MULTI-OBJECTIVE OPTIMIZATION OF HOLLOW FIBER MEMBRANES ARRANGEMENT USING MODIFIED ENHANCED JAYA ALGORITHM

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Introduction

Recently extracorporeal membrane oxygenators (ECMO) have been widely used in critical care situations, especially for patients with dysfunctional hearts and lungs. Gas permeable membranes are this circuit's main component, and mass transfer generally has been done by increasing the fibers and module size. Thrombosis and hemolysis are the most critical complications during ECMO, which are associated with high patient mortality [1].

This study presents the optimization of the fiber membranes arrangement using a modified enhanced Jaya algorithm which is the combination of modified Jaya [2] and Enhanced Jaya algorithm [3].

Methods

In Lukitsch's study [4], the radial velocity fraction around the fibers is obtained at almost 1, indicating that the flow will be primarily radial around the fibers. So, 2D models with 24 fibers were investigated for fiber arrangement optimization. Three parameters have been considered in fiber arrangements: 1) Angle, 2) Diameter, and 3) distance-to-diameter ratio.

To completely understand each parameter's effect, 120 simulations have been done (100 for model identification and 20 for model verification). The 120 cases above were generated using a uniform random distribution function considering the angle of 30 to 60 degrees, the diameter of 300 to 700 μm, and the distance-to-diameter ratio of 1.25 to 2.25.

Three outputs and objectives have been considered in this study:

1) Membrane performance: The ratio of exchanged gas (CO_2) flow rate to the fluid flow rate.
2) Dead zone area ratio: The ratio of the area with a velocity of less than 2% of the inlet velocity to the total area.
3) Wall shear stress average

Each objective has been modeled with a linear polynomial function. Inputs of the models were considered dimensionless, so the Reynolds number was used instead of the diameter. The models are considered as follows:

$$\text{Objective} = f\,(\text{Angle}^a, \text{Re}^b, L/D^c) \qquad (1)$$

A modified enhanced Jaya algorithm has been employed to find the best values for powers a, b, c, and the polynomial model degree (a maximum degree of 6 has been considered for each input). Also, a single objective function with the summation of normalized mentioned objectives with weights that indicate their importance has been considered as follows:

$$\text{Objective} = w_1\,Obj_1 + w_2\,Obj_2 + w_3\,Obj_3 \qquad (2)$$

Results

Based on the obtained models, the maximum mass performance of 28% is calculated with an angle of 30 degrees, a diameter of 300 μm, and a distance-to-diameter ratio of 1.25. The maximum wall shear stress of 3.26 Pa and the minimum dead zone area ratio of 0.57% are obtained with the same parameters. Also, the minimum wall shear stress average of 0.1555 Pa is calculated with an angle of 40 degrees, a diameter of 700 μm, and a distance-to-diameter ratio of 2.25. For a better understanding and comparison of the objectives, the Pareto optimal solution, along with dominated points, is shown in Fig 1.

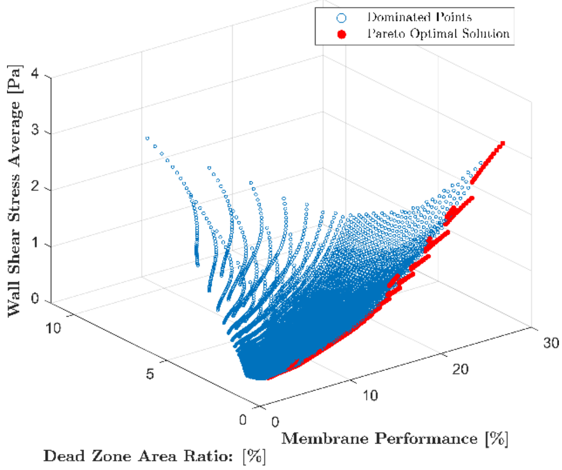

Figure 1: Pareto optimal solution graph

Discussion

As shown in Fig 1, increasing membrane performance results in decreasing the dead zone area ratio and increasing the wall shear stress average. So, based on the importance of each objective, the best arrangement will be obtained. For example, considering the equal weight result in membrane performance of 22.06%, dead zone area ratio of 0.64%, and wall shear stress average of 1.95 Pa with an angle of 30 degrees, a diameter of 300 μm, and a distance-to-diameter ratio of 1.35.

References

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