RJM

Urea SCR for Diesel and Natural Gas Engines

Presented to

U.S. Maritime Administration

Workshop on Maritime Energy and Clean Emissions

By

RJM Corporation

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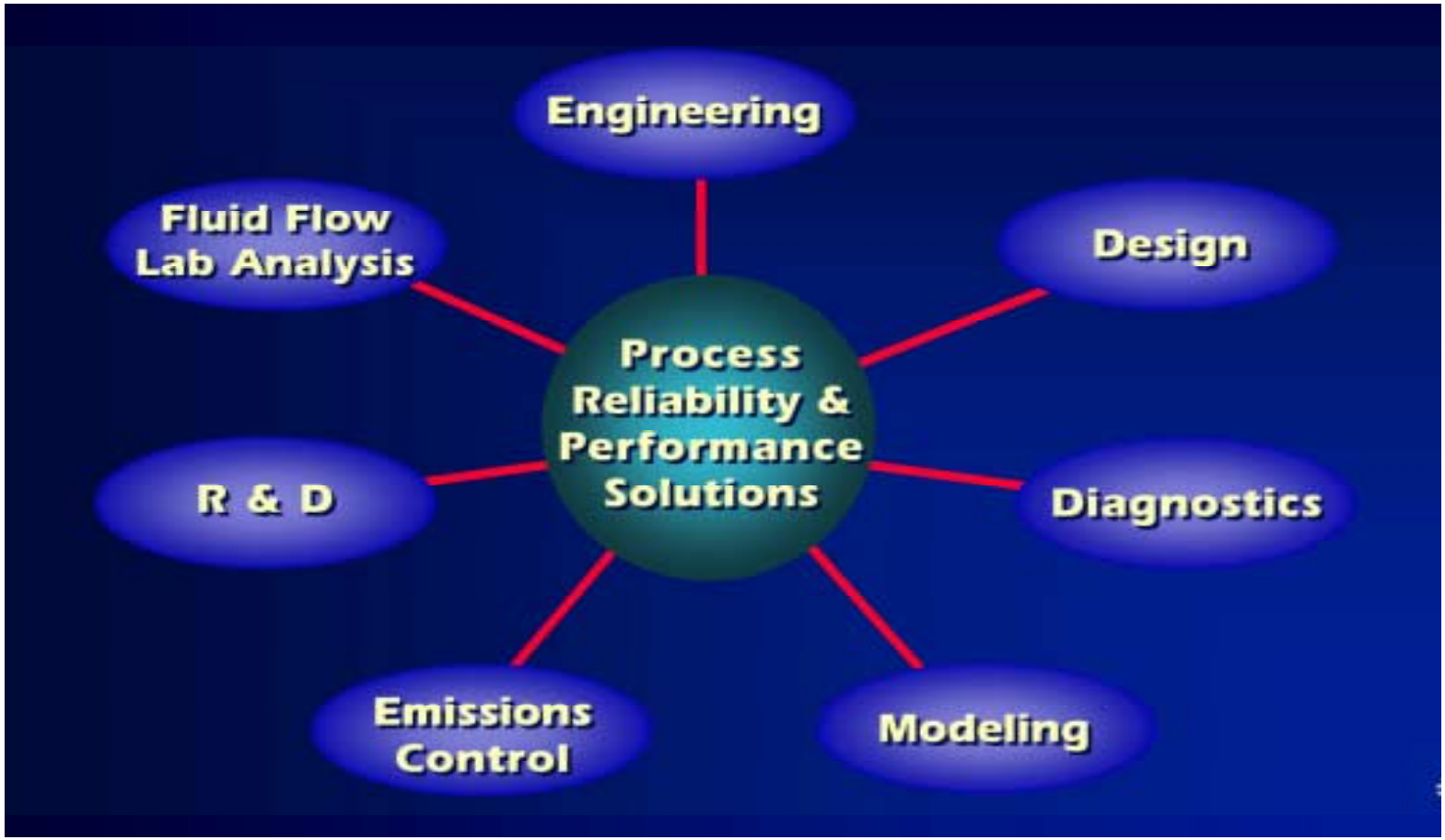
RJM Corporation

- **Formed in 1977**
- **50,000 MW of NOx Compliance Experience**
- **300+ Utility & Industrial Customers**
- **15 years of urea based process control experience to control NOx using SCR and SNCR**
- **Staff includes several U.S. Coast Guard licensed engineers**
- **European office opened in June 2001**
- ***ARIS™ Technologies Group* – NOx reduction using urea injected, SCR after-treatment on Diesel and Lean Burn Natural Gas exhaust and other emissions needing control.**

RJM - Market Presence

> 50,000 MW – Coal, Gas, Oil Fired Units

RJM Corporation Capabilities



RJM ARIS Technology

Application and Installation List

(updated 9/01)

- **Development Programs Completed:**
  - Cummins, 90 hp, 500 hour durability Test
  - Cummins L-10, 300 hp
  - Detroit Diesel Series 50, 240 hp truck
  - Cummins 5.9 liter, 230 hp
  - Cat 3406, 600 hp, 1500
  - Cat 3406, 400 hp in Class 8 truck
  - Cummins M11, 375 hp in Class 8

- **Stationary Systems in Operation:**

Georgia	– Cat 3516B, 2600 hp, peak shaving (2 Units)
	– Detroit Diesel DDC16V-149T, peak shaving (4 units)
New Jersey	– Cat G-3406, 460 hp 3000 hours estimated
	– Mack T9, 1500 hours estimated
	– Cat C-12, 1500 hours estimated
Pennsylvania	– Cat 3516, Peak Shaving (5 units)
Rhode Island	– Cat 3512B, Prime Power (1 unit)
	– Cat 3516B, Prime Power (1 unit)
Texas	– Cummins NTA 855 G3, Crane (1 unit)

RJM ARIS Technology

Application and Installation List

(Continued)

Systems in Engineering/Installation/Startup:

Georgia	– Cat 3512, 1400 hp, peak shaving (1 unit)
	– DDC 16V149T, diesel (4 units)
Illinois	– Cat 3516, (1 unit)
	– Cat 3512, (1 unit)
Louisiana	– QSK45-G4, 1622 hp, prime power (20 units)
Nevada	– Cummins QSK60-G6, 2922 (18 units)
New Jersey	– Cat 3512, (3 units)
	– Cat 3516, (4 units)
Rhode Island	– Cat 3516B, prime power (1 unit)
Washington	– Cummins QSK60-G5, 2319 hp, diesel (16 units)
	– Cat 3516B, 2593 hp, (2 units)
	– Cummins QSK60-G5, 2140 hp, (5 units)
	– Cat 3512B, 1500 hp, diesel (1 unit)
	– Cat 3516B, (12 units)

Cummins NW
Okanogan Site-16 Engines

Grays Harbor, Public Utility District
Aberdeen, WA

Aggreko Site

Typical Installation on Caterpillar 3516B

Urea SCR

- **Urea reagent is injected into the exhaust stream in front of an SCR catalyst to selectively reduce NOx to N_2 and H_2O**
- **NOx reductions of 70% to 90% at typical exhaust temperatures of 300°C to greater than 450°C**
- **Approximately 2 tons of 32.5% urea solution per ton NOx removed**

Urea SCR Chemistry

Decomposition

Urea Hydrolysis

$(NH_2)_2CO + H_2O \gg 2NH_3 + CO_2$ ($T > 135\ ^oC$, $P > 200$ psi)

Urea Pyrolysis

$(NH_2)_2CO \gg NH_3 + HNCO$ ($T > 300\ ^oC$)

Catalytic Reduction of NOx

NH_3 or $HNCO + NOx + O_2 \gg N_2 + H_2O + CO_2$

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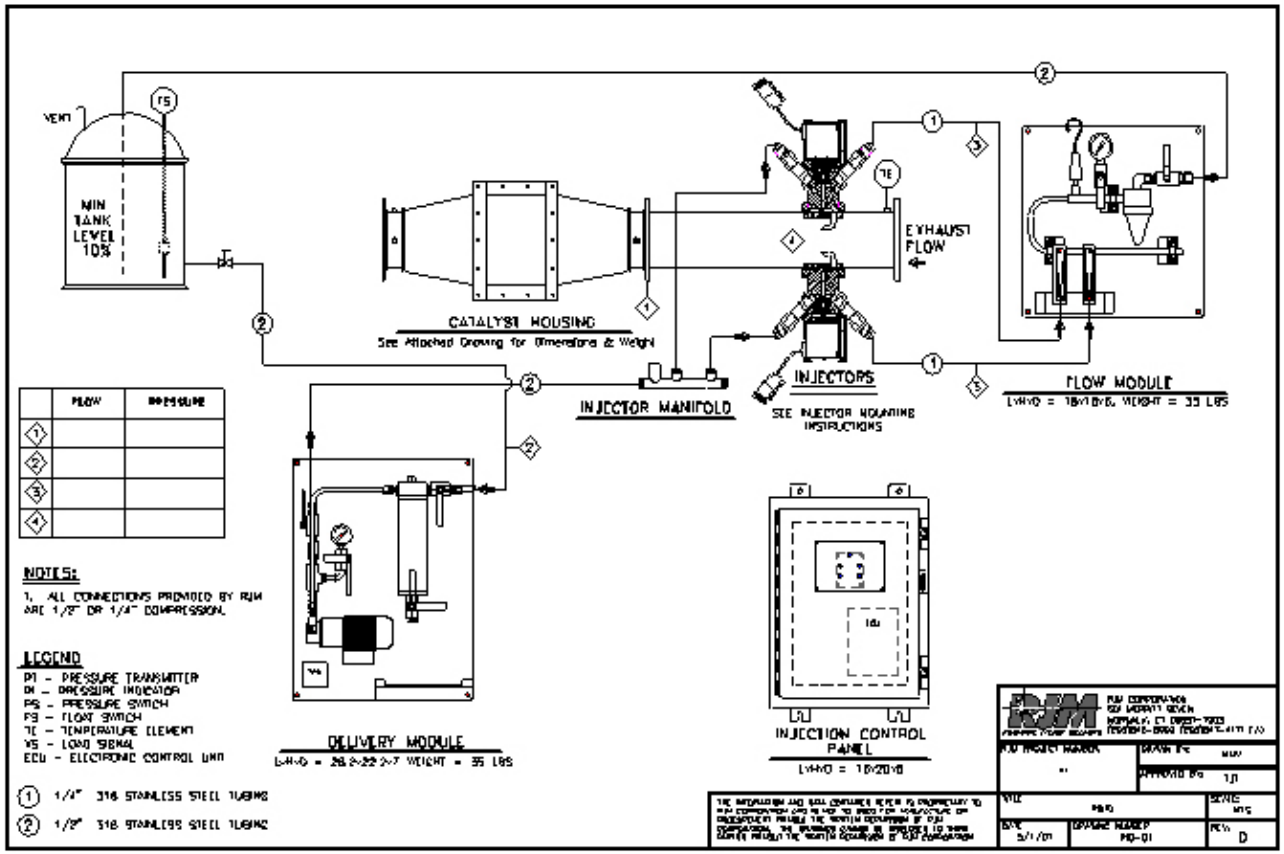
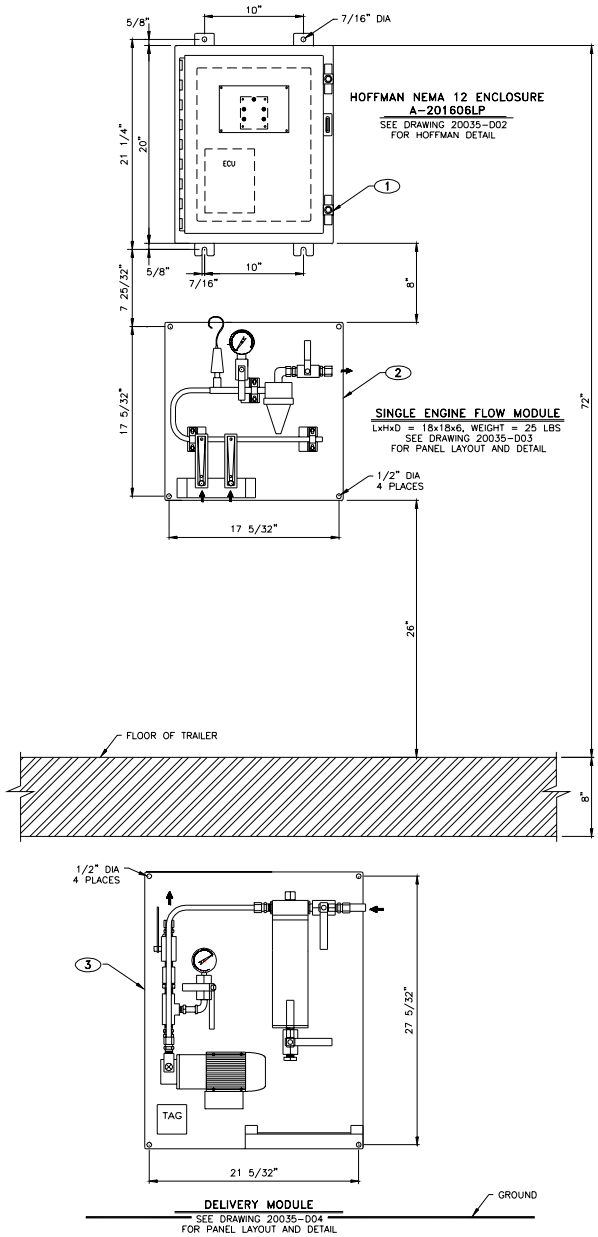
Typical Urea SCR Flow Diagram for Diesel & Natural Gas





Typical ARIS Modules Arrangement

Urea SCR - Advantages

- **Suitable for all lean burning engines**
- **Cost effective NOx control with high NOx conversion**
- **New or retrofit installations**
- **Allows the engine to operate at maximum fuel economy**
- **Safe and non-hazardous**
- **Can be combined with other control technologies for removal of PM, CO, HC, and toxic emissions**

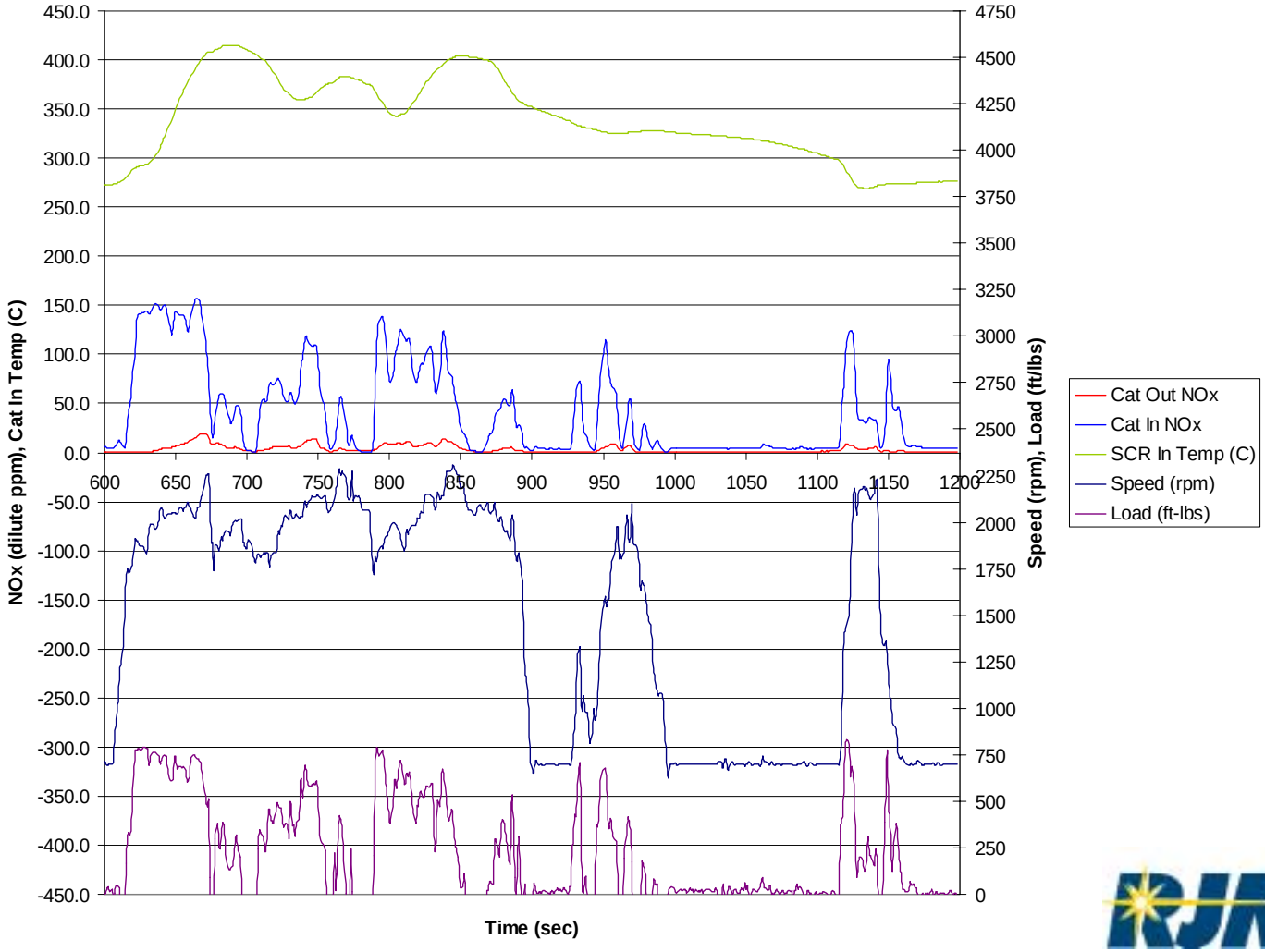
Urea SCR
SwRI Laboratory Performance

- **Caterpillar 3126**
- **HDD Transient and steady state modes**
- **Steady state NOx:**
  - **5.1 g/bhp-hr in**
  - **0.4 g/bhp-hr out**
  - **92% NOx conversion**

RJM ARIS SCR Technology

Ability to Follow Load and Speed Changes

Caterpillar 3126 Engine

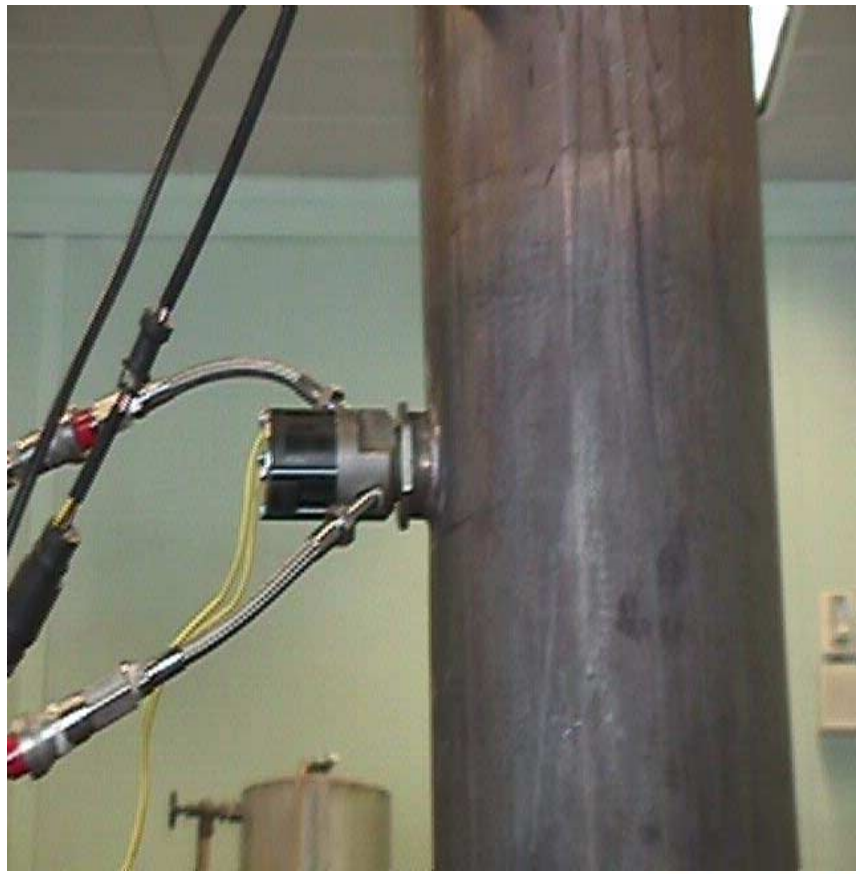


Urea SCR
Field Performance

- Caterpillar G3406
- 389 bhp gas engine
- 3700 ppm NOx
- Guaranteed 90% NOx reduction
- Achieved >95% NOx reduction
- Installed June 1999

Urea SCR
Field Performance

- **Caterpillar G3406**
- **Urea injector**



Port of Houston - Rubber Tire Gantry Crane (RTG)

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Prior to SCR Installation

Port of Houston - Rubber Tire Gantry Crane (RTG)

Post SCR Installation

Port of Houston - Post SCR Installation

Urea Tank & Delivery Module

Injector w/support equipment

Port of Houston - Post SCR Installation

Injection Control Panel

Port of Houston –
NOx Reduction Results

- **Steady State conditions w/testing accomplished by RJM NOx reductions exceeded 90%.**

- **Over transient cycle created by the POH, w/testing accomplished by others, NOx reductions reportedly to exceed 80%.**

SCR FAQ's & Concerns

Q: Is Urea SCR hazardous?

A: Neither the catalyst nor reagent are hazardous. The SCR catalyst can be disposed of in landfills.

Q: Is SCR too expensive?

A: Recent advancements in RJM ARIS™ Urea based SCR technology have reduced cost considerably. For prime power diesel applications, the cost per ton of NOx reduced is less than $1000 per ton.

SCR FAQ's & Concerns

continued

Q: Is SCR proven?

A: SCR has been operating effectively on IC engines since the mid-90's. More recently it has been operating effectively on stationary IC engines meeting regulatory requirements.

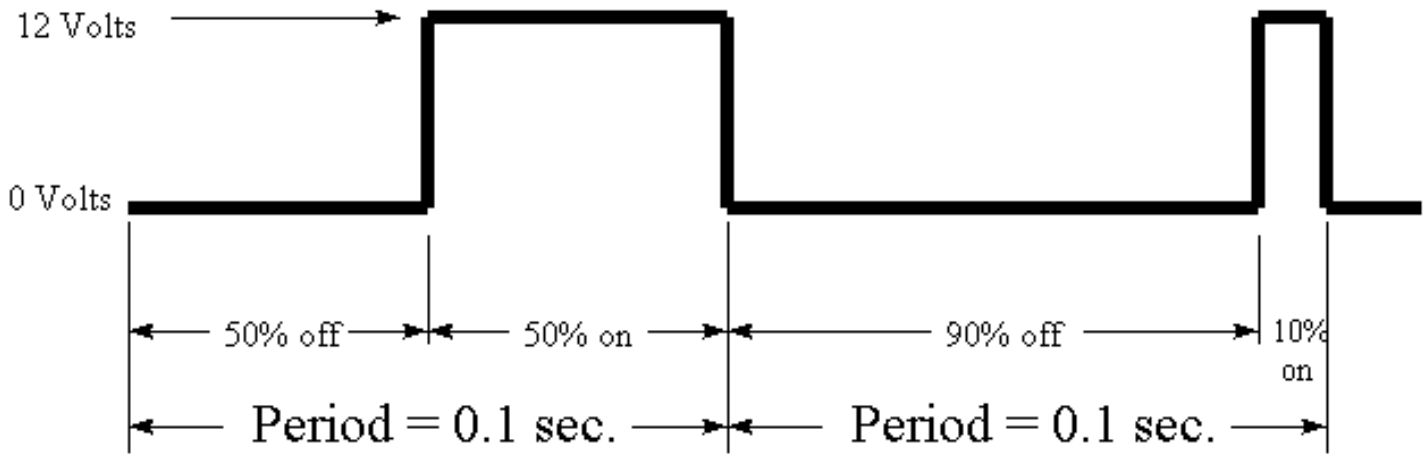
Q: Can SCR follow load changes?

A: It has effectively followed the EPA HD Transient FTP.

RJM ARIS Technology

- **Flow-through pulse-width-modulated *Single-Fluid* injector**
- **Available for Commercial Stationary engines using the ARIS™ with SCR Catalyst**
- **Licensed Patents**
  - **Flow Through Injector Design**
  - **SCR + EGR**

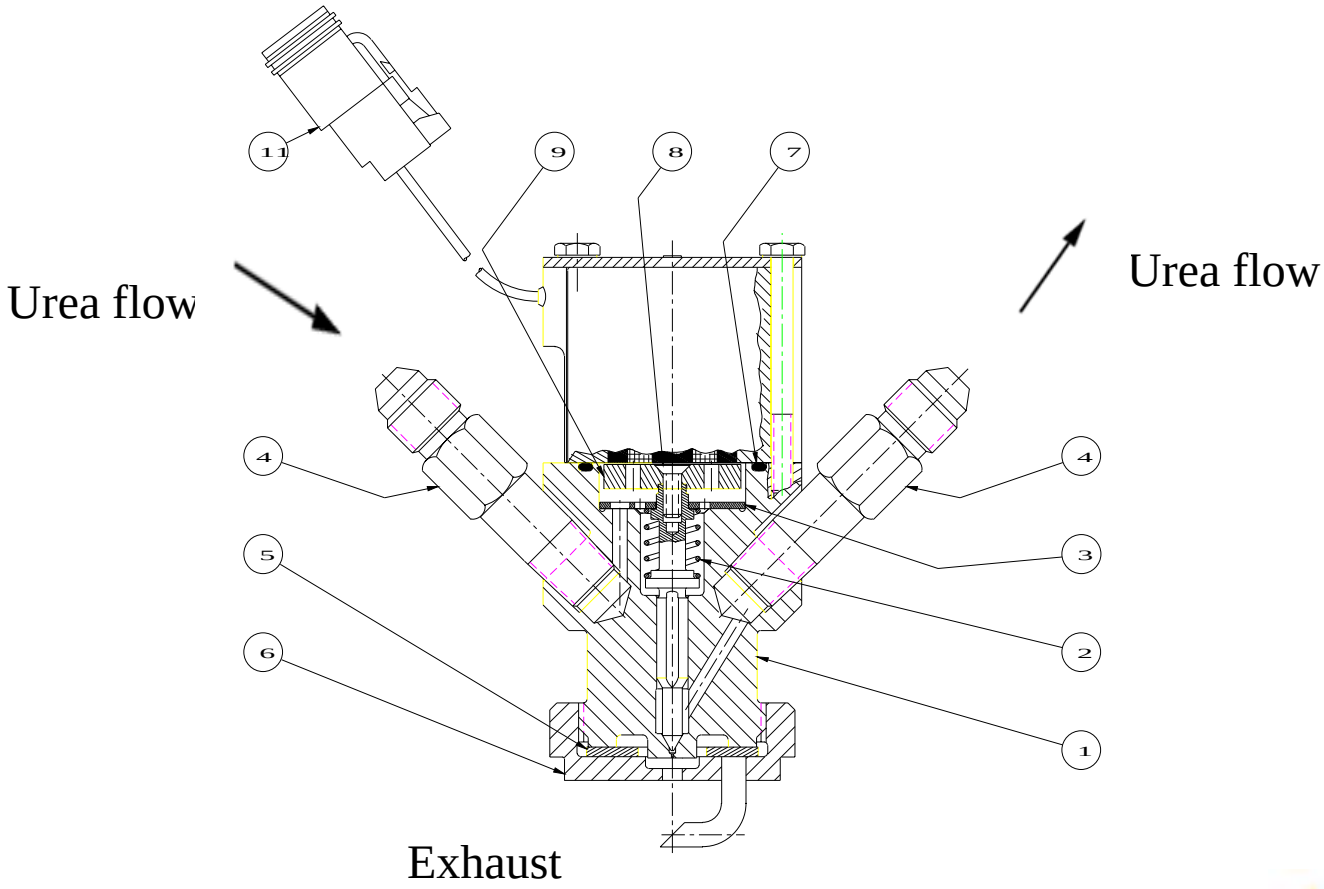
RJM Pulse Width Modulation (PWM)



10 Hz injector-There are 10 periods in a second. The injection quantity is proportional to the on time or pulse width of a given period.

Pulse width commonly refers to the injector on time which is shown above at 50% and 10%. The industry standard is to specify between 20% and 80% on-time to maintain accuracy & reliability

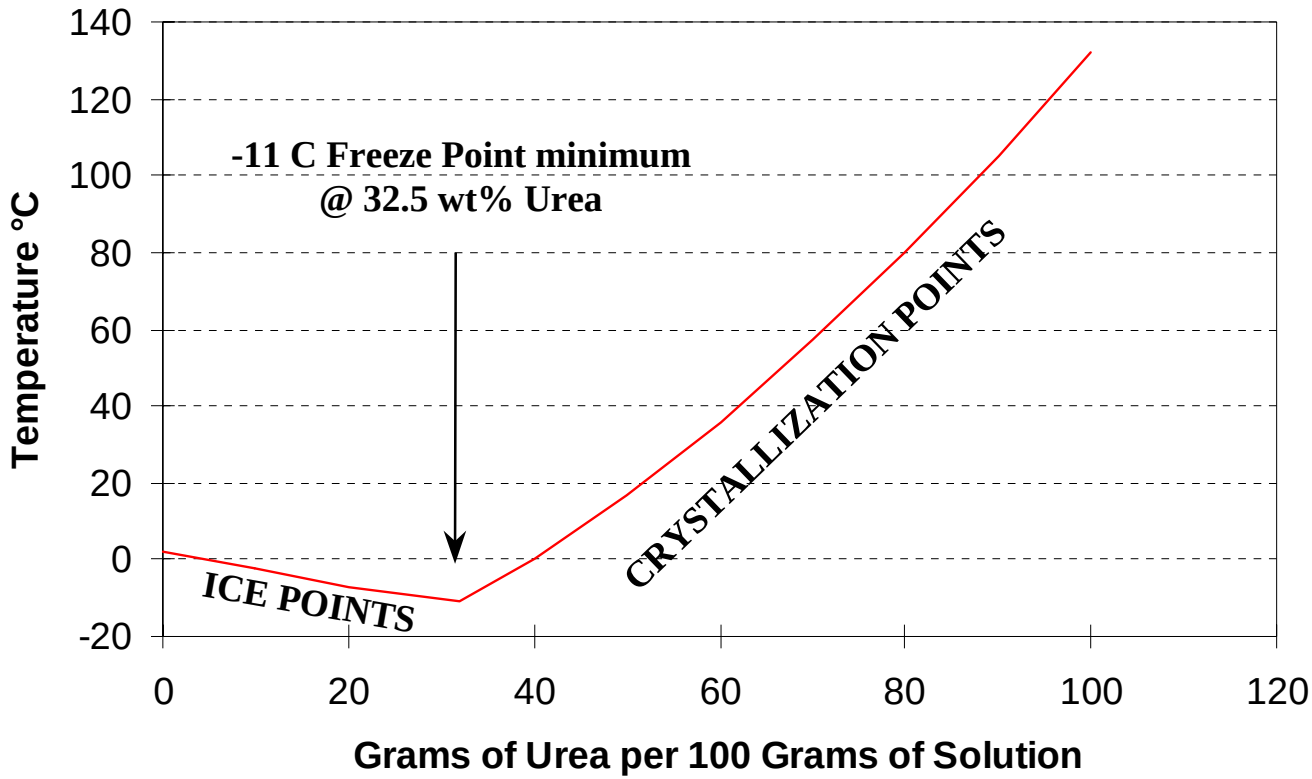
RJM Urea Injectors



RJM ARIS Technology Components & Options

- **Modules: Transfer, Delivery, Flow, Injector**
- **Injectors: 1,2,3 or 4 Injectors / Engine**
- **Panels: Injection Control Panel, Pump Control Panel**
- **Options:**
  - **Thermal Protection**
  - **Rate Indicator**
  - **Flow Totalizer**
  - **Multi-Engine Configurations**
  - **Tanks**

Crystallization and Ice Points vs. Urea Concentration



Conclusions

- **Urea SCR is a viable, proven technology**
- **It is the most cost effective solution for prime power applications**
- **Can be used to convert standby equipment to peak shaving**
- **Can be used to expand capacity or run hours for emissions limited sites**
- **Urea SCR can achieve >90% NOx reduction**
- **Urea SCR is cost effective**
- **It can pay for itself in fuel savings if injection timing is currently retarded**
- **Urea SCR is available today**