362e Minimization of Cell Migration between Flowing Blood and Concurrent Miscible Layers in a Microfluidic Environment

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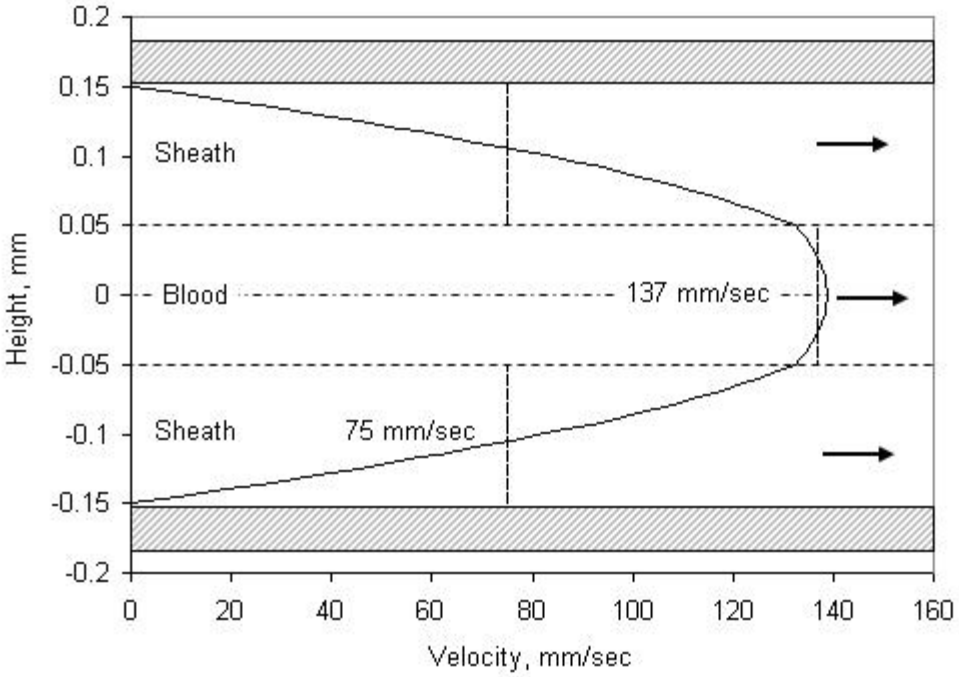
Current dialysis treatment requires several hours per week of patient time at a treatment facility, induces a high-amplitude cyclic level of water and toxins in the patient's body, and generates discomfort during treatment due to the required pressure and rate of blood flow. Current treatment entails pumping blood through a membrane filter to remove water and returning the blood to the body over a 3-4 hour treatment 3 times per week. The filters tend to lose permeability over time, and the large surface interface provokes a large set of chemical reactions with blood components. The possibility of treating a patient's blood more steadily and outside of the clinic is truly an intriguing and desirable concept. However, current efforts to extend membrane technology to longer periods of dialysis, outside of the clinic, encounter two difficulties: they require intermittent blood access which is painful, difficult, and potentially dangerous, and most systems closely follow clinical devices presenting practical problems and inviting decreased efficiency due to membrane fouling

We have proposed a wearable, indirect dialysis system that is permanently connected to the circulation. It employs diffusion between miscible fluids in direct contact to transfer water and toxins from the blood into a re-circulating "sheathing" fluid. The cell-free sheath fluid is then dialyzed and ultrafiltered to remove solutes and water before being returned to contact with the blood stream. The most important factor, by far, in such a system is preventing blood cells from entering the sheath fluid. Past research shows the tendency for such cells to migrate to the center of a flowing stream, and it is believed that blood cells can be retained with proper system design and operation. The nominal design of the current experimental device has a blood channel of 100 microns thick flowing between two identical streams of sheath fluid also each of 100 microns thickness (figure 1). Equilibrium of the contacted phases is dependent upon the diffusion coefficient of water in blood and the sheath fluid and is on the order of seconds for small molecules (water, ions, sugars etc.). The transient diffusion equation between static fluids, originally obtained by Boltzmann, yields a solution that closely follows a finite difference representation of the exchange.

We have used a combination of computational fluid dynamic simulations (Fluent) and experimental analysis to show: (1) that red blood cells should remain in the blood stream in high proportion; and (2) the effect of the design of "diverters" that converge and then separate the side and center streams of the contact region, 3) that cell-free fluid can be removed from a cell-bearing stream in such a system. However, very small numbers of cells affect performance of the indirect dialyzer and dictate how often the secondary stream must be displaced back into the bloodstream to avoid unacceptable buildup of cells near the membrane. We are measuring cell migration rates by obtaining cell counts in the recirculating sheath fluid as a function of time. These experiments use a Coulter counter to tally individual cells as they pass through a small orifice. Results will be reported and compared with the simulations. The use of this system to measure cellular and molecular diffusion rates in flowing blood will also be described.

Figure1: Cross-section of blood flowing at a mean velocity of 137 mm/sec, sandwiched between two layers of sheath fluid, each flowing at a mean velocity of 75 mm/sec. Each layer is flowing from left to right. Each layer is 100 microns (0.1 mm) thick. The blood layer is isolated from wall contact by the layers of moving sheath fluid and experiences a very low rate of shear, evidenced by its very flat velocity profile.


0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
Height, mm
Sheath
Blood
137 mm/sec
Sheath
75 mm/sec
0
20
40
60
80
100
120
140
160
Velocity, mm/sec