Mechanical Engineering Dissertation Defense

Automated-Flow Integrated Urine Chemistry Analyzer for Acute Kidney Injury

School for Engineering of Matter, Transport and Energy

Piyush Hota

Advisors: Erica Forzani and Mary Laura Lind

Abstract

Acute kidney injury (AKI) remains a major clinical challenge in critical care, largely due to the lack of reliable, real-time biomarkers that can be monitored continuously at the bedside. Urine output is a critical diagnostic indicator; however, it is still predominantly measured manually and intermittently in hospital settings. Emerging urinary biomarkers, such as ammonia, have been hypothesized and experimentally shown to provide sensitive indicators of renal dysfunction. This work presents the design, development, and experimental validation of a novel, catheter-integrated system termed PCODA (Physical Chemical and Biological Dynamics Analyzer), aimed at enabling real-time monitoring of urine volume and ammonia concentration as early indicators of AKI.

The PCODA system integrates three core subsystems: (i) an automated urine flow meter (P-meter) for continuous volumetric measurement; (ii) a vacuum-driven mixing and transport module that extracts gaseous ammonia from urine through controlled chemical reactions; and (iii) a modular optical sensing module (CODA) employing threshold-responsive colorimetric sensing for reversible ammonia detection. System control is achieved through a model-based firmware architecture enabling parallel operation of multiple subsystems, while a custom MATLAB-based user interface facilitates real-time visualization, control, and data logging. Computational fluid dynamics simulations characterized pressure losses and mixing behavior within the reaction chamber, and experimental spectrophotometric analysis validated mixing efficiency and flow performance.

Experimental results demonstrate that the integrated PCODA system reliably detects dynamic changes in ammonia concentration in both aqueous standards and spiked urine samples. Calibration experiments using ammonium chloride solutions exhibited strong linearity, with coefficients of determination up to R2 = 0.97. Urine validation experiments confirmed the system's ability to track ammonia concentration trends, with good agreement against ion-selective electrode measurements. While variability increased across multiple urine samples, the system consistently captured concentration evolution, supporting its utility for trend monitoring.

This work establishes PCODA as a functional proof-of-concept for continuous urine-based biochemical monitoring. The results demonstrate the feasibility of integrating volumetric sensing, chemical extraction, and optical detection into a single automated platform, laying the groundwork for future refinement toward a clinically deployable AKI monitoring device.

February 13, 2026; 12:30pm; Health Futures Center (HFC) 169

Arizona State University