A porous media approach for hemodialysis using hollow fiber membranes

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Hollow fiber dialyzers are widely used in the therapy of hemodialysis, which is a method for removing waste products such as creatinine and urea, as well as free water from the blood when the kidneys are in renal failure. This dialyzer utilizes a bundle of hollow fibers of ultrafiltration membrane to remove metabolic endproducts from the human body. Mass diffusion and untrafiltration processes through such membranes or dialyzer modules are most commonly described by experimental formulas, which estimates the volume and solute flows of nonelectrolyte solutions across membranes.

In this study, we present a rigorous mathematical development based on the volume-averaging theory, so as to obtain a complete set of the volume-averaged governing equations for fiber membrane dialyzer systems. In this model, three individual concentrations are assigned for the blood, dialysate and membrane. This three concentration equation model derived through the porous media approach for the first time can be used to account for the effect of mass transfer between the blood compartment and the dialysate phase through the membrane.

In order to verify the performance of the present model, a numerical approach has been proposed by utilizing a countercurrent hollow fiber dialyzer. The three-dimensional numerical computations have been conducted to capture individual concentration fields, namely, blood, dialysate and membrane phases within a hollow fiber dialyzer. Clearances for the Creatinine and Vitamin B12 obtained from present numerical simulations are compared against available experimental date. Subsequently, the effects of housing of countercurrent hollow fiber dialyzers on the mass transfer rate have been also investigated by utilizing several types of hollow fiber dialyzers. The present numerical methods based on the present membrane transport model can be useful for optimization of hollow fiber dialyzer systems.