A constitutive rheological model for agglomerating blood derived from nonequilibrium thermodynamics

Many cardiovascular diseases leading to severe pathological conditions or even death are often associated with unusual hemodynamic behavior in the circulatory system. For example, intense red blood cell (RBC) aggregation (RBCs tend to aggregate in the presence of plasma proteins, forming structures known as rouleaux) and hyperviscosity syndrome are observed in many pathological conditions altering the transport properties of blood. Owens and coworkers considered blood as an ensemble of rouleaux, each rouleau modeled as an elastic dumbbell (Fig. 1). This model drew ideas from the temporary polymer network theory to account for rouleau aggregation and disaggregation. However, it has not been checked for thermodynamic consistency.

We derived a constitutive rheological model for human blood which accounts for the formation and dissociation of rouleaux using the generalized bracket formulation of non-equilibrium thermodynamics by following the variables employed by Owens and coworkers. The thermodynamic nature of our model allows for the reaction rates to depend on the instantaneous conformation of the rouleaux. The final set of evolution equations for the microstructure of each rouleau and the expression for the stress tensor turn out to be very similar to those of Owens and co-workers. However, by explicitly considering a mechanism for the formation and breakage of rouleaux, our model further provides expressions for the aggregation and disaggregation rates appearing in the final transport equations, which in the kinetic theory-based network model of Owens were absent and had to be specified separately. The predictions of our model compare reasonably well with available experimental data on the size distribution of rouleaux (Fig. 2).

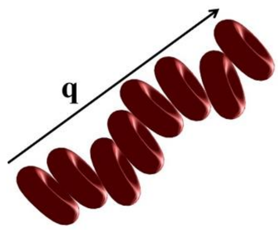

Fig. 1: Schematic representation of a rouleau and its corresponding end-to-end vector

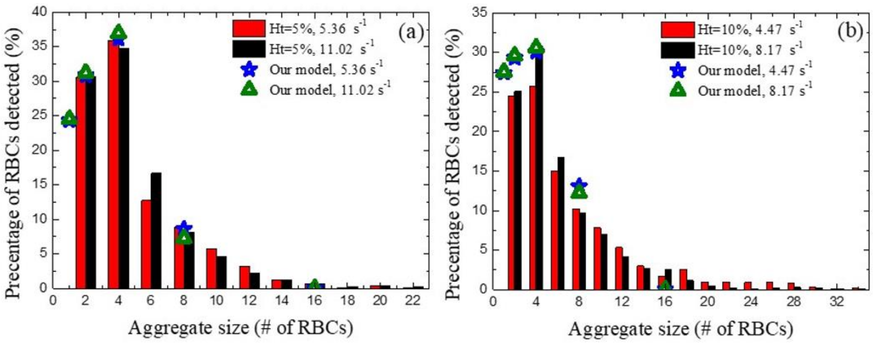

Fig. 2: We manage to predict the experimental data for the rouleau size distribution for blood samples under the following conditions: (a) Ht = 5 % and shear rate 5.36 and 11.02 s^{-1}, and (b) Ht = 10 % and shear rate =4.47 and 8.17 s^{-1}.

Reference

I. Ch. Tsimouri, **P. S. Stephanou**, and V. G. Mavrantzas, "A rheological model for blood from nonequilibrium thermodynamics: Model development", *Phys. Fluids*, 30, 030710 (**2018**).