10. Nadler, N. J., Sarkar, S. K., Leblond, C. P., Endocrinology, 1962, v71, 120.

11. Nadler, N. J., Young, B. A., Leblond, C. P., Mitmaker, B., ibid., 1964, v74, 333.

12. Alexander, N. M., ibid., 1964, v74, 273.

13. Soodak, M., Maloof, F., Sato, G., Federation Proc., 1964, v23, 268.

Received November 23, 1964. P.S.E.B.M., 1965, v119.

Effect of Pneumococcus SIII Polysaccharide on Viscosity and Heat Transfer of Human Blood. (30173)

W. J. NUNGESTER
Department of Microbiology, University of Michigan, Ann Arbor

The problems related to the Anomalous Viscosity of Blood are well described by Bayliss as one of a compilation of papers on blood and other body fluids showing non-Newtonian rheological properties(1).

It is recognized that blood cells having varying degrees of aggregation might easily be disturbed by shear forces as blood is passed through a capillary tube under pressure of gravity forces, and thus affect the rheological properties of blood. Therefore, I tried several approaches to minimize these shear forces with the hope of developing a new technique for measuring the viscosity of blood. Included in these methods was a procedure to measure by a photo cell and record the movement of an 8 mm round aluminum disc balanced with a Du Nuoy tensiometer as the sample was oscillated on a vertical axis at varying speeds. The results were unsatisfactory. Finally it was decided to measure the time required for the transfer of heat from a water bath at 42° to a mercury thermometer through a 5 ml sample in a test tube and to determine the time required for the sample temperature to rise from 35° to 40°.

The importance of viscosity as affecting heat transfer in Newtonian liquid systems is well accepted. Less evidence exists as to the relationship between viscosity of non-Newtonian systems and heat transfer.

This paper contains data comparing the time required for samples to pass through an Ostwald viscosimeter at 36° and the time for the temperature of the sample (5 ml) to rise from 35° to 40° when the sample was placed in a water bath at 42°. Samples of oxalated (0.2%) human blood containing varying amounts of pneumococcus SIII polysaccharide were examined. Also samples of oxalated human plasma with different concentrations of SIII* were tested, as were varying concentrations, by weight, of glycerol in water. Glycerol solutions were used since this system has been extensively used in viscosity measurements.

Methods. It was recognized that heat transfer as measured in these experiments depended on (1) the temperature gradient between the water bath and the sample, (2) heat transfer from the water bath reservoir through a film of water on the external surface of the sample tube, (3) through the glass wall of the tube, (4) through a film of the sample on the inner surface of the sample tube, (5) agitation of the sample by external forces or convection currents, (6) heat transfer through a film of sample on the thermometer and (7) through the thermometer wall and the mercury in the thermometer. The variables related to the nature of the sample are listed as 4, 5 and 6 above. By attention to certain details, an effort was made to minimize variation in factors, 1, 2, 3 and 7. These experimental details are listed:

1. All glassware was rinsed with ammonium hydroxide, water, ethanol, ethyl ether and dried between tests on each sample.
2. The water was circulated in a bath with a baffle by means of a pump.
3. In the work presented 5 measurements were made on each sample by the heat trans-

* Obtained from Dr. Michael Heidelberger.

TABLE I. Changes in Rheology of Human Blood Produced by Pneumococcus SIII Polysaccharide as Measured by Ostwald Viscosimeter, Heat Transfer and Sedimentation of Blood Cells. Glycerol solutions for comparisons.

Sample	Time in seconds for sample: To rise from 35° to 40° in water bath at 42° (sec)	Time in seconds for sample: To pass thru Ostwald in water bath at 36° (sec)	"Relative viscosity"*: Heat transfer	"Relative viscosity"*: Ostwald method
Water	54.2 ± .4	59.1 ± .2	1.0	1.0
Blood alone	74.6 ± .6	412 ± 2.0	1.37	6.98
Blood + SIII .0125%	75.7 ±1.0	494 ± 4.3	1.40	8.37
.025%	76.8 ± .9	576 ±43.0	1.42	9.76
.050%	78.0 ± .5	707 ±91.0	1.44	11.98
.10%	77.3 ±1.2	847 ±65.0	1.43	14.35
.20%	77.3 ± .7	1296 ±19.0	1.43	21.97
H_2O	57.6 ± .4			
Plasma alone	63.2 ± .8	106.2 ± .4	1.11	1.80
Plasma + SIII .0125%	62.1 ± .8	167.3 ± .4	1.15	2.83
.12%	64.9 ± .8	304.2 ± .2	1.20	5.15
Glycerol 40%	67.1 ± .2	150.0 ± .5	1.24	2.54
50%	69.4 ± .6	198.0 ± .3	1.27	3.35
60%	75.4 ± .5	278.7 ± .9	1.39	4.70
70%	80.8 ± .3	398.1 ± 1.7	1.49	7.37
80%	87.5 ± .5	619.8 ± 1.1	1.60	10.50
90%	94.1 ± .3	1004.6 ± 4.9	1.74	17.05

SIII on sedimentation of human blood cells. Measured at 3 hr.

% SIII: 0 = 2 mm; .0125 = 6 mm; .025 = 7 mm; .050 = 22 mm; .10 = 41 mm; .20 = 38 mm.

* "Relative viscosity," the ratio of time for the sample to pass through the viscosimeter as compared to water or for the temperature of the sample or water to rise from 35° to 40° is used for convenience only. See *Conclusions.*

fer method and 4 with the Ostwald viscosimeter.

4. A plastic jig was turned out on a lathe to hold the thermometer in the same relative position within the one 16 mm test tube used for all tests.

5. The water bath was maintained at a constant depth so that the test tube holding the 5 ml sample was immersed 55 mm in water. This was sufficient to insure that the entire sample in the tube was below water level.

6. Water bath readings were made for each reading of heat transfer or viscosity by the Ostwald technique. Maximum bath temperature variations were 0.2°.

7. In the heat transfer tests the sample was precooled to 32° or 33° before placing in the water bath at 42°. The time for the temperature to rise from 35° to 40° a distance of 50 mm on the thermometer used was measured with a stop watch.

Results. From the data presented in Table I and plotted on Fig. 1 several conclusions are possible. 1. Pneumococcus SIII polysaccharide greatly affects the sedimentation rate of blood cells, as described by Nungester and Klein(2) and confirmed by Shedlovsky and Scudder(3). This effect of SIII was also obvious in the settling of blood cells as the sample passed through the Ostwald viscosimeter and to a lesser degree in the heat transfer tests. It is probable that the results of the heat transfer test were complicated by this sedimentating of cells particularly in samples containing over 0.050% of SIII.

2. The shape of the "viscosity" curves for the Newtonian system, glycerol in water were similar but not identical as determined by the Ostwald and heat transfer methods. However, "relative viscosities" as calculated were much greater for glycerol solutions when determined by the conventional Ostwald technique than by the heat transfer method.

3. The relative viscosity of oxalated blood by the Ostwald method approached that of

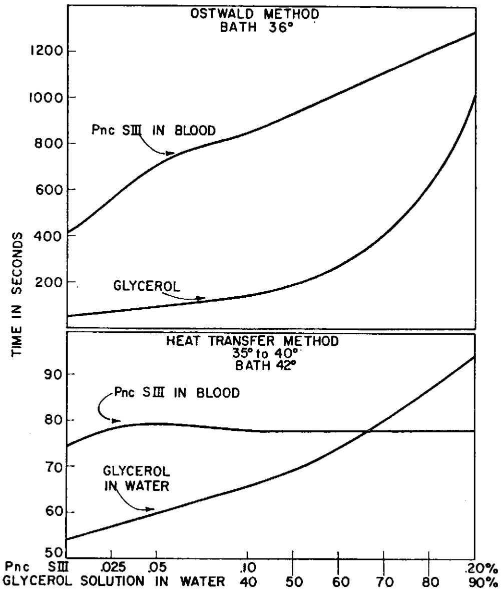

FIG. 1. Effect of pneumococcus SIII polysaccharide on time required for blood to pass through an Ostwald viscosimeter or for temperature of sample to rise from 35° to 40° in a 42° water bath. Glycerol in water for comparison.

70% glycerol and by the heat transfer technique approached that of 60% glycerol.

4. The relative viscosity of 0.10% pneumococcus SIII polysaccharide in oxalated blood was somewhat less than that of 90% glycerol by the Ostwald measurements and of 70% glycerol by heat transfer measurements.

5. Pneumococcus SIII polysaccharide (0.10%) in plasma increased its relative viscosity as measured by the Ostwald method to nearly twice that of plasma alone but affected its heat transfer much less. The "relative viscosity" as determined by the two methods was comparable to between 60% and 70% glycerol by the Ostwald method and to less than 40% glycerol by the heat transfer method.

Conclusions. The resistance of blood flow to cardiac effort in health and disease depends, in part, on the viscosity of blood, a non-Newtonian system. Measurements of viscosity of such systems are open to question. Measurement of the viscosity of blood, particularly in infectious diseases, presents still more problems due to the varying aggregation of blood cells sometimes referred to as "sludging." These aggregates are often broken up, in part at least, as blood is forced through small capillary tubes *in vitro*.

In an effort to obtain a measurement which might be related to viscosity, heat transfer of blood in a static situation was examined. No correlation was obtained between heat transfer of blood with all concentrations of the added pneumococcus SIII polysaccharide, and the time required to pass through an Ostwald viscosimeter. A decrease in heat transfer was noted with addition of 0.025% SIII but more of the polysaccharide did not decrease heat transfer although such additions greatly increased the time required to pass through the Ostwald apparatus. Therefore, heat transfer of blood-pneumococcus SIII systems and viscosity as measured by the Ostwald technique must be considered as probably dependent on other properties of blood not yet definable.

In contrast, a good correlation was obtained, as would be expected, between heat transfer and viscosity of varying concentrations of glycerol in water, a Newtonian system, as measured by the Ostwald viscosimeter.

It is hoped that this report may stimulate those qualified to design more sophisticated methods in the area of the rheology of blood to clarify the relationship between heat transfer and viscosity of non-Newtonian systems. Inasmuch as heat transfer from internal organs to the skin or lungs represents an important physiological mechanism in itself, such measurements assume independent significance.

1. Copley, A. L., Stainsby, G., Flow Properties of Blood and Other Biological Systems, Pergamon Press Ltd., Oxford, 1960.

2. Nungester, W. J., Klein, L. F., Proc. Soc. Exp. Biol. and Med., 1937, v36, 315.

3. Shedlovsky, T., Scudder, J., J. Exp. Med., 1942, v75, 119.

Received December 18, 1964. P.S.E.B.M., 1965, v119.