ANALYSIS OF HUMAN BLOOD FLOW THROUGH NARROW TUBES

by

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CERTIFICATE

This is to certify that the thesis entitled "Analysis of Human Blood Flow Through Narrow Tubes" being submitted by Mr. Bharat Bhushan Gupta to the Indian Institute of Technology, Delhi, for the award of the Degree of Doctor of Philosophy in Applied Mechanics, is a record of bonafide research work carried out by him. He has worked under my guidance and has fulfilled the requirements for the submission of this thesis, which has reached the requisite standard.

The results contained in this thesis have not been submitted in part or in full, to any other University or Institute for the award of any Degree of Diploma.

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A C K N O W L E D G E M E N T S

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A B S T R A C T

The flow of human blood through tubes with diameter less than 500 microns has been investigated. In order to quantitatively study the anomalous behaviour of blood, simultaneous measurements of hematocrit reduction, i.e., the difference between reservoir hematocrit and average tube hematocrit, and apparent relative fluidity are made for red blood cell and hardened red blood cell suspensions, over a range of hematocrit (0 to 45%) and tube to cell diameter ratio (7 to 60).

Plasma has been found to be Newtonian in character and its viscosity to be same for all tubes and at all flow rates. The results are independent of the flow rate for the range of wall Shear Stresses investigated. The tube hematocrit is found to be always lower than the cup-mixing or feed hematocrit, the effect being more pronounced at small tube diameters. Increase in the cup-mixing hematocrit causes a reduction in the hematocrit defect. The apparent relative viscosity at any given hematocrit is found to decrease with decrease in tube diameter. The bulk property hypothesis, i.e., apparent relative viscosity being a function of tube hematocrit only, is an adequate approximation (maximum error 5%) for diameter ratios larger then 15, at all hematocrits. A comparison of hematocrit defect in RBC and HRBC suspensions shows that the hematocrit reduction is almost same, and the apparent relative

viscosity for the HRBC suspension is found to be larger at all hematocrits as compared to RBC suspension. This can be attributed to flexibility of RBC which plays an important role in reducing the apparent viscosity in narrow tubes.

Analytical and semi-emperical models are used for calculating the wall layer thickness and velocity profile with present experimental data. Most of the models failed at hematocrit more than 30% and the tube diameter less than 130 microns. It is seen that wall layer thickness increases as tube diameter is decreased and plug flow radius increases with increase in the hematocrit. At high hematocrits the extent of plug flow increases with decrease in tube size. The comparison with HRBC shows that wall layer thickness is slightly more and plug flow radius is less in the case of RBC suspension.

Flow of blood in capillaries, 4 to 10 microns in diameter, is analysed by Finite Element Method, using stream function formulation. Solution of Stokes flow problem is obtained by the principle of minimization of local viscous energy dissipation. Triangular plate bending element, with slope smoothening functions are used in discretization of the flow field and the solutions for unknown nodal variables are computed by Front Solution technique. A computer programme has been developed and implemented on ICL 1909 Computer. Fully developed and entry flow problems are analysed in order to test the convergence of the solution procedure.

Flow of neutrally buoyant spheres with sphere to tube diameter ratios, 0.5, 0.7, 0.9 and 0.95, has been analysed and results of additional pressure drop, wall shear stresses and stream lines are compared with other published results. It is seen that the disturbance due to presence of sphere is confined to a region of about one tube radius on both sides of sphere surface. The wall shear stresses are found to increase rapidly for diameter ratios more than 0.7. Effect of spacing between two spheres, shows that the recirculatory motion decreases with the decrease in spacing.

Actual deformed shapes of erythrocytes are incorporated in the analyses with undeformed cell to tube diameter ratio of 1.0, 1.3 and 2.0 . Results of shear stress distribution (both on capillary wall and cell surface), additional pressure drop and stream line patterns are presented. The maximum value of wall shear stress was found to occur just before the largest cross section of the deformed cell and the maximum value for surface shear stress was found at a position slightly down stream of the largest cross section. The spacing between two cell surfaces is varied between zero and 2 tube radius. It is seen that flow pattern between any two erythrocytes changes considerably with change in spacing. Apparent viscosity of blood at different hematocrits in capillaries of different diameters has also been calculated.

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