

Abstract

The invention delivers fully closed-loop citrate anticoagulation for continuous renal replacement therapy (CRRT) by embedding a modular sensor-pump ensemble into the TraceLoop-MX architecture. A post-filter ion-selective calcium sensor (505) and a systemic calcium sensor (506) stream potentiometric signals to a microcontroller that drives paired gear pumps: pre-filter trisodium-citrate (307) and post-filter calcium-chloride (308). Cascaded PID/model-predictive algorithms hold post-filter Ca^{2+} at 0.25-0.35 mmol L^{-1} while maintaining systemic Ca^{2+} at 1.0-1.2 mmol L^{-1} , automatically compensating for metabolic shifts and filter changes. On-board MEMS flow meters, EEPROM dose ledgers, hardware rate ceilings, and dual-bus hot-swap detection furnish single-fault tolerance; breach of critical thresholds (<0.20 or <0.80 mmol L^{-1}) halts citrate, boosts calcium, and can auto-pivot to heparin. Disposable keyed cartridges prevent misconnections and lock out on dose exhaustion, while tamper-resistant audit logs satisfy 21 CFR 820.70(i). The platform extends multi-loop ICU automation, reducing clotting events and clinician workload, and enabling longer filter life and overall safer regional anticoagulation therapy.