College of Engineering
UNIVERSITY OF GEORGIA

Capstone Design Project Abstract

Project Title: Bioartificial Liver Support Device

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Acute liver failure carries high mortality, and liver transplantation remains the only proven curative treatment. However, its widespread use is critically constrained by organ donor shortages and the time required to identify a sufficient match. This project proposes the conceptual design and bench-scale modeling of an extracorporeal bioartificial liver (BAL) support device intended to temporarily sustain hepatic function in patients allowing transplantation. The system centers on a two-compartment, flat-sheet membrane bioreactor in which filtered plasma flows co-currently alongside a porcine hepatocyte culture compartment, separated by a single polysulfone semi-permeable membrane. Co-current flow was selected over countercurrent and cross-flow configurations to produce stable, gradually declining concentration gradients that prevent hepatocyte overexposure to peak toxin fluxes while maintaining consistent solute driving forces along the reactor length. Upstream plasma separation minimizes viscosity and immune activation. The device is designed to replicate two critical hepatic functions, including ammonia detoxification via the urea cycle and drug metabolism via cytochrome P450-mediated lidocaine-to-MEGX conversion. Material balances were formulated across two control volumes, the plasma side and the hepatocyte side, for ammonia, urea, lidocaine, MEGX, media, and plasma, with membrane flux and Michaelis-Menten reaction kinetics incorporated as governing terms. Due to resource and biosafety constraints, a cell-free prototype approach was adopted, with literature-derived kinetic parameters serving as the basis for performance modeling. To simulate and validate system performance, a digital twin model was developed using discrete state functions and modular architecture, with each physical component of the BAL system, including the plasma separator, pump and control system, bioreactor, reactor sample, blood mixer, and output sampler, represented as an independent computational module. The governing differential equations for ammonia, urea, lidocaine, and MEGX are integrated numerically within the bioreactor module, with validation checks implemented at each module boundary to ensure outputs remain within physiologically and design-specified bound before being passed downstream. The digital twin was designed with accessibility and flexibility as central priorities. An intuitive graphical interface allows users to interact with the simulation without requiring direct manipulation of the underlying code, enabling clinicians, researchers, and engineers to run and interpret simulations with menial computational expertise. Key system parameters, including flow rates, membrane permeability, initial solute concentrations, hepatocyte cell density, and Michaelis-Menten kinetic constants, are exposed as adjustable inputs, allowing users to rapidly explore a wide range of operating conditions and patient-specific scenarios. Modular architecture further supports this flexibility. Individual component modules can be independently modified, substituted, or expanded without disrupting the broader simulation framework, facilitating iterative design refinement and sensitivity analysis. Together, these features position the digital twin not only as a validation tool for the current bench-scale model, but as a scalable platform for guiding future optimization and clinical translation of the BAL device.

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