Journal of Special Topics

A3_8 If You Want Blood (You've Got It)

S. Sirovica, R. Ruston, C. May, T. Smith

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH.

November 30, 2011

Abstract

This paper explores the possibility of estimating the density of red blood cells in a one millimetre section of vein in a human adult by measuring the temperature of the blood. The results show that this novel method gives an answer that is four orders of magnitude too large and so would be inappropriate to use in practice.

Introduction

The density of red blood cells is typically found by the use of a haemocytometer and has a value ranging from 2 to 5 million red blood cells [1] per millimetre of length within the vein of an adult human. This paper will attempt to calculate the red blood cell density by treating a vein segment as a small pipe, with the thickness of the pipe being the lumen [2] that sheaths the vein. An approximate for the density value will be calculated via the thermal current equation and assuming that the temperature of blood is 310K [3].

I'm Hot Blooded Check It And See!

The vein is modelled as a pipe segment which is 1mm in length. The equation for the thermal current is given as [4];

$$Q = \frac{2\pi L k(\Delta T)}{\ln{(r_o/r_i)}}, \qquad (1)$$

where k=0.461W/mK is the conductivity of lumen tissue [5], L= 1mm is the length of the segment, ΔT =17K is the temperature difference between the blood and the temperature outside the vein (assumed to be 293K), r_i = 2mm is the radius inside the cavity [1], and r_o= 2.02mm is the radius outside the vein [1].

Substituting these values into equation (1) gives a value for the thermal current as 4.92J/s. If it is assumed that the flow of blood and hence its temperature is measured for a period of one second, then the aforementioned value is the energy being transferred through the outer radius of the vein to some arbitrary measuring device.

The kinetic energy (E_k), due to the bulk flow [6] of all of the blood in the body (5L [7])i.e. the volume V, travelling at a velocity v, of 3.5mm/s[8], is calculated;

$$E_k = \frac{\rho V v^2}{2}, \qquad (2)$$

where ρ is the density of blood [9] (1060kg/m^3). The bulk flow energy is used as the entire volume of blood will pass through this point over time and so the energy is taken for all of the blood. Equation (2) gives the bulk flow energy to be equal to 3.23 × 10^{-5} J. If this value were to be scaled to apply to the 1mm segment of blood then the value would be significantly smaller i.e. the bulk flow contribution is negligible.

It is assumed that the energy value of 4.92J is produced solely by the transfer of the binding energy (oxygen binding to haemoglobin) to the heating of the blood. The energy provided through collisions of individual red blood cells and intercellular heat transfer is not taken into account as it is beyond the scope of this paper.

According to the Bohr curve [10], the molecule haemoglobin which is present in every red blood cell (280 million per red blood cell [10]), is responsible for the transport of oxygen (by binding with it) and can carry a minimum of zero oxygen molecules and a maximum of four. For this case the median value of two bound molecules is used. The binding energy for one oxygen molecule is

0.6eV [11] or 9.6×10^{-20} J and hence the binding energy for two oxygen molecules is approximately 1.92×10^{-19} J. The total number of haemoglobin molecules in the blood segment (n_H), which each carry two oxygen molecules is given as

$$n_H = \frac{E_T}{E_0}, \qquad (3)$$

where E_T is the aforementioned heat energy (4.92J) and E_0 is the binding energy of the two oxygen molecules. This gives n_H equal to 2.56 × 10^{19}. With there being 280 million haemoglobin molecules per red blood cell [10], the number of red blood cells (RBC) in the 1mm segment is calculated by;

$$RBC\ number = \frac{n_H}{280 \times 10^6}, \qquad (4)$$

This gives a red blood cell density of 91.5 billion red blood cells per 1mm segment.

Conclusion

The results for the red blood cell density found by using the method as presented in this paper do not comply with currently accepted values. The values in this paper are four orders of magnitude greater than what has been found experimentally via a haemocytometer (between 3 and 5 million red blood cells per 1mm length [9]). This may be because the contribution of the binding of oxygen molecules has been assumed to be too great and that more care must be taken when considering other heat transfer methods i.e. intermolecular collisions (between red blood cells) and intercellular heat transfer. Lastly, this model is very simple and assumes that the red blood cell density increases to maintain the temperature. This is not the case and so it remains for a more accurate theoretical method of calculating red blood cell density to be formulated. Perhaps this will be investigated in a future paper.

References

[1]. F.H. Martini, *Fundamentals of Anatomy and Physiology*, (Benjamin Cummings, 2006), 7th edition, p.644.

[2]. F.H. Martini, *Fundamentals of Anatomy and Physiology*, (Benjamin Cummings, 2006), 7th edition, p.716.

[3]. F.H. Martini, *Fundamentals of Anatomy and Physiology*, (Benjamin Cummings, 2006), 7th edition, p.640.

[4]. http://www.engineersedge.com/heat_transfer/conduction_cylidrical_coor.htm (10/11/11).

[5]. http://sm7.net/upload/Detali%20mashin/bmt/The%20Biomedical%20Engineering%20Handbook%20-%202Ed%20%20Bronzino/ch098.pdf (30/11/11)

[6]. http://www.centennialofflight.gov/essay/Theories_of_Flight/Conservation/TH8.htm (16/11/11).

[7]. http://hypertextbook.com/facts/1998/LanNaLee.shtml (11/11/11).

[8]. Sugii, Y., Okuda, R., Velocity measurement of both red blood cells and plasma of *in vitro* blood flow. Institute of physics Publishing using high-speed micro PIV technique. Meas. Sci. Technol. **16** (2005) 1126–1130.

[9]. F.H. Martini, *Fundamentals of Anatomy and Physiology*, (Benjamin Cummings, 2006), 7th edition, p.643.

[10]. F.H. Martini, *Fundamentals of Anatomy and Physiology*, (Benjamin Cummings, 2006), 7th edition, p.645.

[11]. Chow, Y.W., Pietranico, R., Mukerji, A., *Studies of oxygen binding energy to hemoglobin molecule*. Biochemical and Biophysical Research Communications Volume **66**, Issue 4, 27 October 1975, Pages 1424-1431.

[12]. F.H. Martini, *Fundamentals of Anatomy and Physiology*, (Benjamin Cummings, 2006), 7th edition, p.644.