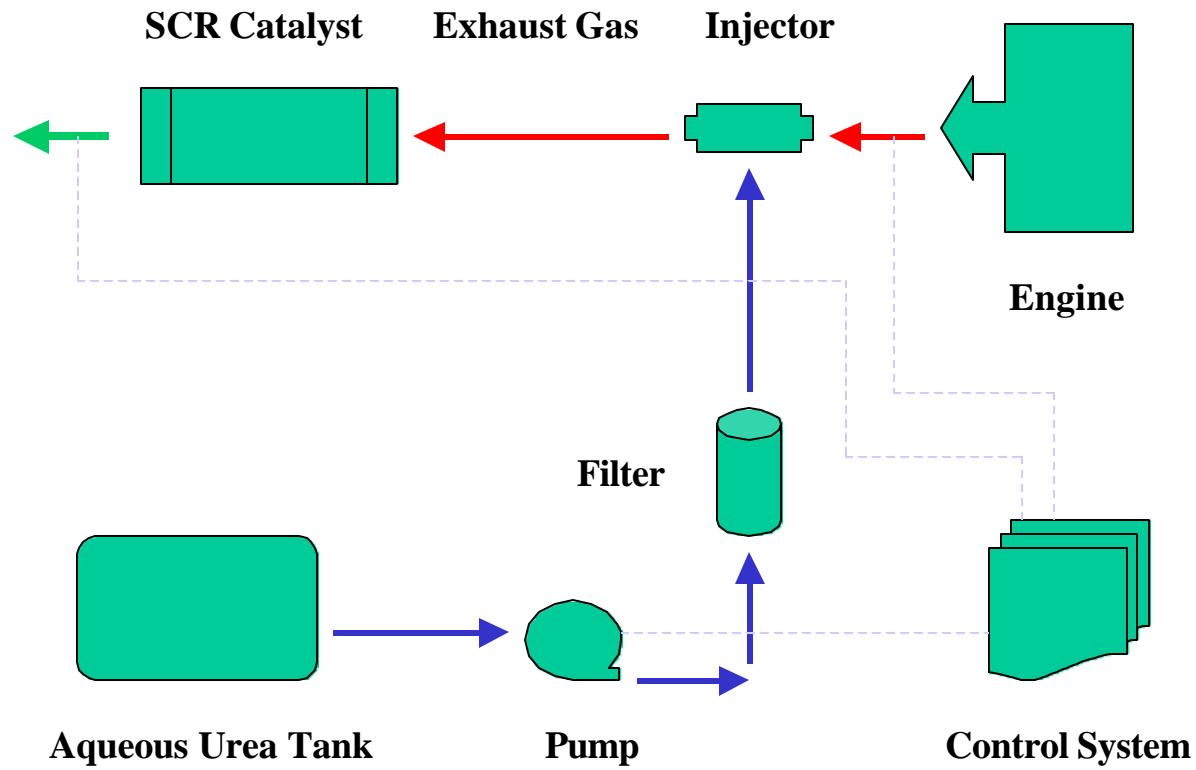


Urea-Ethanol-Water Solution Properties for Diesel NO_x Control Using Urea

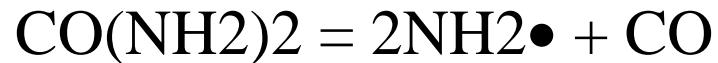
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Cummins Engine Company
DEER 2000
August 21 - 24, 2000**

Diesel Engine Urea SCR System

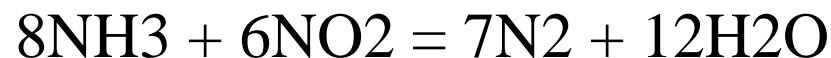
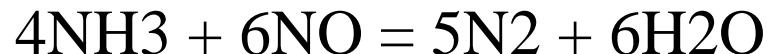
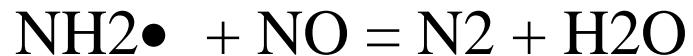


Urea SCR for NOx Reduction

- **Urea decomposition:**



- **NOx reduction:**



Applications of Urea SCR

- **Engine**
- **Power Generation**
- **Highway application**
- **Off-Road application**

Urea Injection Requirements

- **Inject sufficient urea to convert NOx at maximum conversion rate**
- **Avoid excessive urea to minimize NH₃ slip**
- **Control urea injection rate to match the NOx emission peaks and dips**

Properties Influencing Injection

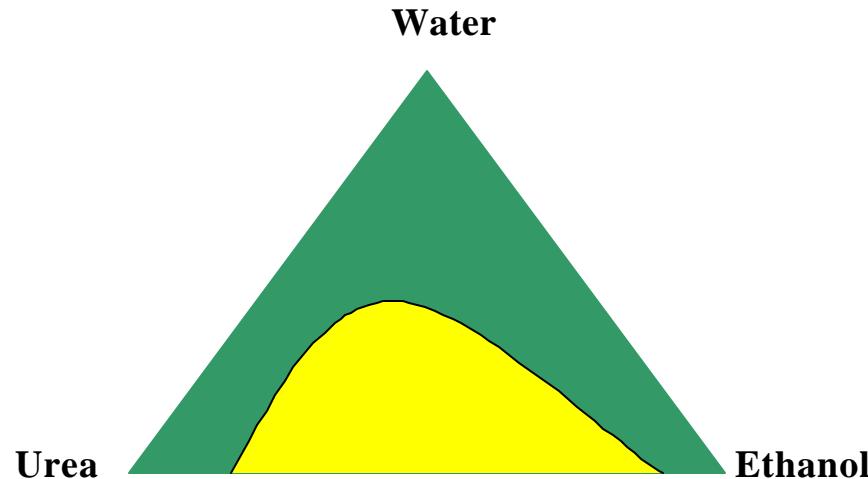
- **Density of urea solution**

Mass Flow of Urea =
Pump Intervals ×
Volume per interval ×
Density of urea solution ×
Urea concentration (wt.)

- **Uniform urea concentration (no precipitation and freezing in solution tank and injection line)**

Solution Experiments

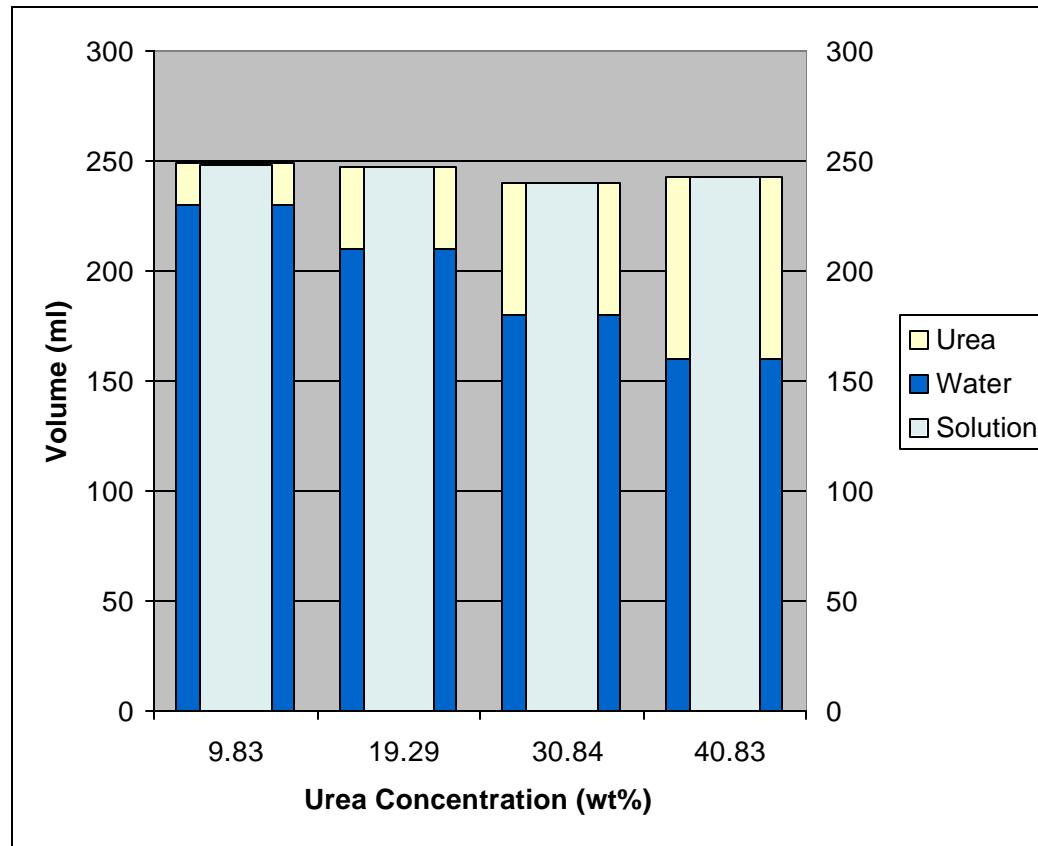
- **Binary solution: UREA / Water**
- **Ternary solution: UREA/Ethanol/Water**



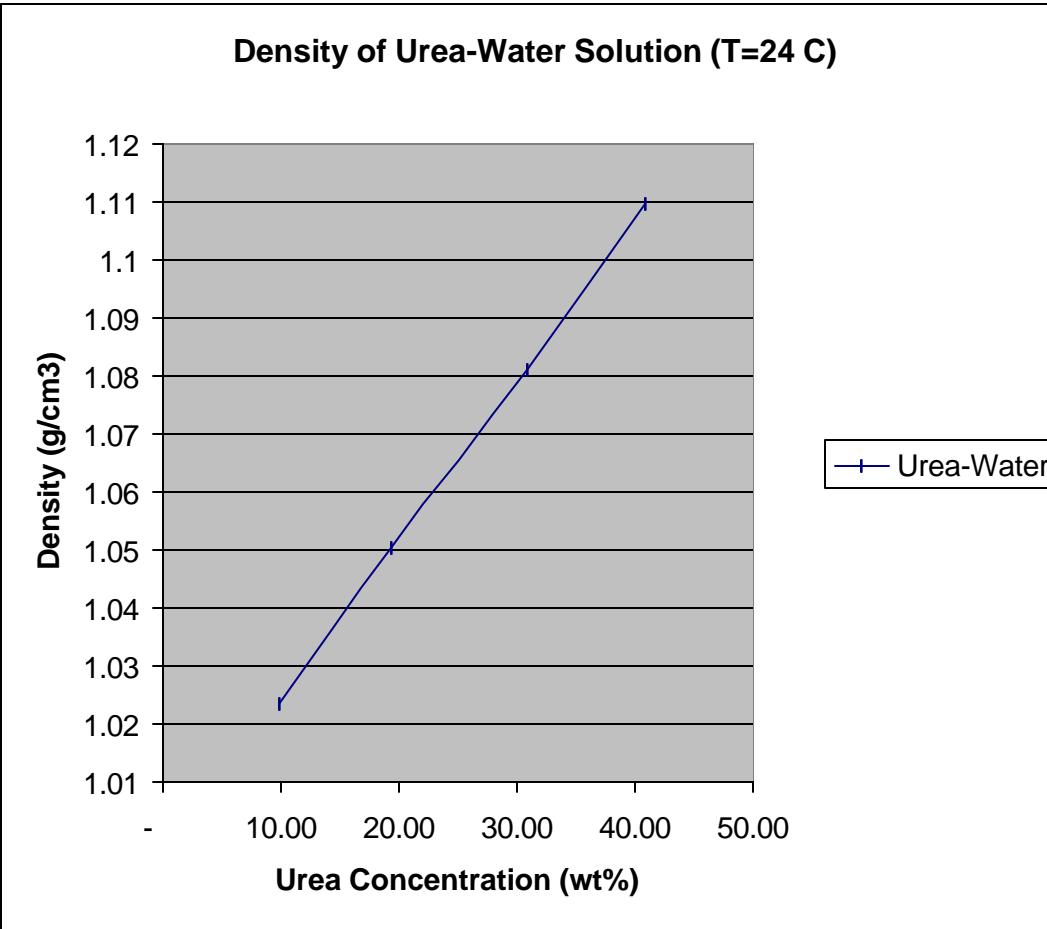
Urea Solution Samples

Sample ID	Water (ml)	Urea (g)	Wt.%
U-W-1	230.0	25.01	9.830
U-W-2	210.0	50.04	19.29
U-W-3	180.0	80.01	30.83
U-W-4	160.0	110.09	40.84

Binary Urea Solution Prop.



Density of Urea Solution

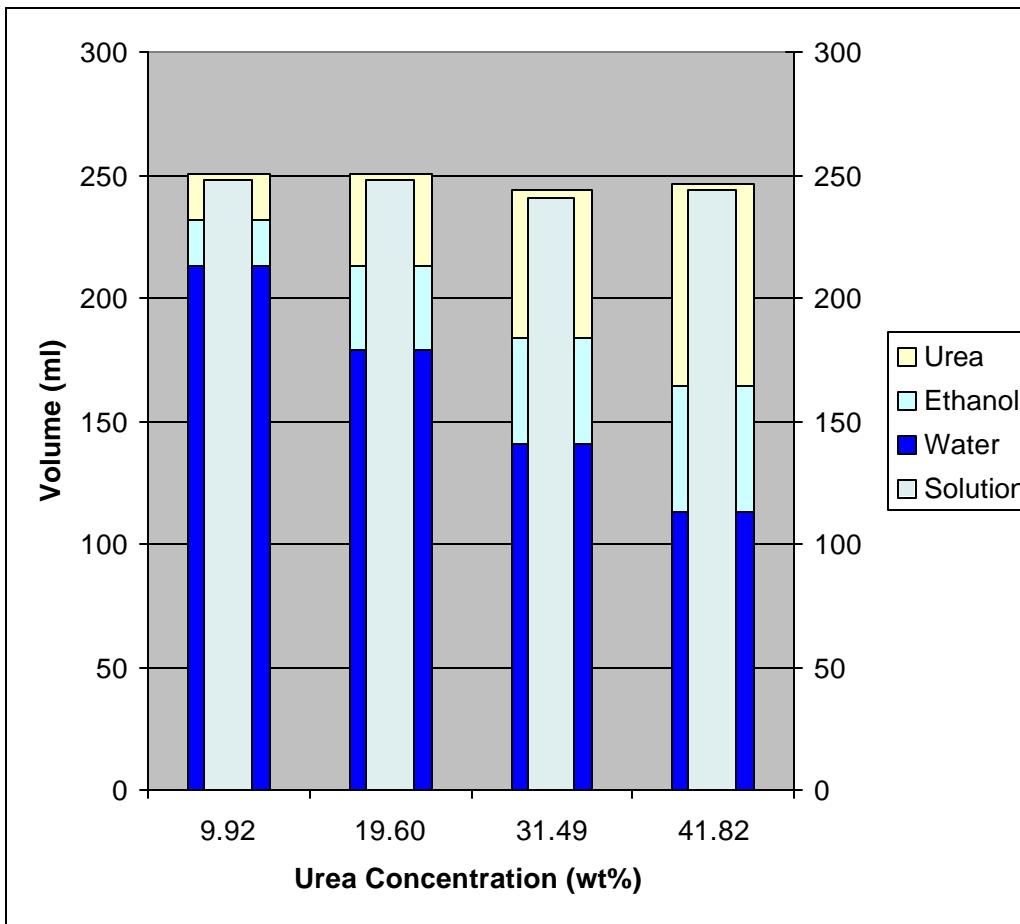


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Urea-Ethanol Solution Samples

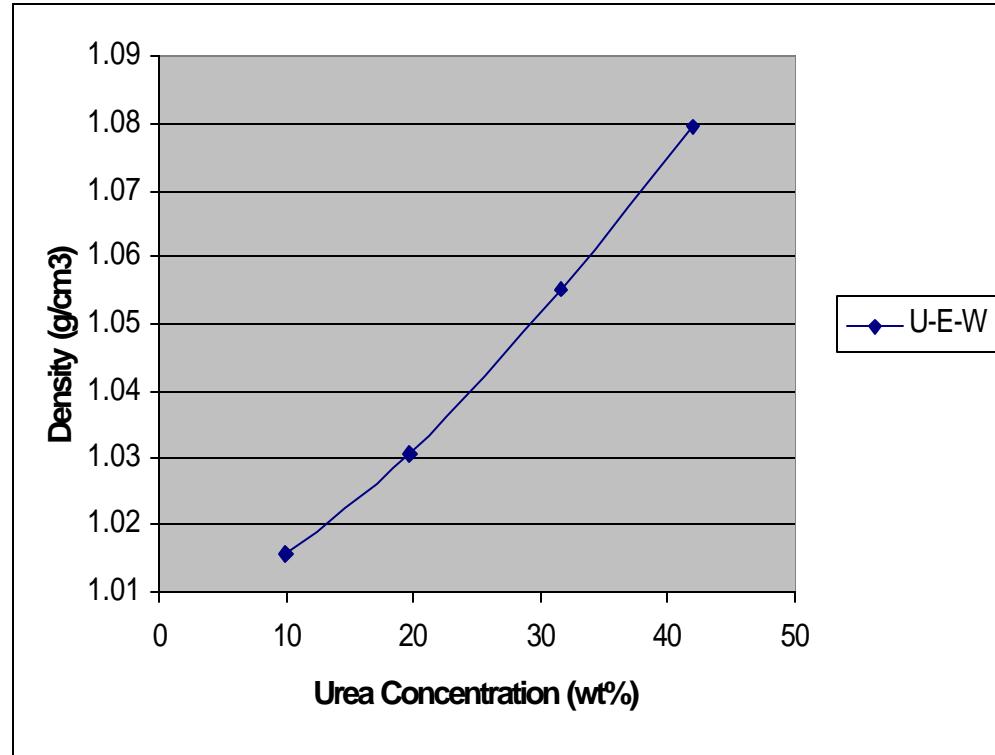
Sample ID	E (ml)	U (g)	U (wt.%)	E (wt.%)
E-U-W-1	18.4	25.03	9.92	5.76
E-U-W-2	33.6	50.02	19.60	10.39
E-U-W-3	43.2	80.02	31.49	13.41
E-U-W-4	51.2	110.02	41.82	15.36

Ternary Urea Solution Prop.



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Density of Urea-Ethanol Solution



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Solution Freeze Temperature

**Samples were immersed in a coolant bath
@ -12 °C**

Sample ID	Freezing Time (hour)		
	4	48	72
U-W-1	F	F	F
U-W-2	L	F	F
U-W-3	L	L	F
U-W-4	F	L*	F
U-E-W-1	L	F	F
U-E-W-2	L	L	L
U-E-W-3	L	L	L
U-E-W-4	L	F	F

Path Forward

- **Freezing point as function of urea and ethanol concentrations**
- **Other important solution thermodynamic properties: evaporation heat, boiling points, decomposition points, and reactivity with metals**
- **Urea solution vaporization, dissociation, and solidification phenomena**