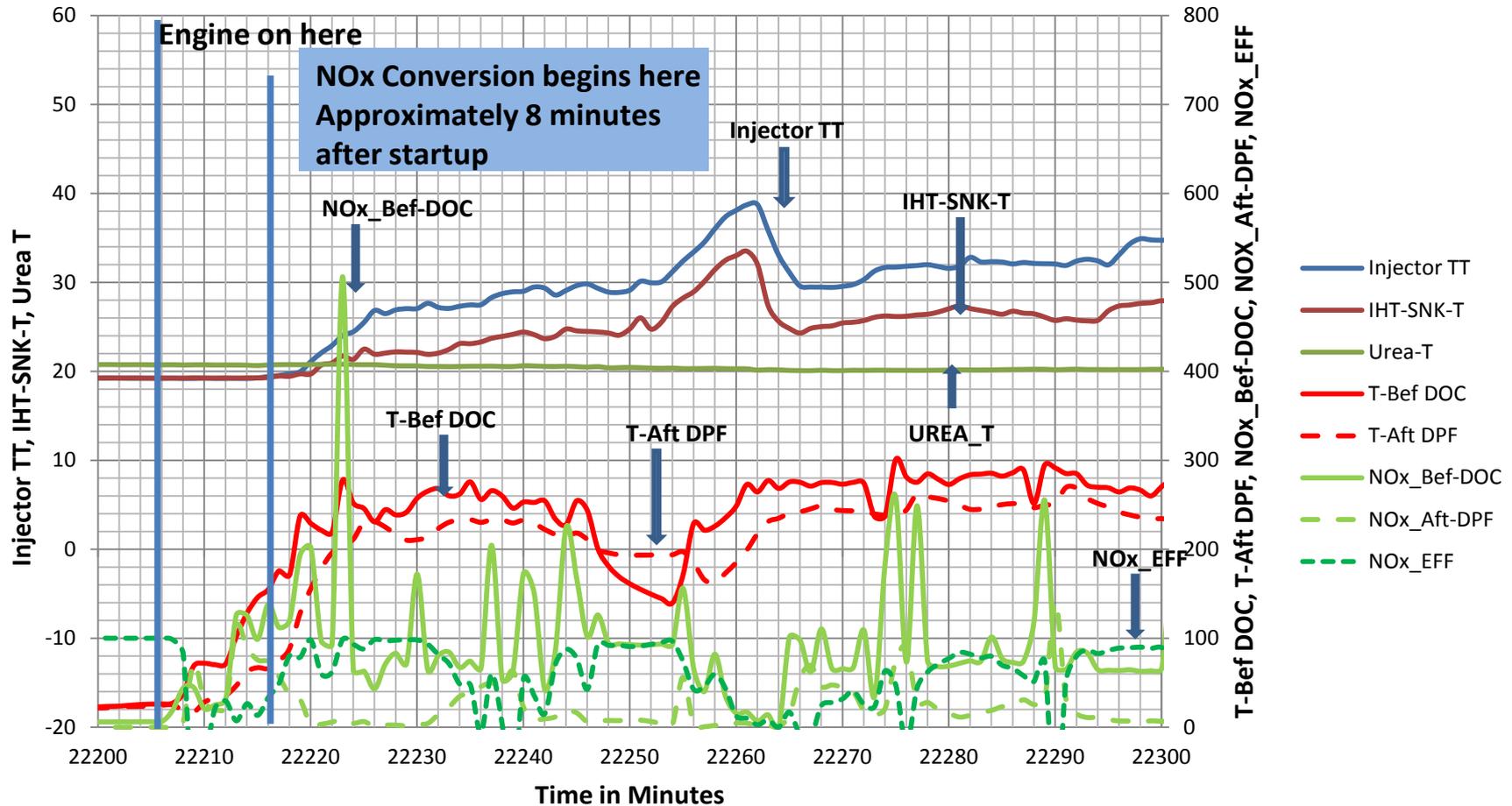
Vehicle Summary Data	
Vehicle Start/Stop Test Trial	01/20-5/18
Additional Weight Added To Vehicle (Kg)	1043
Service Engine Lights to Report	0
Number of Durability Test Days	74
Number of Durability Test Engine Run Hours	500
Number of Durability Test Engine Idle Hours	86
Number of Engine Oil Changes	3
Total Number of Kilometers Traveled	41,986
City/Highway Kilometers	10,496/31,490
Approximate Liters of Diesel Consumed	5315
Liters of TerraCair Plus Consumed	102

TCP - 500 Hours of City/Hwy Drive Cycle



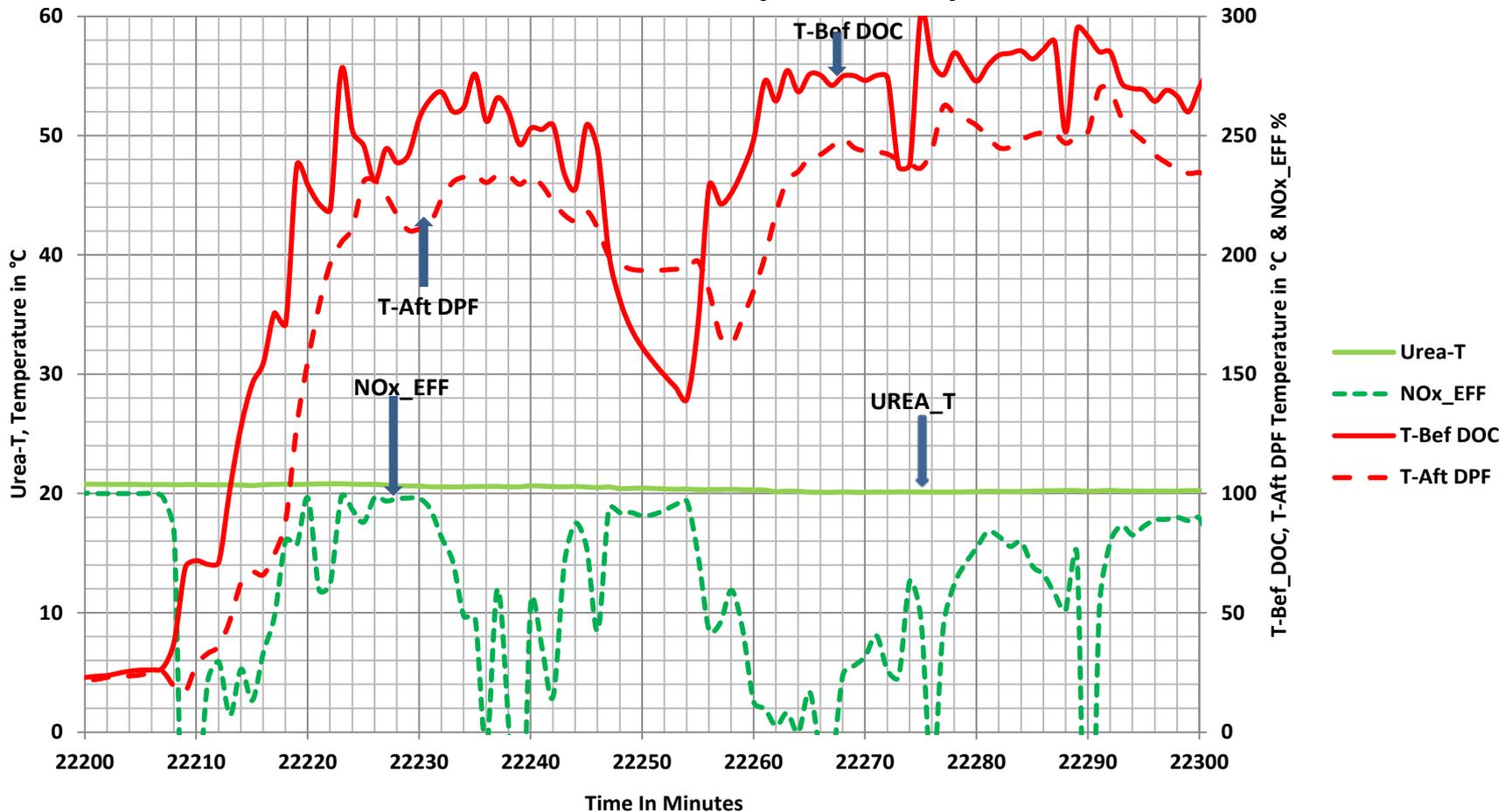
TCP – Data @ The 370 Hours For 100 Minutes of Drive Cycle

SNAP SHOT OF START UP TO 100 MINUTES
@ 370 HOURS, NO_x Efficiency AND Temps

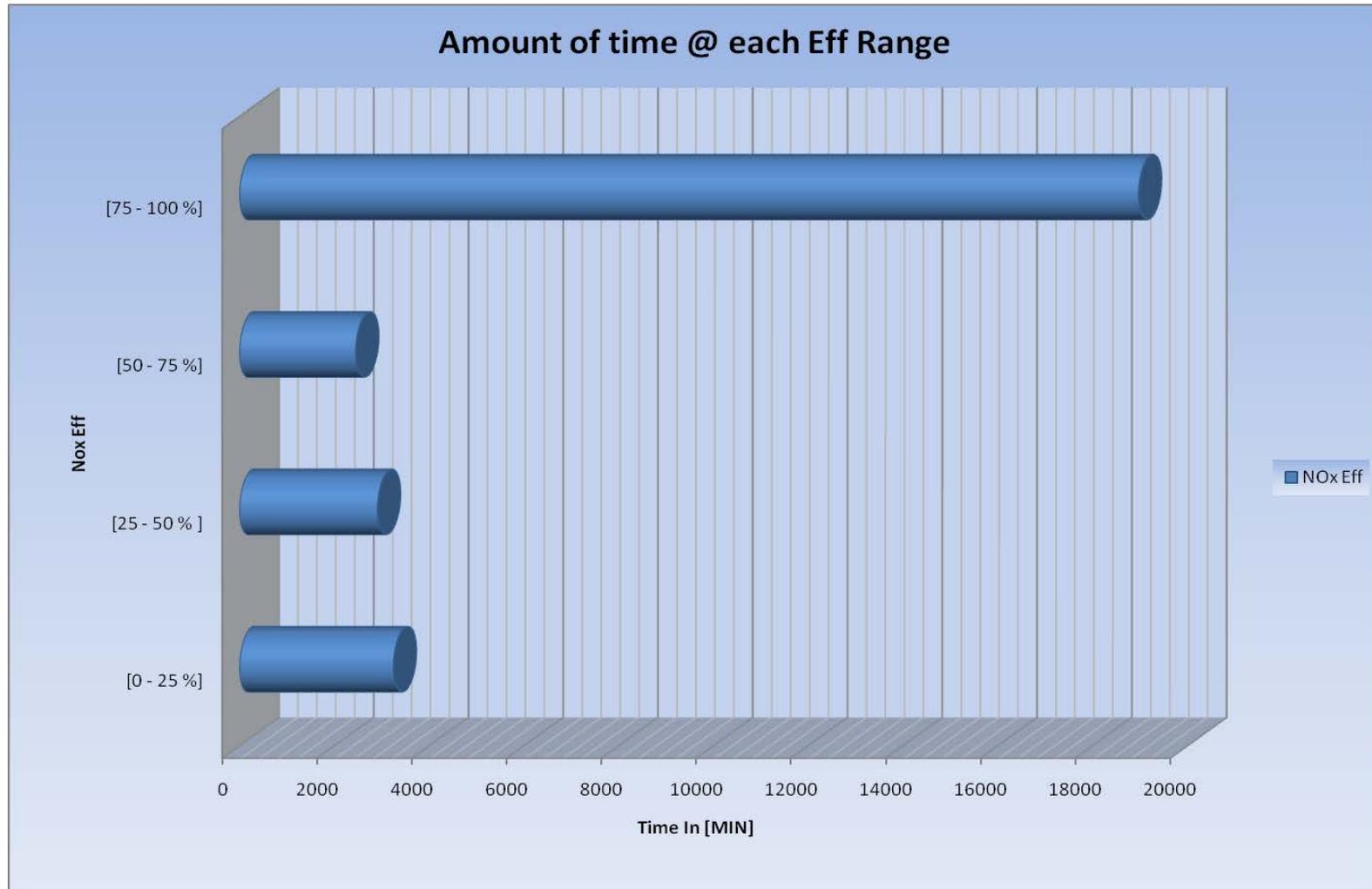


TCP and NOx Efficiency @ 370 Hour Mark for 100 Minutes of Drive Cycle

SNAP SHOT OF START UP TO 100 MINUTES
@ 370 HOURS, NOx Efficiency AND Temps



TCP - Cumulative Time at Each NO_x Efficiency Range Over The 500 Hour Trial



Photographs of the Actual Dosing Injector, 0 Hours and 500 Hours Using TCP only

Injector 0 Hours



Injector After 500 Hours



Injector after 500 hours of actual vehicle service. No visual corrosion or fouling observed.

Vehicle Trial Summary: TerraCairPlus

Summary

1. No service engine lights appeared throughout the trial.
2. Over 71% of the drive cycle time the NOx Removal Efficiency was spent between the range of 75 to 100%.
3. No corrosion is observed on the injector tip after 500 hours of vehicle operation using TCP only.
4. TerraCairPlus Fluid was fully substitutable for this trial.

Further Evaluation

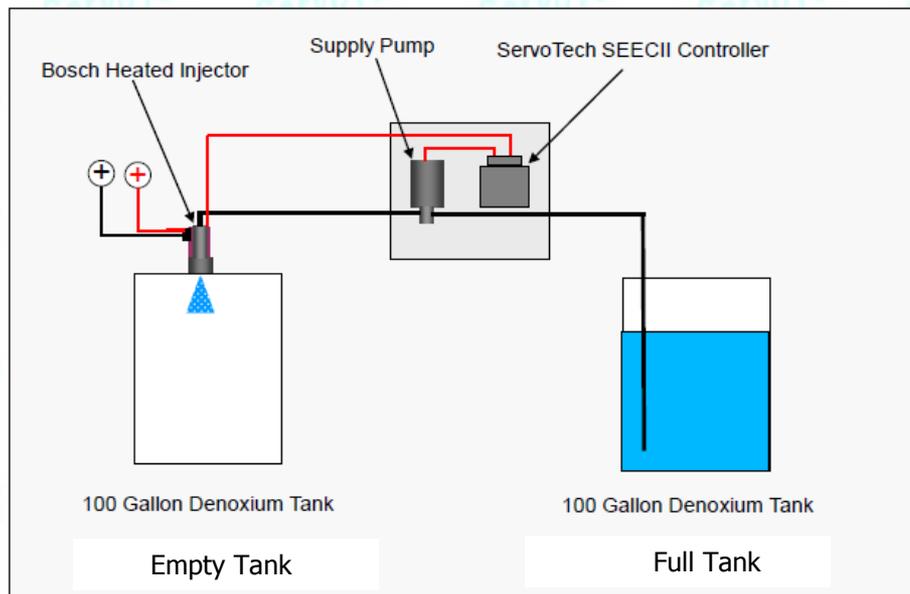
1. MTU is scheduled to evaluate the spray characteristics of the dosing injector used for the 500 hours of operation test trial.

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-

Bench Tests of DEF Injectors

Objective: Investigate potential corrosion of DEF Dosing Injector using DEF and TCP fluids at constant injector temperature while cycling off and on.



DEF Injector Bench Testing: Experimental Conditions

Experimental Conditions

- Injectors operated 8 hours per day at the 57°C.
- Injectors heated to 57°C with external heaters.
- Injector pumps shut down and allowed to cool to room temperature next 16 hours.
- Fluid remained in the injectors during shutdown period.

Bench Testing Summary: DEF Versus TerraCairPlus

Temperature of Fluid	20 °C
Temperature of Injector	57 °C
Injector Inlet Pressure	482 kPa
Number of Operating Hours	328
Number of Injection Pulses	11,808,000
Injector Flow Rate of Fluid	11 g/min

DEF Injector - After 50 Hours of Operation



- **Observed white crystals (identified to be Urea) forming around the injector tip.**
- **The picture on the right clearly shows how the liquid spray keep the solid from forming.**
- **Slight urea formation around the injector mounting plate.**

TerraCairPlus Injector - After 50 Hours of Operation

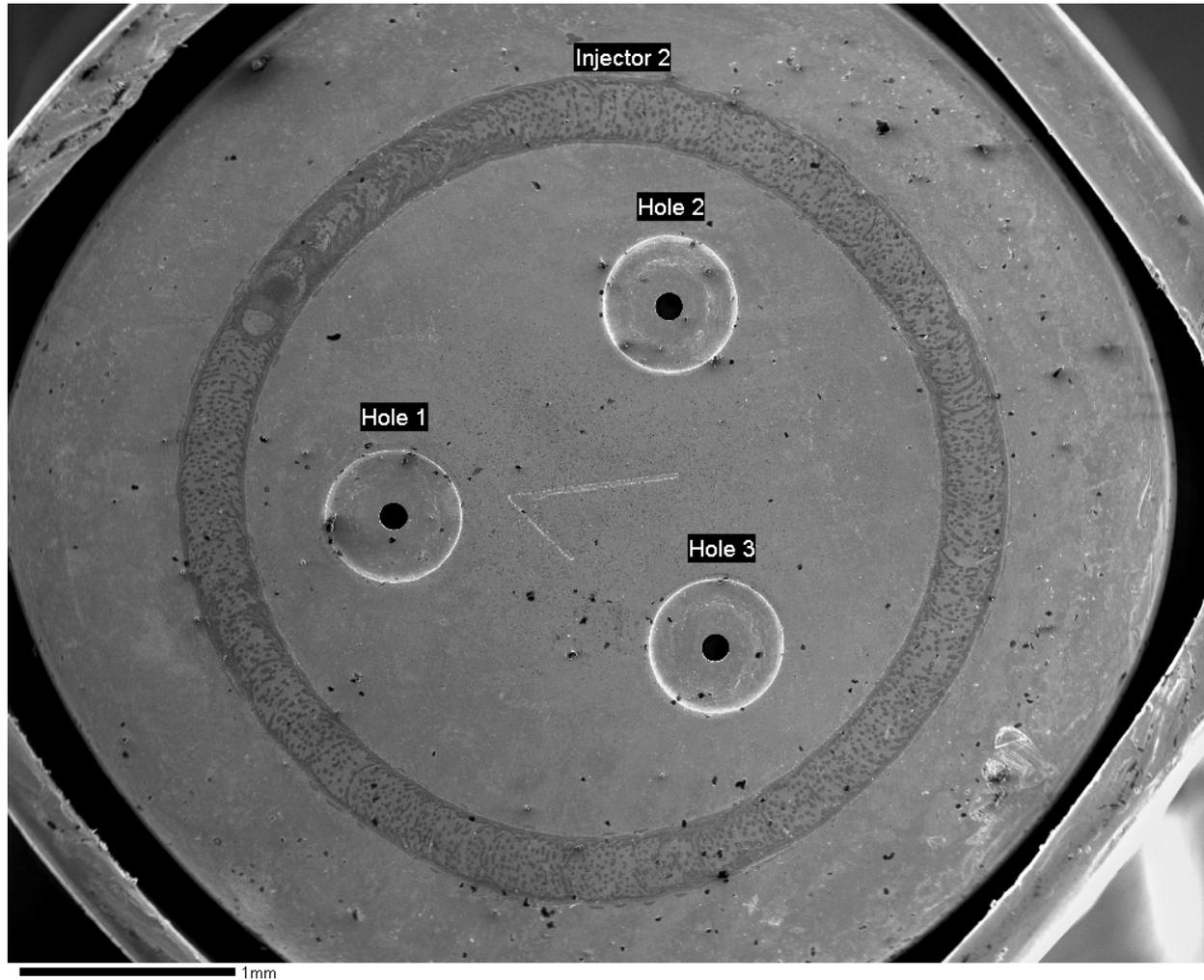


- **No white crystal material formation around the injector tip.**
- **Photograph on the right shows the position of the thermal couple which controlled the constant temperature.**
- **Slight crystal formation around the injector mounting plate.**

TerraCairPlus versus DEF – Comparison of Injector Orifices

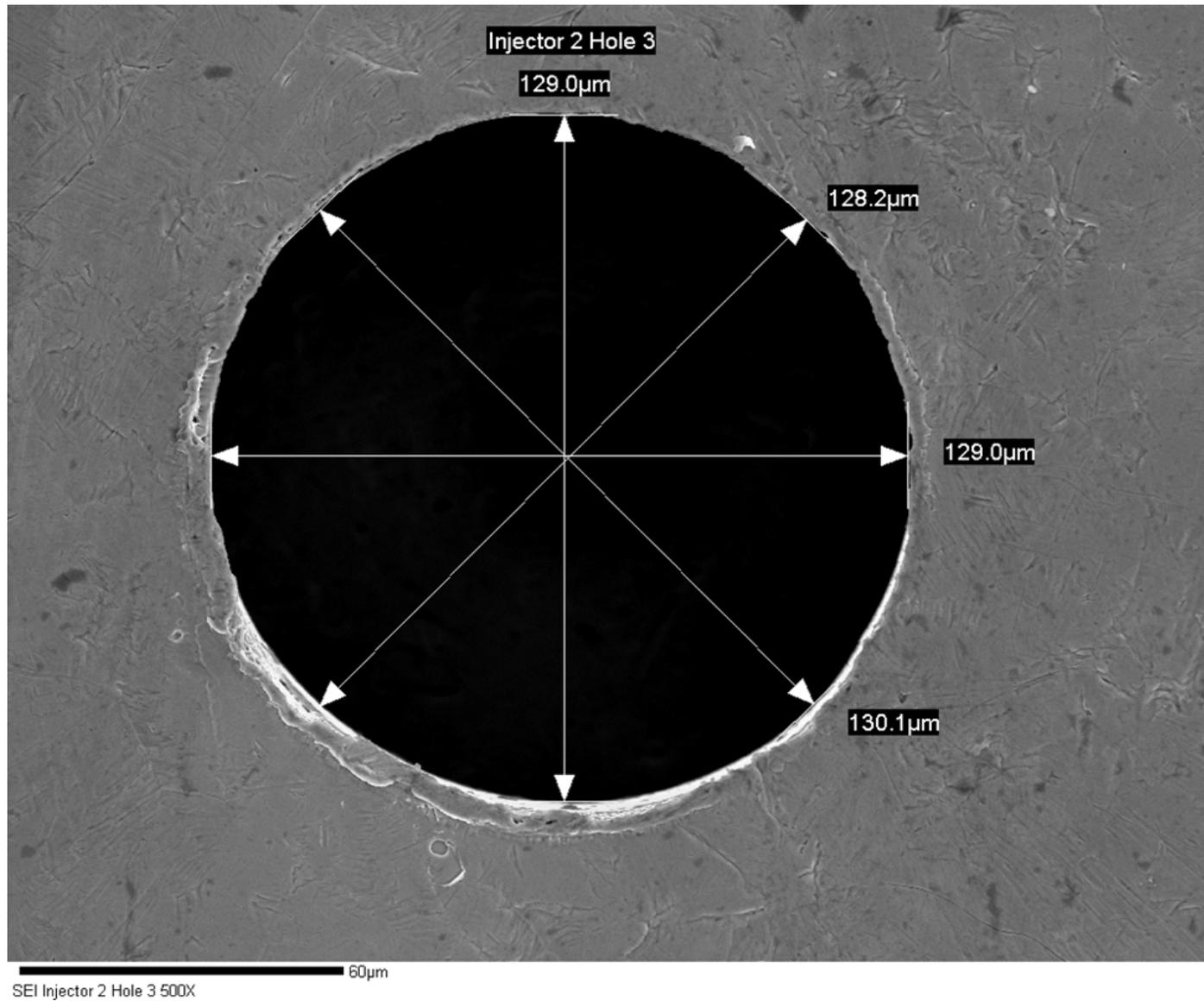
- Compared the injector orifice hole diameter changes after 328 hours of bench test cycling.
 - MTU – Michigan Tech University photographed the injector and measure the injector orifice holes.
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TerraCairPlus Injector: 3 Holes After 328 Hours of Service



SEI Injector 2

DEF Injector: Hole Diameter



TerraCairPlus vs. DEF Injector

Hole Size Comparison Chart After 328 Hours of Cycling Operation at 57 C.

New Injector				TerraCair Plus Injector				DEF Injector			
		4 Pts.	12 Pts.			4 Pts.	12 Pts.			4 Pts.	12 Pts.
Hole No.1	128.1	Mean 127.6	Average 128.4	Hole No.1	129.9	Mean 130.1	Average 129.8	Hole No.1	129.9	Mean 130.2	Average 129.5
	128.1				130.4				130.9		
	127.1	Stdev 0.5			130.3	Stdev 0.3			129.9	Stdev 0.5	
	127.2				129.9						
Hole No.2	126.7	Mean 128.4	Stdev 1.23	Hole No.2	130.3	Mean 130.3	Stdev 0.78	Hole No.2	129.4	Mean 128.4	Stdev 1.10
	127.9				131.1				129		
	129.4	Stdev 1.3			130.3	Stdev 0.6			128.5	Stdev 1.2	
	129.5				129.6						
Hole No.3	129	Mean 129.2	Max 130.8	Hole No.3	129.0	Mean 129.1	Min 128.2	Hole No.3	129	Mean 129.8	Min 126.7
	127.4				128.2				130.3		
	129.4	Stdev 1.4			129.0	Stdev 0.8			130.3	Stdev 0.6	
	130.8				130.1						

TerraCairPlus vs. DEF Injector - Hole Size Comparison Conclusions

- ❑ Some erosion of hole diameter observed in both the DEF and TerraCairPlus holes vs. the New Injector.
 - ❑ We believe the DEF and TerraCairPlus hole diameters are comparable in diameter at the end of the trial.
 - ❑ We plan to Repeat these examinations with on-vehicle injector.
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 - ❑ **Corrosion Testing**
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Corrosion Testing : TerraCairPlus and DEF

Objective: Compare Corrosion rate of various Alloys present in the DEF Injector when exposed to TerraCairPlus and Traditional DEF.

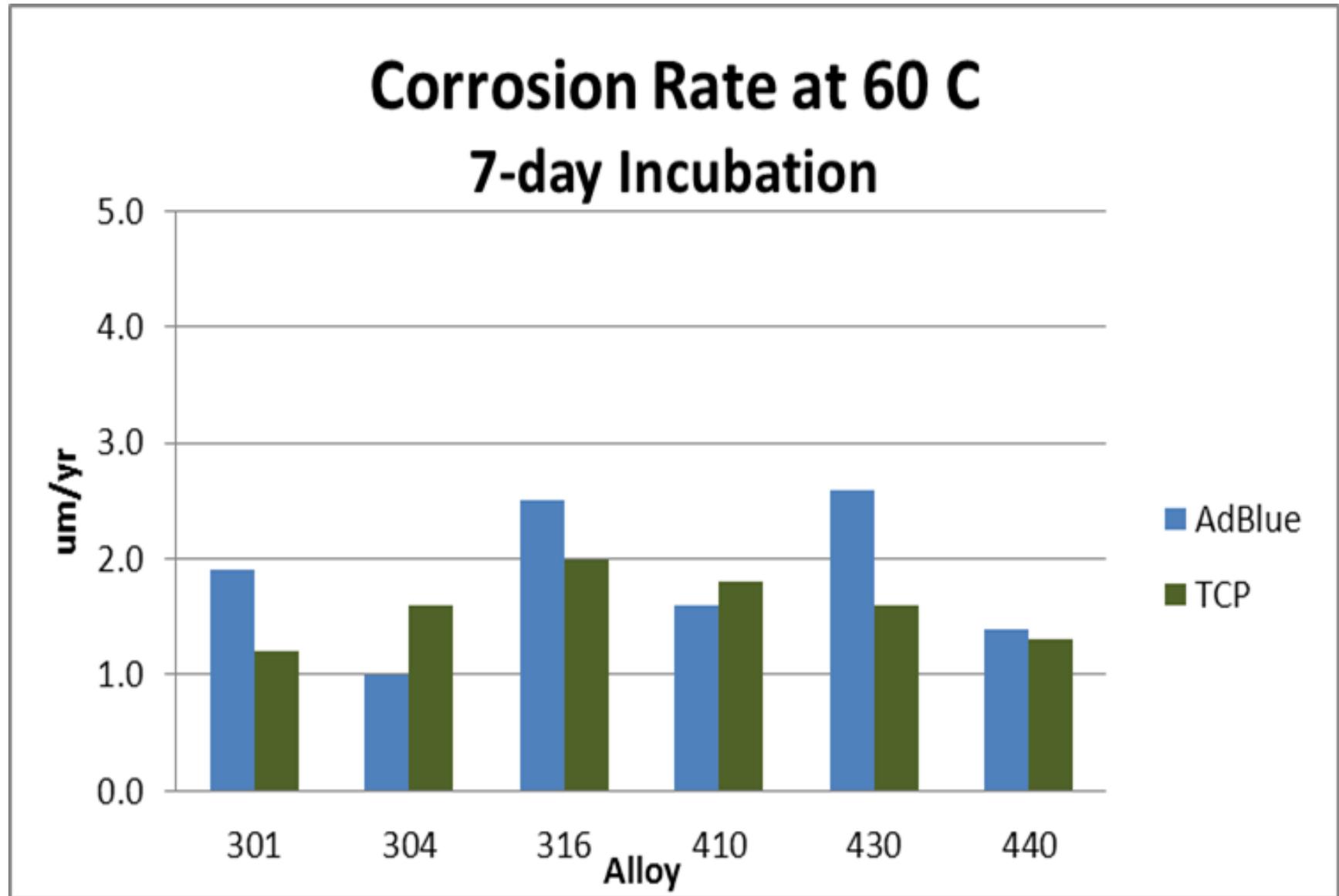
Experimental Conditions

1. Measure corrosion on Coupons prepared by ASTM G1 and G31.
 2. Coupons tested fully submerged.
 3. 2, 3 and 7 Day Incubation at 30°C, 60°C and 80°C.
 4. Incubation at Temperatures as high as 120°C boiled and Decomposed the fluids causing radical corrosion of alloys with both DEF and TerraCairPlus - Not considered a realistic experiment.
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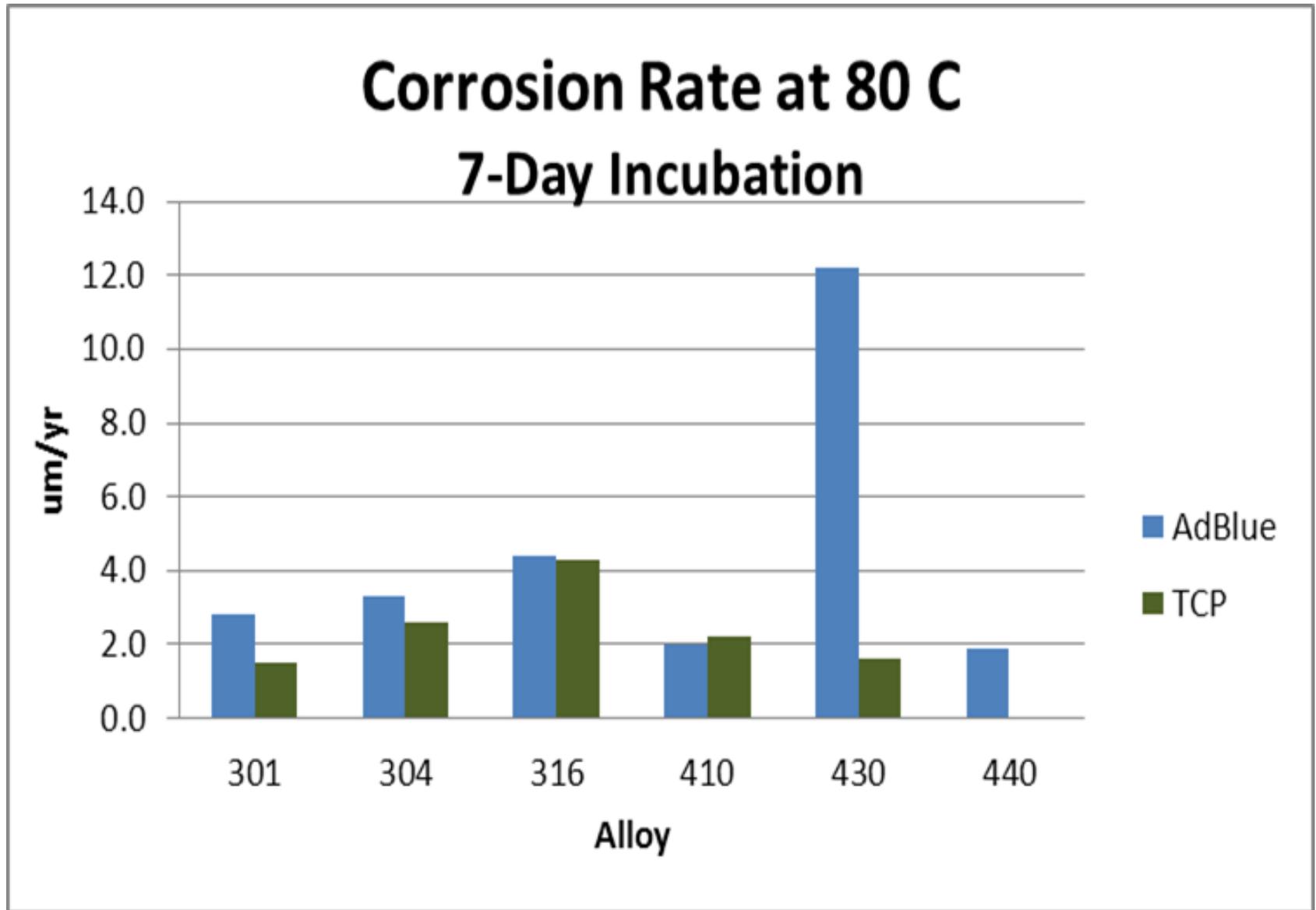
Corrosion Study – Alloys Tested

Alloy	AISI Equivalent
1.4310	AISI 301
1.4301	AISI 304
1.4436	AISI 316
CC13FM	AISI 410
1.4016	AISI 430
1.4112	AISI 440

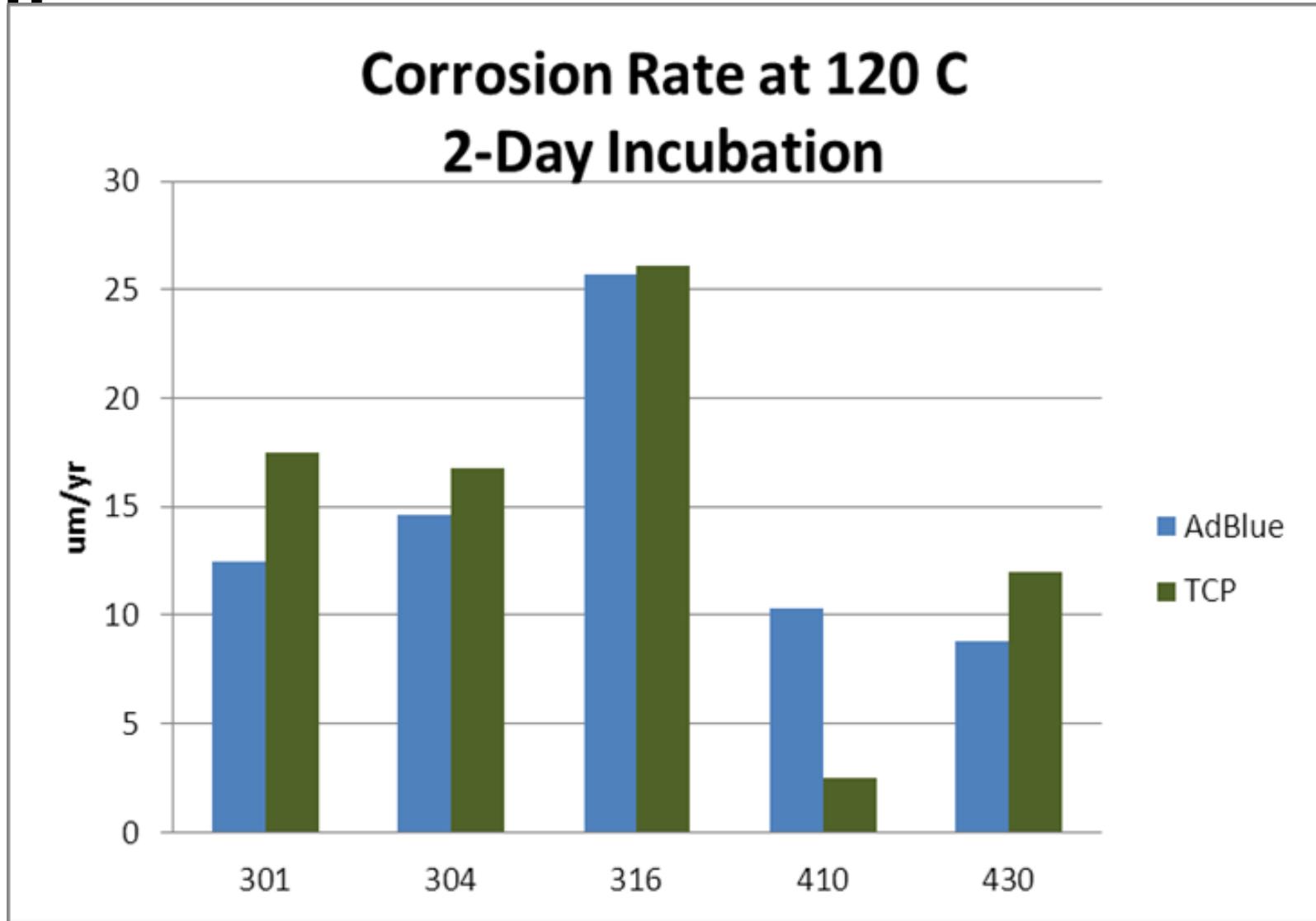
7-day Incubation at 60°C



7-day Incubation at 80°C



2-Day Incubation at 120°C – Fluids Boiled Off



Corrosion Study Conclusions

- TerraCairPlus and DEF have comparable corrosion rates on the Alloys tested.
 - DEF maybe more corrosive for 1.4016 (AISI430) steel than TCP but this needs to be repeated.
 - We plan to Repeat these experiments with actual injector components and for longer periods of exposure at Real World Injector Temps.
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TerraCairPlus Presentation Summary

- TerraCairPlus Chemistry has Advantages over traditional DEF – Much Lower Freezing Point.
 - TerraCairPlus was fully substitutable for DEF in the Vehicle Trial with No OBD Warnings or Injector performance Issues.
 - TerraCairPlus demonstrated no DEF Injector fouling in Bench Trials.
 - TerraCairPlus demonstrated an equivalent corrosion rate to DEF for the alloys tested.
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Thank-you



 **TerraCairPlus**TM
EXTREME TEMPERATURE DEF

Does your Diesel Exhaust Fluid Freeze at
-30°C? *TerraCairPlus* Doesn't!