

Analysis of White Solids Derived from Urea Solution in a Urea SCR System

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In urea SCR systems, white solid deposits tend to form within the exhaust pipe under low-temperature conditions. This phenomenon causes several issues, including a shortage of ammonia gas required for the reduction reaction at the SCR catalyst and an increase in pressure loss due to exhaust pipe blockage. Given domestic driving patterns characterized by low average vehicle speeds, it is essential to understand the formation behavior of these deposits under lower exhaust temperatures. To address this, this study collected white solids generated across various low-temperature exhaust fields and conducted thermochemical analyses to estimate their compositions and understand their formation and disappearance processes. The experimental collection utilized a multi-cylinder diesel engine with an exhaust flow rate of 25 g/s, where exhaust temperatures were varied from 150°C to 225°C in 25°C increments. The samples collected from the inner wall of the exhaust pipe at these settings are denoted as D150, D175, D200, and D225, respectively. To evaluate the mass loss characteristics upon reheating, 10 mg of each sample was analyzed using a thermogravimetric and differential thermal analyzer (TG-DTA) in an air environment at a heating rate of 10.0°C/min. Additionally, an organic elemental analysis was conducted to measure the mass fractions of carbon (C), hydrogen (H), and nitrogen (N) within the solids. Intermediate products, denoted as D'150 (heated to 245°C) and D'225 (heated to 275°C) based on the first-stage reaction temperatures, were also analyzed to track the chemical transitions. The TG-DTA results revealed a rapid mass decrease in two distinct stages for all samples: a low-temperature range of approximately 200–250°C and a high-temperature range of 350–400°C. Although about 90% of the white solid disappeared at 380°C across all samples, temperatures exceeding 500°C were required for complete elimination, indicating that it is difficult to achieve 100% disappearance under normal driving exhaust temperatures. Furthermore, differences in the disappearance process suggested that the composition of the white solids varies depending on the exhaust temperature they are exposed to during formation. To estimate the exact composition of the samples, it was assumed they consist solely of C, H, N, and O, allowing the mass fraction of oxygen to be calculated by subtracting the sum of the C, H, and N mass fractions from 100%. Based on this, the primary components were estimated as urea, biuret, cyanuric acid, and ammelide. The molar ratio b_j [mol%] was obtained from the measured mass ratio m_j [wt%] and the atomic weight M_j [g/mol] using the formula:

$$b_j = \frac{m_j}{M_j}$$

By letting x_i [wt%] be the target mass ratio of a component in the white solid and $a_{i,j}$ [mol%] be the atomic molar ratio of that component, the following determinant was established and solved to estimate the composition:

$$\sum_{i=1}^4 a_{i,j} x_i = b_j$$

As shown in Figure 1, the composition analysis demonstrated that while D150 was predominantly composed of urea, the formation of biuret became prominent in D200, and the contents of cyanuric acid and ammelide significantly increased in D225. This indicates that as the temperature rises, urea undergoes a deammoniation condensation reaction, causing the chemical composition to gradually transition from low-molecular-weight compounds to cyclic high-molecular-weight compounds. Ultimately, the study concluded that although the decomposition process varies depending on the temperature field in which the solid is formed, the temperature at which 90% of the solid disappears is consistently around 380°C. White solids formed at lower temperatures consist mainly of urea, biuret, cyanuric acid, and ammelide; as the exhaust temperature rises, the urea content decreases while cyanuric acid and ammelide increase, with biuret serving as an intermediate product.

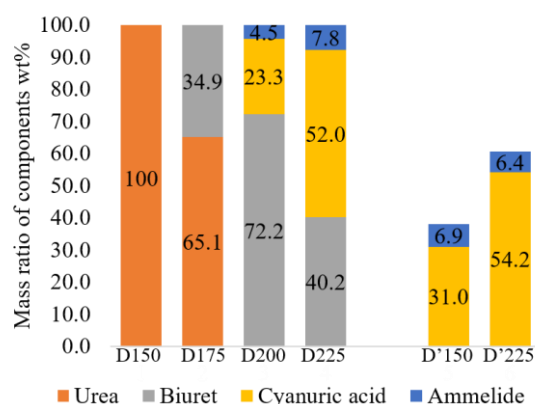


Fig.1 Numerical analysis results