Experimental characterization, numerical modeling and optimization of hollow fiber membrane modules for hemodialysis/hemodiafiltration

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Hemodialysis

Concept

Hemodialysis (and related, e,g, hemodiafiltration) is one of the few treatments which can allow a person with end-stage renal diseases to live even with impaired kidneys. It consists in circulating the patient's blood through a hollow fiber membrane filter called hemodialyzer, inside of which blood is purified of toxins and excess liquids. Patients receive the treatment 3 times a week for sessions of 3-4 hours: this generates approximately 300,000 tons of plastic waste and uses 156 billion liters of water, yearly[1-2]. For this reason, the cost of the treatment is high, and people in less developed countries struggle to afford it.

This research project aims at finding innovative ways to reduce the cost of the treatment and increase its efficiency. Furthermore, the use of artificial intelligence (AI) is explored to address the possibility of creating a fast and accurate simulation tool of the hemodialysis process. This could help nephrologists deliver patient-specific treatments.

Scientific approach

The research goals are pursued primarily through the study of the fluid dynamics inside the hemodialyzer both with experimental and Computational Fluid Dynamics (CFD) techniques. First, a CFD model and a 1-D model have been developed. To make these models accurate, some of the parameters have been determined through experimental tests (e.g. Darcy permeability). With the models, then, an exploration on design improvements of the filter has been started. Some of the explored possibilities include the use of undulated fibers instead of the commercially used straight ones and the modification of the filter design to ease the removal of air bubbles. The integration of fouling effects in the models will be explored with tailored tests. Lastly, an AI model will be developed with the aim of reducing the time (i.e. computational resources) needed to obtain a CFD-level accurate result of the treatment efficiency, given the process parameters as input (blood flow rate, membrane area and others).

Research objectives

- Improve the mass transfer efficiency of the hollow fiber membrane hemodialysis filter
- Minimize the amount of membrane used while maintaining state-of-the-art performances
- Characterize fouling effects occurring during the treatment and include them in the models
- Create a dataset of CFD simulations to develop and train an artificial intelligence model of hemodialysis

[1] Connor et al., The carbon footprints of home and in-center maintenance hemodialysis in the United Kingdom, Hemodial. Int. 2011, 15(1):39-51.
[2] Connor et al., Clinical Transformation: The Key to Green Nephrology, Nephron Clin. Pract. 2010, 116:c200–c206

What to improve?

Hemodialyzer

$↓ Cost

Effectiveness (time, environmental impact, etc.)

? Suggestions from clinicians

Collaboration with nephrologists

Final aim: Optimization

How?

Experiments → Model parameters + Fouling effects

Mathematical modeling & simulations → CFD simulations

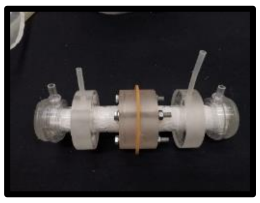
Model parameters → CFD simulations

CFD simulations → AI model

CFD simulations → Optimized design!

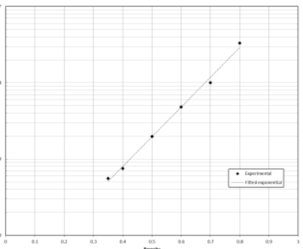
Details about the activities

1)



Custom module

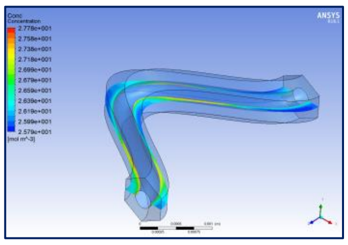
Experimental setup



Darcy permeability vs porosity

2)

Straight fibers → Undulated fibers ? →



CFD model

3)

Data → Python → AI model

Python