THE VISCOSITY OF HUMAN BLOOD AT HIGH HEMATOCRITS

bу

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by

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Abstract

The viscosity of human blood was measured in both plasma and saline suspensions with a Haake Rotovisco RV100 viscometer. Hematocrits of samples ranged from below physiologic to greater than 98, and shear rates ranged from 0.03 to 300 sec⁻¹. Even at high concentrations, blood retained its fluidity, with viscosity at high shear rates on the order of 50-100 cP. At high hematocrits, where cell-cell crowding is the dominant rheological mechanism, the type of suspending fluid had a negligible effect on the absolute viscosity, but led to an artificially higher relative viscosity for the saline suspensions. At lower hematocrits and lower shear rates, where aggregation and cell-protein interactions are important, the absolute viscosity of plasma suspensions was higher. The emulsive properties of the red cell, however, created a lower relative relative viscosity for plasma suspenisons than for cells in saline. The data was fit to the three-parameter Quemada equation, and empirical curves were developed to represent blood viscosity as a function of shear rate and hematocrit over the range of experimentation. Examination of the rheological parameters provided some indication as to the thresholds of influence for the important mechanisms of blood viscosity. Most noteworthy, it appears that at hematocrits of 65 to 80 and higher, the erythrocytes begin to behave as a continuous phase and blood viscosity becomes independent of the suspending fluid. The mathematical expressions are of interest in the design of clinical cross-flow membrane plasmapheresis devices, in which high concentrations are established near the filter.

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Christine and Ed have put up with me for a long time and will have to continue to do so. The chances are that they'll probably never read this, so I'll admit that they have been better friends than I deserve.

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:

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Chapter 1

INTRODUCTION

The study of the viscosity of blood traces its roots back to the dawn of rheology, to the pioneering days of Poiseuille [1843], and with advances in scientific instrumentation reached its peak in the 1960s with the numerous works of Merrill, Cokelet, Dintenfass, Copley, Chien, and many others. In more recent times, attention has turned to the microscopic phenomena underlying the observed physical behavior, such as the properties of the red cell membrane and the mechanisms of the cell-cell and cell-fluid interactions [Skalak et al., 1981a and 1981b; Secomb et al., 1983a and 1983b]. Despite the complex rheological nature of blood suspensions, they in many ways are an ideal system for the study of non-Newtonian fluid mechanics: The particles are well-defined and almost identical to one another, they deform in a well-characterized manner, and the extent of their aggregation and deformation can be controlled through the system properties. The fluid-like nature of the erythrocytes and their aggregability give blood suspensions properties similar to emulsions and polymers.

Since most blood viscosity work has been carried out with an eye toward understanding phyisological and clinical-pathological conditions, the vast majority of data exists at cell concentrations around 40-50 volume per cent. A limited amount of data for concentrated (>80%) suspensions exists (see Chapter 2) which was gathered primarily as a means of assessing properties of the red cell, but which also had applications to the pathophysiological effects of polycythemia, where hematocrits of up to 80 to 85 per cent may be recorded at high altitudes [Harris and Kellermeyer, 1970].

Recent research on extracorporal blood treatment has provided a new incentive for a greater understanding of blood viscosity in concentrated suspensions. An analysis of the ultrafiltrate flux and blood flow characteristics of cross-flow membrane plasmapheresis devices has led to conclusions that the local cell concentration near the filter is at least 95% and may be up to or greater than 98% [Zydney and Colton, 1982; Zydney, 1985]. In order to generate accurate expressions for the mass and momentum profiles, it is necessary to expand the present data base at high hematocrits and to develop a means for representing blood viscosity as a function of both hematocrit and shear rate over the broadest possible range of applicability.

The scope of this thesis, then, will be to present systematic work on blood and red cell suspension viscosity as a function of hematocrit with particular emphasis on hematocrits above 90 and shear rates in the region of interest for plasmapheresis (50-500 sec⁻¹). The data will then be fitted to mathematical models from the literature and combined with empirical formulations of the relevent parameters in order to derive an expression that will provide general usage. By examination of the parameter variation with hematocrit, an assessment of the microscopic behavior of red cell rheology can be made.

Chapter 2

BACKGROUND

2.1 Composition of Blood and Structure of the Red Blood Cell

Blood is composed of the corpuscles--erythrocytes (red blood cell, RBC), leukocytes (white blood cells, WBC), and platelets--suspended in a fluid medium, the plasma. Erythrocytes in normal human blood make up greater than 99 per cent of the corpuscular volume, outnumbering leukocytes by 500-1000 to 1 and platelets by approximately 20 to 1. Therefore, the cellular contributions to the physical characteristics of blood come almost exclusively from the red cells.

By weight, the plasma is 90 per cent water, 7 per cent proteins, 1 per cent inorganic salts and 2 per cent low molecular weight organic solutes. The plasma proteins are principally albumin (4.5 gm.%, mol. wt. = 69,000), globulins (2.5 gm.%, mol. wt. = 35,000 to 1,000,000), and fibrinogen (0.3 gm. %, mol. wt. = 330,000).

The red blood cell under normal conditions is typically a biconcave disk 6-9 μ m in diameter, 1 μ m thick in the center and increasing to 2-2.5 μ m at the periphery. The average cell volume is 90 μ m³ and the surface area is about 140 μ m².

The red cell membrane is believed to be a two-layer structure consisting of an inner, rigid shell of proteins covered by a more fluid phospholipid bilayer (see Figure 2-1). Choline phospholipids (phosphatidyl choline and sphingomyelin) are found primarily in the outer surface of the bilayer, while the inside half is composed mostly of amino phospholipids (phosphatidyl ethanolamine and phosphatidyl serine).

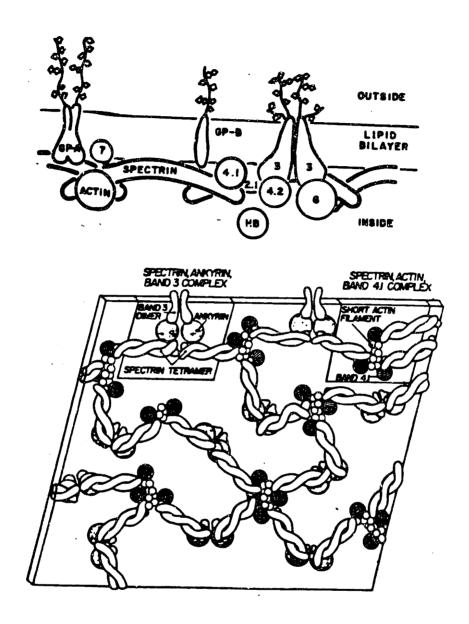


Figure 2-1: Schematic of the red cell membrane.

Top, cross-section illustrating lipid bilayer, integral membrane proteins, and cytoskeleton proteins. Bottom, structure of the membrane skeleton. From Lux, [1981].

Interspersed throughout the bilayer are molecules of glycolipids and unesterified cholesterol along with integral membrane proteins which penetrate or span the bilayer. Peripheral membrane proteins (spectrin, ankyrin, red cell actin, and band 4.1) bind to or are absorbed to the integral proteins and to each other, providing an internal microfibrillar "cytoskeleton" for the membrane. The exact nature of these connections is the subject of much current research but it appears that a complex of spectrin-actin-band 4.1 is responsible for the intraskeletal connections while a spectrin-ankyrin-band 3 complex provides the bonds to the lipid bilayer [Lux, 1981].

It has been proposed that the red cell membrane can be modeled as a solid-liquid composite [Evans and Hochmuth, 1977]. The solid cytoskeleton provides the membrane's resistance to shear deformation at constant surface area. It is also responsible for the elastic reversibility and the yield behavior of the membrane [Evans and Hochmuth, 1978]. The liquid-like lipid bilayer resists changes in membrane surface area. The ratio of the elastic modulus ($\equiv \frac{\Delta force}{\Delta dimension}$) for surface area changes to that for shear deformation at constant surface area is on the order of 10^4 - 10^5 [Waugh and Evans, 1976; Evans et al., 1976].

The cytoplasm of the erythrocyte is predominantly a 34 per cent hemoglobin-in-water solution. Adult hemoglobin (hemoglobin A) consists of four globin polypeptide chains each bound to a separate heme group. It has a molecular weight of 64,458. The main function of the red blood cell is to transport oxygen bound to the hemoglobin. The physical characteristics of blood and of the red blood cell are summarized in Appendix A.

Blood is stored in liquid state at 4 °C under mandate from the Food and Drug Administration. The time limits for classification of indated blood are also under federal regulations. For citrate phosphate dextrose, the time is 21 days; for citrate phophate dextrose-adenine, it is 35 days; and for adenine-saline, it is 42 days.

While stored, blood undergoes a variety of changes which include loss of platelets, granulocytes, plasma proteins, enzymes, and seepage of intracellular electrolytes [Sherwood, 1981]. Additionally, as cells begin to age, the content of membrane lipids decreases and the mean corpuscular hemoglobin concentration increasess. These factors increase the viscosity of erythrocytes with time [Erslev and Atwater, 1963; Usami et al., 1971].

2.2 Rheological Behavior of Blood

2.2.1 Rheological Properties of Plasma

The earliest studies of plasma viscosity indicated that it was a non-Newtonian fluid with shear-thinning properties [Copley et al., 1960; Wells and Merrill, 1961; Cerny et al., 1962], but subsequent data [Charm and Kurland, 1962; Copley and Scott-Blair, 1962; Merrill et al., 1963a] showed that indeed plasma did conform to Newtonian behavior, with a viscosity of 1.6 cP at 20 °C. The apparent shear rate dependence of the original measurements was attributed to interactions at the fluidair interface of cone-and-plate viscometers and of Couette viscometers without guard rings [Copley, 1971; Copley and King, 1972]. This will be addressed later in the section on viscometry (Section 3.3).

Serum, the fluid remaining after blood is allowed to clot in vitro, is essentially a defibrinogenated plasma solution. It shows none of the non-Newtonian behavior attributed to plasma's surface effects. Based on this observation, it has been suggested that the plasma proteins and principally fibrinogen may form an interlocking network which is irreversibly degraded at shear rates greater than 5 sec⁻¹ [Charm and Kurland, 1974]. Plasma does exhibit some additional non-Newtonian characteristics such as drag reduction in turbulent flow [Chmiel, 1974].

Using a sphere-in-sphere viscometer to minimize surface effects, Chmiel and Walitza [1980] have confirmed Newtonian behavior and have described the temperature dependence of plasma viscosity by

$$\mu(T) = \mu(T_0) \cdot \exp\left(\frac{420(T_0 - T)}{(T + 162)(T_0 - 162)}\right) \tag{2.1}$$

where T is the temperature of interest in degrees Kelvin, T_0 is the reference temperature at which the value $\mu(T_0)$ is known. This temperature dependence is much the same as that of water.

The effect of protein concentration on plasma viscosity has been looked at in some investigations, but has not beeen well characterized [Eastham and Morgan, 1965; Wells, 1965; Mayer, 1966; Mayer et al., 1966; Rand et al., 1970]. Serum typically has a viscosity 20% less than that of plasma. Bayliss [1952] proposes an equation for correlating plasma viscosity $\mu_{\rm p}$ to total protein concentration

$$\frac{\mu_p}{\mu_w} = \frac{1}{1 - b \cdot c_{\text{protein}}} \tag{2.2}$$

where $\mu_{\mathbf{w}}$ is water viscosity, b is a constant, and c_{protein} is the protein concentration in gms/100 ml. Eastham and Morgan [1965] found that increasing albumin concentration to 11 per cent increased viscosity from 1.6 to 2 centipoises at 25 °C while fibrinogen at 4 percent increased the viscosity to greater than 3 centipoises. MacKenzie and co-workers [1970] found a proportional increase in viscosity with an increase in globulin concentration. In summary, there appears to be an increase in viscosity with an increase in plasma proteins, although the viscosity is least sensitive to changes in albumin concentration. There is evidence that in some clinical pathological states, such as severe leukemia or macroglobulinemia, shear-thinning behavior of plasma may be present [Dintenfass, 1965b and 1966].

2.2.2 Rheological Behavior of Red Blood Cell Suspensions

Since the plasma is essentially Newtonian, and since leukocytes and platelets have a negligible effect on flow properties, the singularities of blood rheology stem from the behavior of the erythrocytes. At low shear rates the cell reversible form stacked primary aggregates, called rouleaux, which can in turn form larger secondary aggregates (see Figure 2-2). The rouleaux disintegrate with increasing shear. The mechanism behind the aggregation phenomenon is not yet understood, although electrostatic attraction, plasma surface tension, and molecular bridging between membranes have all been proposed [Fahraeus and Lindqvist, 1931; Casteneda et al., 1965; Merrill et al., 1966]. Experiments suggest that fibrinogen concentration is the most important determinant of cellular aggregation [Merrill, et al., 1963b and 1965b].

Skalak and co-workers [1977] have developed a general formulation for energy conservation in rouleau aggregation and disaggregation:

$$\frac{dW}{dt} = \frac{dE}{dt} + \frac{dK}{dt} + \frac{dD}{dt} - \gamma \frac{dA_c}{dt}$$
 (2.3)

where W is work done by external forces (surface and body); E is elastic stored energy (strain energy); K is kinetic energy; D is dissipated energy (including viscous energy of solids, fluids, and the process itself); and $-\gamma \frac{dA_c}{dt}$ is the rate of energy required to separate the contact surfaces, with γ being the surface energy and A_c the common contact area. For static equilibrium it can be shown that

$$\gamma = \frac{\partial E}{\partial A_c}. (2.4)$$

Using a known strain energy function, the surface energy can be estimated to be in the range of 10⁻⁴ dyne/cm [Skalak et al., 1981b]. There is presently no method of proceeding from equation (2.3) and deriving an expression for rouleau formation and disaggregation in dynamic states [Skalak et al., 1981a].

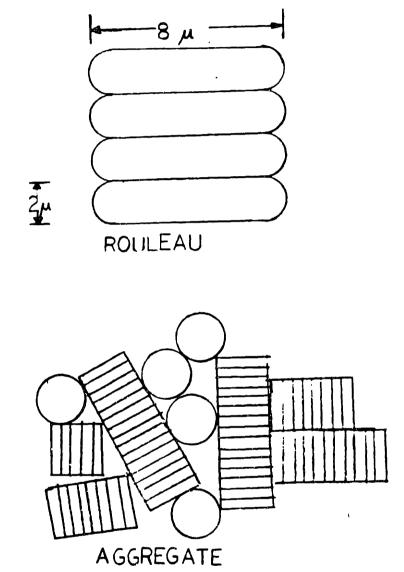


Figure 2-2: Red blood cell rouleau and aggregate.

At very high shear rates, on the order of 50-100 sec⁻¹, the cells undergo deformation and orient themselves with the flow in order to achieve the smallest possible effective volume. Since the cell membrane is highly resistant to changes in surface area but relatively receptive to shear deformation, they assume the shape of prolate ellipsoids. The membrane rotates cyclically around the cellular contents in a "tank-treading" motion, which establishes an internal velocity profile in the cytoplasm [Schmid-Schonbein et al., 1971]. The circulation of fluid inside the membrane has the effect of aligning the cell along the external streamlines and it also reduces the effective volume of the cell. The increase in deformation with shear for the red cell follows the theoretical development for the behavior of a fluid drop developed by Rumscheidt and Mason [1961b].

The effects of these structural changes on the viscosity are shown schematically in Figure 2-3, from Chien [1970], where three sets of data are represented. One curve is for normal blood in plasma, one is for normal blood cells in an 11% albumin solution and the third is for gluteraldehyde-hardened blood cells in 11% albumin.

The albumin solution lacks the proteins necessary for aggregate formation, principally fibrinogen. At low shear rates, therefore, the difference in viscosity between the plasma-suspended RBC and the albumin-suspended normal RBC is due to the effects of aggregation. Similarly, at high shear rates, the difference between the hardened RBC viscosity and the normal RBC viscosity represents deformational effects. The hardened RBC in albumin solution undergo no microstructural changes and thus viscosity is relatively constant with shear rate, with a degree of shear-thickening behavior common to suspensions of rigid particles or of polymers.

For suspensions of rigid particles, the viscosity of the suspension is directly proportional to the viscosity of the continuous phase. In other words, the relative

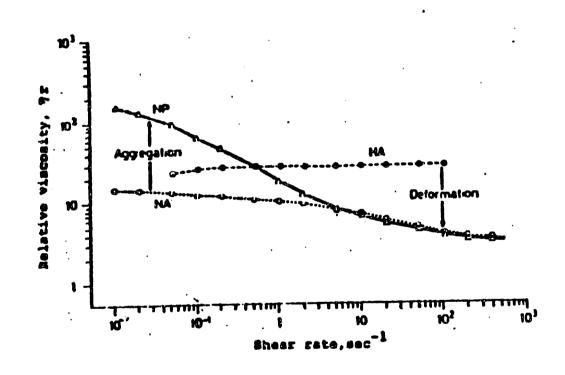


Figure 2-3: Effects of aggregation, deformation, and orientation of the red cell on viscosity.

H=45, η_f =1.2 cP. NP=normal cells in plasma. NA= normal cells in 11% albumin. HA=hardened cells in 11% albumin. From Chien, 1970.

viscosity η_r is independent of the viscosity of pure suspending fluid η_f , where $\eta_r \equiv \eta/\eta_f$. For blood suspensions, however, this is not the case: Experimental work has shown that η_r decreases with increasing η_f [Dintenfass, 1965a]. Blood in this respect is analogous to an emulsion, for which Taylor [1932] and Oldroyd [1953] have shown that, for dilute emulsions, the viscosity is a function of the ratio of the droplet viscosity to that of the non-miscible suspending fluid. Taylor's expression for the bulk viscosity of a dilute emulsion is

$$\eta_r = 1 + 2.5cT \tag{2.5}$$

where c is the volume fraction of the disperse phase and T is the Taylor coefficient equal to $\frac{\eta_i + 0.4\eta_f}{\eta_i + \eta_f}$, where η_i , the internal viscosity, is the viscosity of the pure disperse phase of the emulsion. This coefficient results from the internal velocity profile established in the fluid drop from the shear and normal forces of the continuous phase. The higher the viscosity of the suspending fluid relative to that of the droplet, the greater is the magnitude of the effect. For $\eta_i \approx 50\eta_f$, the droplets behave as rigid particles. For blood cells, the internal viscosity is not a true liquid viscosity but also includes effects from the red cell membrane on the cytoplasm, and therefore η_i has a shear rate dependence.

Secomb and co-workers [1983a] have developed a model for the tank-treading motion of the RBC membrane. This model is based on the following observations:

- 1. Cell membranes labeled with Heinz bodies or latex spheres show tanktreading motion in high-viscosity dextran solutions.
- 2. All areas of the membrane move with uniform frequency.
- 3. Tank-treading motion is seen in whole blood, but not in dilute RBC/plasma suspensions.

From observations (1) and (3), they conclude that the tank-treading motion results from physical interactions with other cells or with very viscous media. This

also supports the hypothesis of a shear-thinning internal viscosity.

The effects of anticoagulation have been characterized by Rosenblum [1968], who classifies anticoagulants into those which shrink the red cell, such as citrate and oxalate, and those that do not change cell size, such as acid-citrate dextrose (ACD). The former increase blood viscosity while the latter show no effect. Cokelet [1963] was also unable to find any effect of anticoagulation with ACD other than those resulting from dilution of the plasma proteins.

The effects of plasma osmolarity were studied by Meiselman et al. [1967] who found that cells in hypotonic plasma solutions had an increased hematocrit, a decreased viscosity, and an increased yield stress. Previously, Rand and Burton [1964] had found that cells washed with saline had much less rigid membranes in hypertonic saline solutions. This apparent contradiction in results has been related to the loss of membrane proteins and lipoproteins from cell washing [Meiselman et al., 1967].

2.3 Previous Experimental Work

2.3.1 Experimental Work on Blood Viscosity at Normal Hematocrits

The study of blood viscosity literally dates to the beginnings of viscometry itself. The French physician Jean Poiseuille, credited with the pioneering work on fluid flow through glass capillaries [1843], initially had addressed himself to the relationship of blood flow to pressure, temperature, and vessel diameter. It was only after encountering inconsistencies with blood, which he attributed to variations in blood composition, that he turned to water and other fluids.

Hagenbach [1860] first established the theoretical derivation of Poiseuille's law for laminar flow through a capillary, and first included the concept of viscosity:

$$\mu = \frac{\pi \Delta p}{8QL} R^4 \tag{2.6}$$

where Δp is the pressure difference along the capillary of length L and radius R, and Q is the volumetric flow rate of the fluid.

Attempts to correlate blood flow with this equation persisted through the remainder of the 19^{th} century [Ewald, 1877; Lewy, 1897] but systematic work did not begin until the early 20^{th} century with the work of duPre'Denning and Watson [1906], who studied blood anticoagulated with potassium oxalate in capillary viscometers and the effects of hematocrit, temperature, anticoagulant concentration, and the size of the capillary bore. Interestingly, they observed an increase in blood viscosity at diameters of 300 μ m or less.

Other investigations in the early 1900s followed a similar tack and include studies of blood of different animals [Burton-Opitz, 1906 and 1911; Welsh, 1911; Hess, 1911 and 1920; Trevan, 1918; Langstroth, 1919; Berczeller and Wastl, 1924]. Nygaard and co-workers [1935] studied the blood viscosities from H=14 to 58 and proposed a combination of a linear and a hyperbolic equation to model the hematocrit dependence.

Of significant importance is the work of Fahraeus and Lindqvist [1931], who showed that in capillaries of diameters less than 300 μ m, Poiseuille flow is not observed and the apparent viscosity of blood decreases as the tube diameter decreases, in contrast to the results of duPre'Denning and Watson. This phenomenon, known as the Fahraeus-Lindqvist effect, results from the tendency of red cells to migrate away from the vessel walls, establishing a cell-free layer of fluid around the flowing cells. This layer has a lubricating effect which grows more significant as the tube diameter decreases, resulting in detectable alterations in the bulk viscosity.

In the 1940s and 1950s activity in the field of blood rheology further increased [Copley et al., 1942; Moll, 1943; Riehl, 1943; Bingham and Roepke, 1944a and 1944bl, but it was not until the early 1960s that investigators were able to study blood at low rates of shear (less than 100 sec⁻¹), where its non-Newtonian behavior is evident. This became possible through the employment of cone-and-plate and concentric-cylinder (Couette) viscometers with advanced instrumentation, which were more suitable for this purpose than capillary viscometers. Dintenfass [1962a] claims the first report on the shear-thinning behavior of blood; that is, that the viscosity of blood reversibly decreases with increasing shear rate. (Dintenfass uses the term thixotropic throughout his work to describe this behavior, but in the classical sense thixotropy defines behavior under non-steady-state conditions: A thixotropic material is one which experiences a transient decrease in viscosity upon the application of a constant shear stress [Goodeve and Whitfield, 1938; Bird et al., 1960]. Dintenfass [1968a] argues that the difference between shear-thinning and thixotropy is only a question of time scale and instrumentation limits; nevertheless, the classical definitions will be retained in this work.)

Cokelet, Merrill, and co-workers conducted extensive studies into the low-shear rate behavior of blood [Cokelet, 1963; Cokelet et al., 1963, Merrill et al., 1963a and 1965a]. Typical data for normal blood is shown in Figure 2-4.

Figure 2-4 is a plot of the square root of shear stress (τ) versus the square root of shear strain rate (γ). Three regimes are noted: A region at high shear rates (greater than 100 sec⁻¹) governed by Newtonian behavior, a non-Newtonian region below 20 sec⁻¹ and a transition region in-between the two. The low shear rate range (down to 0.1 sec⁻¹) is correlated to a semiempirical equation first derived by Casson [1958] to describe printing ink rheology and later proposed by Reiner and Scott-Blair [1959] to be applicable to blood:

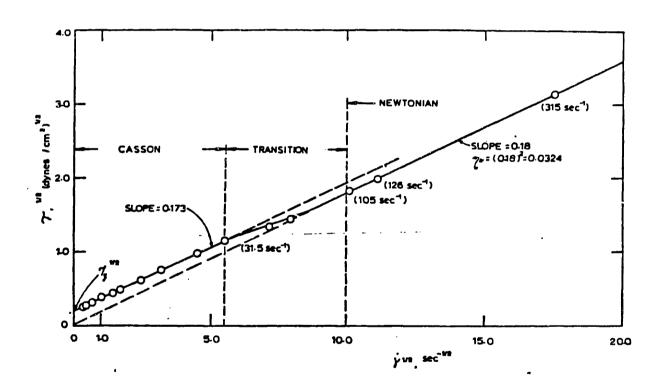


Figure 2-4: Casson plot for normal human blood. H=40, T=37 °C. τ_y \approx 0.04 dynes/cm². From Merrill, 1969.

$$\sqrt{\tau} = \sqrt{\tau_y} + \sqrt{\mu_N \gamma} \tag{2.7}$$

where τ_y is a yield shear stress and μ_N is the asymptotic Newtonian viscosity at high shear rates.

Values for τ_y have been obtained by a variety of experimental methods, all of which have the potential for introducing significant instrument artifact. These methods include extrapolation of Casson plots to zero shear rate [Cokelet et al., 1963; Merrill et al., 1966], torque decay [Merrill et al., 1965a], pressure decay [Merrill et al., 1965a], force on an oscillating plate [Benis and Lacoste, 1968], and sedimentation [Charm and Kurland, 1967]. The values for τ_y measured by these methods range from 0.003 to 0.20 dyne/cm².

Red cells in Ringer or isotonic saline solution or suspended in plasma suspensions lacking fibrinogen do not exhibit a yield shear stress [Cokelet, 1963; Merrill et al., 1963b and 1965c]. Addition of a slight amount of fibrinogen gives conformity to the Casson equation, and the magnitude of the yield stress varies with fibrinogen concentration [Merrill et al. 1963b, 1965c, 1966].

The existence of a yield shear stress for blood, and thus the validity of the Casson equation, is disputed by some researchers [Chien et al., 1970; Chmiel, 1974] who believe it is an artifact extrapolated from the limits of the instrumentation. Experiments conducted at shear rates from 0.1 to 5 x 10⁻³ sec⁻¹ using a wide gap Couette system showed significant deviation from the Casson equation which indicated the absence of a yield shear stress [Chmiel, 1974]. The questions about yield shear stress concern a no-flow situation of principally academic interest. They are of no concern at the shear rates of interest for plasmapheresis devices and require measurements out of the range of the instrumentation used here. The yield shear stress will not be considered at any length in this work.

2.3.2 Experimental Work on Blood Viscosity at High Hematocrits

As early as 1924, there were reports that the viscosity of packed cells was 8 to 90 times that of plasma [Berczeller and Wastl, 1924]. More recently, the viscosity of packed red cells became of interest when it was realized that blood does not behave as a suspension of rigid particles [Dintenfass, 1962b]. A 65% suspension of clay or microscopic glass spheres would have a viscosity 10 to 100 times that of blood at the same cell concentration.

There is a dearth of data on blood viscosity at high hematocrits. What little data that does exist shows a considerable variance in reported values, as plotted in Figure 2-5. Chien et al. [1966] have the most complete base of data to date on the variation of viscosity over a wide range of hematocrits and shear rates. Three types of blood preparations—whole blood, defibrinated blood, and Ringer-suspended cells—were measured over hematocrits ranging from 0 to 95. Their data is shown in Figures 2-6 to 2-8 fitted to fifth-order polynomial curves of the form,

$$\ln\left(\eta\right) = \sum_{i=0}^{5} a_{i} \cdot H^{i} \tag{2.8}$$

whose constants a_i are given in Table 2-I. At low hematocrits (H<5), Newtonian behavior is observed for all suspensions. Newtonian behavior persists up to H=15 when fibrinogen is absent and up to H=30 when all plasma proteins are absent. The viscosity differences between suspensions is the greatest at low shear rates, supporting the contention that protein-mediated aggregation dominates rheology at low shear rates. Viscosity decreases when plasma proteins are removed, but at high hematocrits, the differences between the suspensions become negligible as the volume of non-cellular medium vanishes.

The work of Chien et al. is probably the most referred-to source in the literature and their equations the most used for examining blood viscosity as it

Viscosity vs. Shear rate Literature data at high hematocrits

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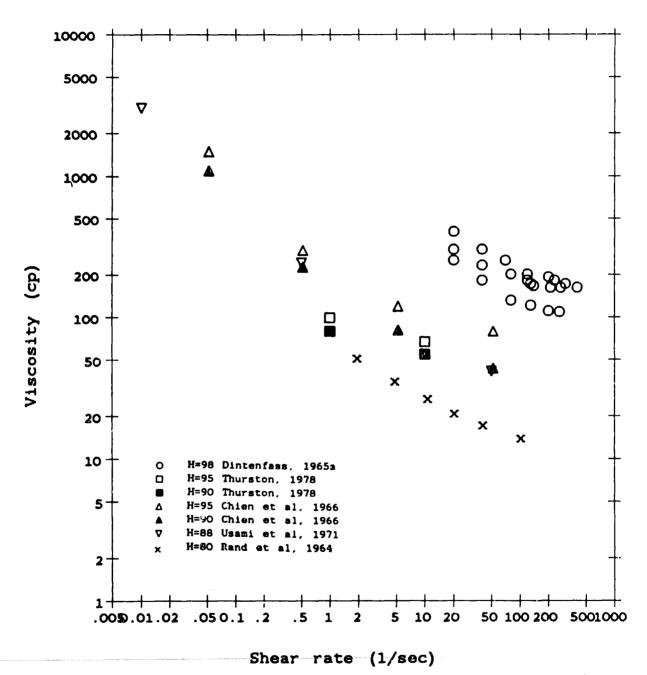


Figure 2-5: Literature data for blood viscosity at high hematocrits.

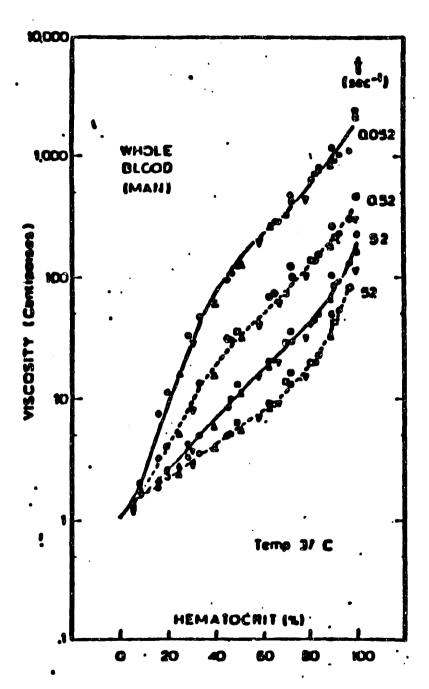


Figure 2-6: Data of Chien et al. [1966] for whole blood.

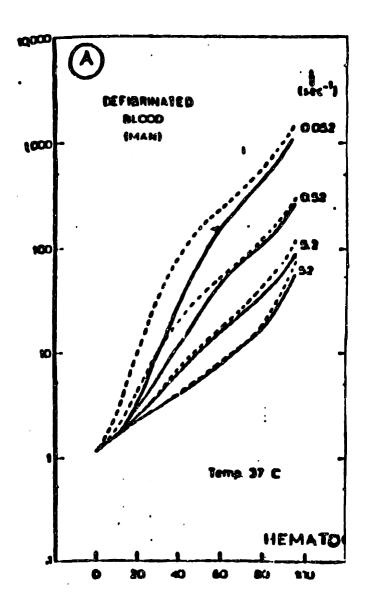


Figure 2-7: Data of Chien et al. [1966] for defibrinated blood.

Dashed lines represent whole blood curves.

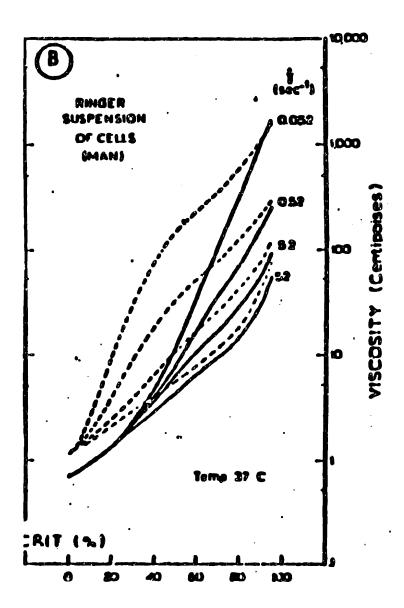


Figure 2-8: Data of Chien et al. [1966] for Ringer's suspenison.

Dashed lines represent whole blood curves.

Constants for polynomial fit of data of Chien et al, 1966.

Solution type/ Shear rate (1/s)	a O	al	a 2	a3	a4	a 5
wb 52 wb 5.2 wb .52	0.2026 0.1817 0.1499	2.928e-02 2.423e-02 2.599e-02	-1.570e-04 9.850e-04 3.598e-03	1.3850e-05 -1.3720e-05 -9.4670e-05	-2.8130e-07 2.9900e-08 9.5240e-07	1.788e-09 3.530e-10 -3.335e-09
wb .052	0.1342	4.250e-02	5.820e-03	-1.6425e-04	1.6958e-06	-6.035e-09
db 52 db 5.2 db .52	0.1336 0.0613 0.1260	5.467e-02 4.245e-03 4.130e-02	-1.369e-03 -4.300e-04 -9.300e-05	4 · 4390e · 05 2 · 4560e · 05 3 · 2280e · 05	-5.2420e-07 -4.0510e-07 -6.0980e-07	2.381e-09 2.097e-09 3.147e-09
db.052	0.0681	-3.440a-03	4.3630-03	-7.3530e-05	4.4460e-07	-7.000m-10
rs 52 rs 5.2 rs .52	-0.3651 -0.3644 -0.3658	4.131e-02 2.160e-02 4.237e-02	-9.700e-04 3.140e-04 -1.508e-03	4.0600e-05 1.7630e-05 6.7960e-05	-6.1720e-07 -4.1340e-07 -8.9610e-07	3.186e-09 2.397e-09 3.908e-09
ra .052	-0.3760	3.763e-02	-6.450e-04	3.8020a-05	-4.0730a-07	1.3690-09

"wb"-whole blood "db"-defibrinated whole blood "rs"-Ringer's suspension $% \left(\frac{1}{2}\right) =\frac{1}{2}\left(\frac{1}{2}\right) ^{2}$

Table 2-I: Constants for polynomial fit of Chien data.

From Chien et al., 1966.

varies with cell concentration and shear rate. An inconsistency with the Chien polynomials is that the a₀ values for any one type of suspension are not equal, and thus non-Newtonian behavior is predicted for pure plasma and saline. The purely empirical constants from these polynomials give little insight into the physical phenomena being observed. The fact that their ranges extend only to hematocrits of 95 and shear rates of 52 sec⁻¹ points out the need for more extensive data at the high-shear, high-hematocrit spectrum as well as a renewed effort to develop a set of equations satisfactory for predicting blood viscosity over a broad range of conditions.

An obvious approach to expanding the applicability of the Chien equations is to derive another set of empirical equations relating the coefficients a_i in equation (2.8) to shear rate. Constraints may be imposed such as requiring that as $H \to 0$, $\eta \to \eta_f$ for all shear rates (i. e., setting a_0 to a constant for each set of curves) and that Newtonian behavior is approached at high shear rates. Such an undertaking was made as a part of this work and the results are reported on in Chapter 4.

2.4 Theoretical Models and Mathematical Correlations

Because of the complex nature of the cell-cell and cell-fluid interactions in blood and red blood cell suspensions, to date it has not been possible to explain their rheology from the standpoint of a unified theory. Such a theory would have to incorporate the various aspects of shear rate and concentration dependence described in the previous sections of this chapter. To recap:

- 1. As shear rates approach zero, non-Newtonian behavior results from the domination of cell-protein interactions and subsequent increased aggregation.
- 2. At high shear rates, cells deform and orient along the streamlines, there

is tank-treading motion of the membrane and establishment of an internal velocity profile. Newtonian behavior is observed.

- 3. The fluid nature of the erythrocyte makes for substantial deviations in behavior of RBC suspensions versus that of rigid particle suspensions. For blood, the relative magnitude of the viscosity is smaller at a given concentration. Even at greater than 95 volume percent, blood suspensions are quite fluid. Analogies can be drawn to emulsions, with the cellular phase represented by a non-Newtonian internal viscosity.
- 4. Suspensions are Newtonian in the limit of dilute concentrations.
- 5. At high concentrations, cell crowding effects predominate and viscosity becomes independent of the suspending fluid.

Most proposed models for blood are extensions of es for suspensions of rigid particles or for emulsions. It is the intent here to brienly mention several approaches.

The Casson equation, equation (2.7), was originally developed to explain the behavior of mutually attractive particles which form structures that diminish in size as shear rate increases. In addition, the structure which exists at zero shear must be subjugated to a yield stress before any flow developes. The Casson equation does not explain blood rheology at low hematocrits, where no yield stress is observed.

Many empirical equations have been modifications of an equation first derived by Einstein [1906] for dilute suspensions of rigid, non-interacting particles,

$$\eta_r = \frac{1}{1 - \alpha \cdot c} \tag{2.9}$$

where α is a shape factor equal to 2.5 for spheres. At hematocrits less than 5, where Newtonian behavior is observed, equation (2.9) describes whole blood adequately. Jeffrey [1923] extended Einstein's theory to particles of ellipsoid shape, from which Taylor [1932] derived his expression for emulsion viscosity, equation (2.5). Dintenfass [1968b], starting with Taylor's equation, proceeded by a method where a

concentrated emulsion is equated to a hypothetical continuous phase of equal viscosity, and then sequential addition of disperse phase to the emulsion is assumed to follow Taylor's equation. The result is

$$\eta_r = \frac{1}{(1 - c \cdot T)^{2.5}} \tag{2.10}$$

Values for η_i from this equation are between 1 and 6 cP [Dintenfass, 1968b]. This is smaller than the reported 6-8 cP viscosity of a 34 per cent hemoglobin-in-water solution, which approximates the makeup of the erythrocyte cytoplasm [Quemada, 1977].

The methodology used to derive this equation is valid only at shear rates high enough to prevent aggregation, so that the cells exist as independent units. Based on attempts at using it with experimental data, it will hold for more dilute suspensions (H<85) only with very viscous suspending fluids. For example, in order to measure η_i at H=38, Dintenfass [1968b] uses a suspending fluid viscosity $\eta_f>0$ cP. The limitations of equation (2.10) would follow from the concept of a shear-thinning internal viscosity and from the previously mentioned observations of Secomb et al. [1983a]. Only at high shear rates would the emulsion properties of blood become apparent from deformation, orientation, and tank-treading. The tank-treading is dependent on viscous stresses from either other cells or from highly viscous media [Secomb et al., 1983a].

Quemada [1977, 1978a, and 1978b] has proposed an interesting equation for concentrated suspensions based on the principle of minimum energy dissipation. His derivation is strictly valid for rigid, attracting spheres but is seen to adequately describe blood rheology. The expression for the relative viscosity as a function of both shear rate and concentration is

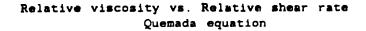
$$\eta_r = \left[1 - \frac{c}{2} \cdot \left(\frac{k_0 + k_\infty \cdot \sqrt{\gamma_r}}{1 + \sqrt{\gamma_r}}\right)\right]^{-2} \tag{2.11}$$

10

$$\eta_{r} = \left[1 - \frac{c}{2} \cdot (k_{\infty} + \frac{k_{0} - k_{\infty}}{1 + \sqrt{\gamma_{r}}})\right]^{-2}$$

where k_0 and k_{∞} are dimensionless "intrinsic viscosities" defined as $(\frac{d\eta_r}{dc})_{c\to 0}$ at zero and high shear rate, respectively. The term in parentheses in equation (2.11) is the intrinsic viscosity $k(c,\gamma)$ at the shear rate of interest. For rigid particles, the intrinsic viscosity is inversely proportional to the packing concentration c_p, which is the maximum concentration to which the effective particles existing at the shear rate may be packed. In other words, the intrinsic viscosity is directly proportional to the volume of an effective particle. For deformable fluid particles such as erythrocytes, the intrinsic viscosity empirically includes any deviations from rigid spheres, and the relationship of intrinsic viscosity to particle volume is more qualitative. The dimensionless relative shear rate γ_r is equal to γ/γ_c where γ_c is a theoretical "critical shear rate" for aggregate formation. Aggregation is assumed to be governed by Brownian collisions while disaggregation is controlled by shearinduced collisions. In the limit of a dilute concentration of rigid spheres, γ_c is roughly equivalent to the rotational diffusion coefficient $\frac{\nu}{2}$, where D is the translational diffusivity and a is the radius of the particle. For blood cell aggregates, γ_c may be on the order of a Maxwell relaxation time $\frac{E_i}{\eta_c}$, where E_i is the elastic modulus of the aggregate. A complete derivation of the Quemada equation is given in Appendix C.

Since the Quemada expression will be employed extensively in the analysis of this work, it will be worthwhile at this point to examine this equation in some detail, first from a purely mathematical standpoint and then later in the context of the physical meaning of its parmeters. Sets of curves for the Quemada equation are



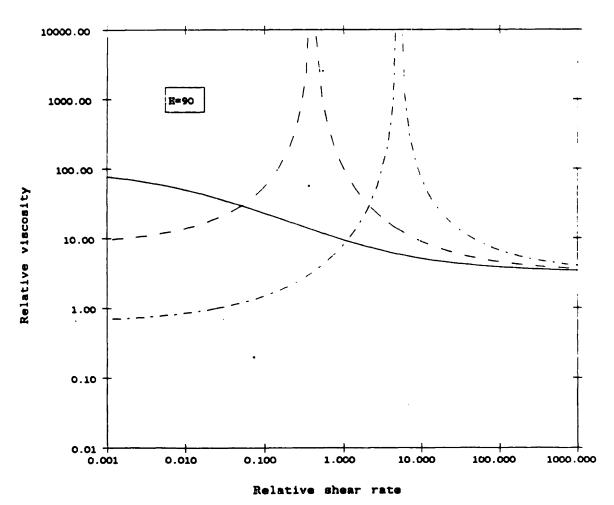


Figure 2-9: Plots of the Quemada equation at H=90.

Solid lines: $k_{\infty}=1$, $k_0=2$

Dashed lines: $k_{\infty}=1, k_0=3$

Dot/dashed lines: $k_{\infty}=1, k_0=5$

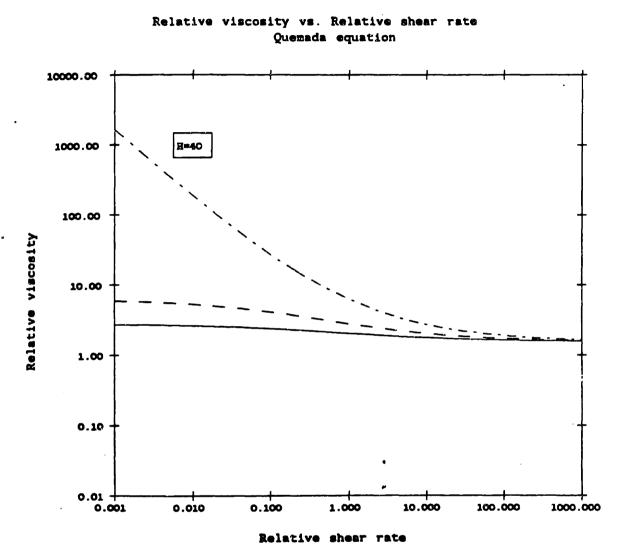


Figure 2-10: Plots of the Quemada equation at H=40.

Solid lines: $k_{\infty}=1, k_0=2$

Dashed lines: $k_{\infty}=1, k_0=3$

Dot/dashed lines: $k_{\infty}=1, k_{0}=5$

Relative viscosity vs. Relative shear rate Quemada equation

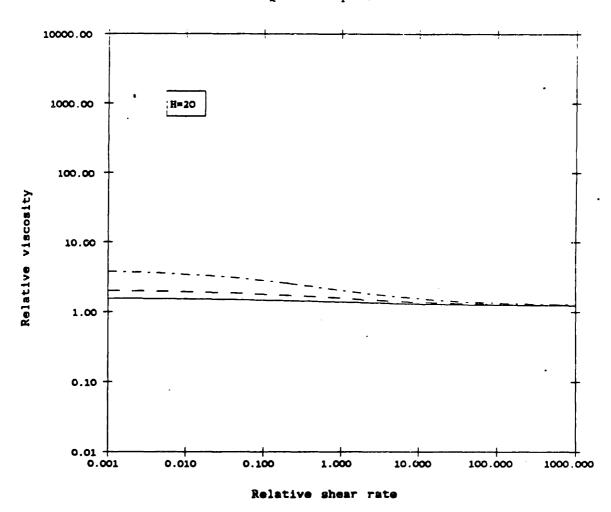


Figure 2-11: Plots of the Quemada equation at H=20.

Solid lines: $k_{\infty}=1$, $k_0=2$

Dashed lines: $k_{\infty}=1$, $k_0=3$

Dot/dashed lines: $k_{\infty}=1$, $k_0=5$

shown in Figures 2-9 to 2-11 for hematocrits of 90, 40, and 20. From these curves it is evident that k_{∞} and k_0 provide the asymptotic values of the viscosity, while the critical shear rate scales the x-axis over the range of shear rates examined. A low value for γ_c shifts the relative shear rate to the right, toward the k_{∞} asymptote. Alternatively, the critical shear rate can be thought of as an analogue to the Michaelis-Menten rate constant: when $\gamma = \gamma_c$, $k = \frac{k_0 + k_{\infty}}{2}$.

As shown in the graph for H=90, there exists the potential for a singular solution at high hematocrit and high k_0 , where the viscosity is infinite. This occurs when the term in brackets in equation (2.11) is zero, and

$$\sqrt{\gamma_r} = \frac{\frac{c}{2}k_0 - 1}{1 - \frac{c}{2}k_\infty}.$$
 (2.12)

This has a real-valued solution only when $\sqrt{\gamma_r} > 0$, and thus the criterion for the existence of a singular point is

$$\frac{1 - \frac{c}{2}k_0}{1 - \frac{c}{2}k_\infty} < 0. {(2.13)}$$

Since $k_0 > k_{\infty}$ for shear-thinning suspensions, this reduces to

$$\frac{c}{2} \cdot k_0 > 1. \tag{2.14}$$

This case has no physical meaning, as viscosity would never follow this behavior, but may result when k_0 values are extrapolated from data at higher shear rates.

Quemada fit his equation to experimental data from the literature [Quemada, 1978b]. The values derived for the rheological parameters from these fits are shown in Table 2-II and the corresponding equations are plotted in Figure 2-12. He has also [Quemada, 1981] fit his equation to the data of Chien et al., 1966, but unfortunately presented his results graphically, in terms of c_p, without reporting the

Source	Н	\mathbf{k}_{∞}	k _o	$\gamma_{\rm c}~({\rm sec}^{-1})$
1	41.9	1.8	4.68	0.69
2a 2b	40 4 5	1.84 2.07	4.65 4.33	2.23 1.8
3a 3b 3c	45 45 45	1.78 1.78 3.62	4.20 3.29 -	5.0 25.0 -
4	88	1.83	2.26	2.16

Table 2-II: Fits of literature data to Quemada equation.

Source codes: 1-Merrill et al., 1965c, whole blood

2-Schmid-Schonbein et al., 1971b, whole blood

3-Chien, 1970: (a) normal cells in plasma, (b) normal cells in albumin,

(c) hardened cells in albumin

4-Usami et al., 1971, packed cells in plasma

 $\eta_f = 1.2$ cP for all samples.

From Quemada, 1978b.

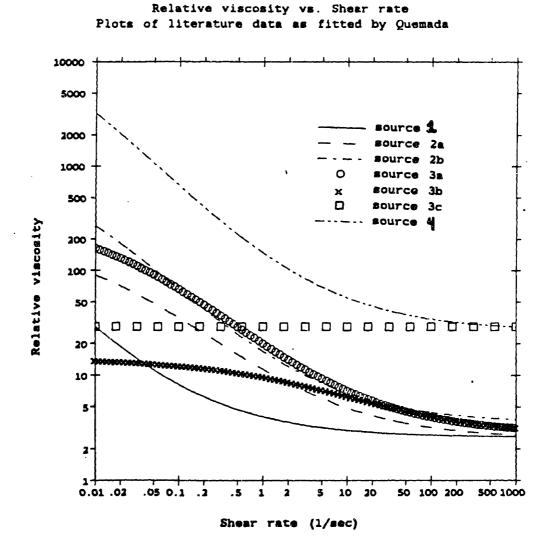


Figure 2-12: Plots of Quemada equation for literature sources given in Table 2-II.

values obtained. As part of the present work, fits were made to the Chien data and are discussed in Chapter 5.

Values for k_{∞} in Table 2-II are very close to 1.8 save for the hardened cells. Ideally, k_{∞} can be thought of as being affected by anything which would affect either the internal viscosity of the cell or the effective hydrodynamic volume of the cell at high shear, since k_{∞} is related to the packing concentration of effective particles (see Appendix C). It should therefore hold that as long as the nature of the cells, the hematocrit, and the suspending fluid viscosity are the same, then k_{∞} should be constant. The value obtained at H=88 is similar to the others in Table 2-II, but in analyzing data from Chien et al. [1966], Quemada [1981] noted that at low hematocrits, k_{∞} decreased as hematocrit increased, reached a minimum at H=75, and then increased. His proposed explanation for this is to imagine that below hematocrits of around 40, the effective particle volume at high shear is the hydrodynamic volume of an individual cell, which is reduced by crowding effects as hematocrit increases. At about H=40, these effective volumes begin to overlap, and at H=75 an inversion phenomenon typical to emulsions happens as the continuous solution phase becomes sequestered between cells and converts into a dispersed phase, while the erythrocytes become the continuous phase.

Comparison of the values of k_0 give an indication of the effects of aggregation. The absence of plasma proteins leads to less aggregation at zero shear rate and higher packing concentrations as described in Appendix C. In fitting the data of Chien et al., Quemada [1981] noted an almost linear decrease of k_0 with hematocrit, which he ascribed to successive effects of increased aggregation and then deformation, both which result in increasing the "compactness" of the red cell aggregates.

The values for γ_c in Table 2-II show a large jump from 5 to 25 ${\rm sec}^{-1}$ in going

from plasma to albumin suspensions. If, as in polymer chains, γ_c is assumed to be proportional to the elastic modulus E_i as shown in Appendix C, and $E_i \sim a^{-3}$ where a is the effective radius of the rouleau, then effects which decrease aggregation would increase γ_c .

In the limit as $c \to 0$, it is reasonable to assume that $\gamma_c \to \infty$ since there is less aggregation and the time constant for rotational diffusion will be small. The term in parentheses is equation (2.11) becomes $1 - \frac{c}{2} \cdot k_0$. In the fits of Quemada for the data of Chien *et al.*, however, it appears that both k_0 and k_∞ are discontinuous at the boundary of Newtonian behavior and that the Newtonian intrinsic viscosity is some intermediate value between the two.

A few other methods will be quickly touched upon. Linear viscoelastic models for blood attempt to model both the dissipative (viscous) and energy-storing (elastic) properties of blood. Thurston [1972] was the first to delve into this arena of biorheology. There have been many proposed constituitive equations for blood, but none have been found to be fully satisfactory in terms of representing all of the material function of blood (shear viscosity, normal stress differences, and oscillatory material functions). If interest is limited to just the shear viscosity, however, several models predict blood behavior reasonably well, although all previous work has been at hematocrits in the physiologic range [Walitza et al., 1979; Riha, 1680]. These models are limited by their complexity and their inability to be related to physical parameters.

Princen [1983] has proposed a method of calculating yield shear stress for foams and concentrated emulsions based on a geometric analysis of the shear stress and membrane tension of hexagonally closed-packed drops. His analysis does not extend to void fractions above 10 per cent.

Secomb et al. [1983b] have developed very complicated expressions for the relative viscosity of packed red cells based on a model for tank-treading motion of the cells. Their model shows good agreement at high shear rates but is very poor at both lower hematocrits and low shear rates, where the tank-treading effect is less important rheologically.

Chapter 3

MATERIALS AND METHODS

3.1 Blood Sampling and Preparation

The blood samples used for the viscosity measurements were either drawn from the author or were units of whole blood or of packed cells obtained from the American Red Cross. Those drawn from the author were used in preliminary measurements and consisted of approximately 7 ml of blood drawn into Vacutainers (Becton-Dickinson no. 6460) with sodium citrate anticoagulant. Each unit was drawn into either citrate phosphate dextrose (CPD), citrate phosphate dextrose-adenine, (CPD-A₁), or adenine-saline, (AS₁) anticoagulant-preservative and was used before its expiration date. Typically these units were obtained approximately 14 days after they had been collected from donors. A unit of whole blood consists of 450 ml of blood drawn into 63 ml of anticoagulant-preservative and a unit of packed red cells consists approximately of 250 ml of blood concentrated to 60-75% cell volume. Units were stored refrigerated at 4 °C.

Saline suspensions of blood were made from the units of packed red cells. Ten 15-ml Pyrex centrifuge tubes were filled with 8 to 10 ml each of packed cells and centrifuged for four hours at 900g in a refrigerated centrifuge (International Equipment Company, model PR6). The supernatant and buffy coat were removed and discarded and the remaining cells (about 5-6 ml) were washed in an equal volume of Eagle's solution and centrifuged again for thirty minutes to an hour. The cells were washed and centrifuged twice more. The final centrifugation lasted for 12 hours and, after removal of the supernatant, Eagle's solution was added to adjust to

the desired hematocrit. The recipe for Eagle's solution is given in Appendix B.

Suspensions of red blood cells in plasma were prepared by spinning down 10 ml aliquots for 12 hours. The supernatant was retained and the cells were not washed in Eagle's solution. Instead, the supernatant was centrifuged for 30 minutes to settle any solid materials, which were discarded, and the plasma was used to adjust the hematocrits of the red cell samples.

3.2 Hematocrit Determination

Hematocrit determination was done by the microhematocrit method. Two 25 μ l Microcap (Drummond Scientific Company) glass capillary tubes were filled one-half to two-third full with the sample in question. One end of each tube was sealed with Seal-Ease (Clay-Adams, Parisippany, NJ), and the tubes were spun in a Readacrit microcentrifuge (Clay-Adams no. 0591, Parisippany, NJ) at 6300g for 5 minutes. The length of the red cell column and the total length of material in the tube was read by graduations built into the centrifuge. For microhematocrits below 98, if agreement was not within 0.5 hematocrit units, a third measurement was done. For microhematocrits above 98, the agreement criteria between tubes was within 0.3 hematocrit units and the values were recorded to the nearest tenth.

It is well known that a column of packed red cells contains a small amount of plasma trapped between the cells, which in the case of microhematocrit determination means that the reading is higher than the actual volume percentage of cells. Methods using radioactive-labeled albumin have been employed to quantify the amount of plasma trapped [Chien et al, 1965; Thomas and Janes, 1968], and an attempt was made to adapt one of these methods to determine with greater accuracy the hematocrit of the high concentration samples. The nature of these samples, their high viscosity and adhesiveness to the sides of glass tubes, made it

impossible to measure out accurate volumes as required by the Chien method and the method of Thomas and Janes proved unsuitable for samples of extremely low plasma to cell ratio. Values of the plasma trapping correction factor (equal to 1 minus the porosity) for the microhematocrit method are in the range of .99 [Chien et al, 1965] at cell volumes of 44.5%. Since the porosity of a centrifuged column decreases with increasing length of cell column, the correction factor should be even higher for highly concentrated suspensions.

The relationship between the steady-state porosity of a centrifuged column of packed cells and the compressive pressure of centrifugation has been examined by Saltzman [1984] and Zydney et al. [1985]. Using a differential force balance on a layer of cells in the column, the compressive pressure π at any point in the column is given by

$$\pi = \frac{1}{(1-\epsilon)} \int_0^y (\rho_c - \rho_f) \,\omega^2 R \,d[(1-\epsilon)y] \tag{3.1}$$

where ϵ is the porosity, ρ_c and ρ_f are the cell and suspending fluid densities, respectively, ω is the rotational velocity of the centrifuge and R is the arm length of the centrifuge. An empirical expression relating compressive pressure to porosity derived by Zydney *et al.* is

$$K\pi = (\frac{\epsilon_0}{\epsilon}) + (\frac{\epsilon}{\epsilon_0}) - 2 \tag{3.2}$$

where K is a parameter fitted from experimental data and ϵ_0 is the porosity at zero compressive pressure, equal to 0.2. From experimental data at 592g and 925g K is determined to be 4.0×10^{-5} cm²/dyne or 5.3×10^{-2} (mm Hg)⁻¹. Assumming that K is a property only of the material being centrifuged, these equations may be used to provide a value for fluid trapping in the microcentrifuge. Solution of equations (3.1) and (3.2) at 6300g for plasma and Eagle's suspensions are shown in Figure 3-1 for both the local porosity and the average porosity, defined as

Local porosity versus distance from top of cell column
Average porosity versus cell column length
Centrifugation at 6300g

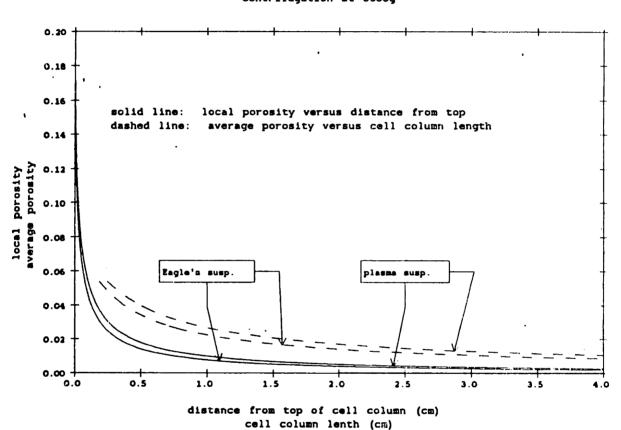


Figure 3-1: Plots of ϵ as a function of position in the cell column and of $\bar{\epsilon}$ as a function of cell column length.

$$\bar{\epsilon} = \frac{1}{L} \int_0^L \epsilon \, dy \tag{3.3}$$

Values for the average porosity at the typical microcentrifuge cell column length of 3 cm are 0.01 for Eagle's solution and 0.012 for plasma, which is in agreement with the value reported by Chien et al. [1965]. The microhematocrit values were multiplied by $(1-\bar{\epsilon})$ to obtain the hematocrits reported in the results. Because of these adjustments, the hematocrit H and cell volume fraction c are used interchangeably throughout this work.

3.3 Viscometry Measurements

3.3.1 Techniques of Viscometry

Before discussing the particulars of the equipment and methods used for measuring blood viscosity, it will be helpful to first review some general considerations of blood viscometry. The rotating coaxial cylinder (Couette) viscometer is in widespread use for these applications. It consists of an inner cylinder placed in an outer cup, with a gap between the two where the sample of fluid to be assessed is placed (see Figure 3-2). Either the inner or the outer cylinder may be rotated, and the viscosity of the fluid being sheared causes a momentum flux which developes a torque which is measured on the cylinder not rotated. If the gap width between the cylinders is narrow (less than 5%) compared to the radius of the cup, the fluid will undergo simple, steady, laminar shear and the velocity profile within the gap can be approximated by a straight line. The shear rate in sec⁻¹ in the annulus is given by

$$\gamma = 2\omega \frac{R_o^2}{R_o^2 - R_i^2} \tag{3.4}$$

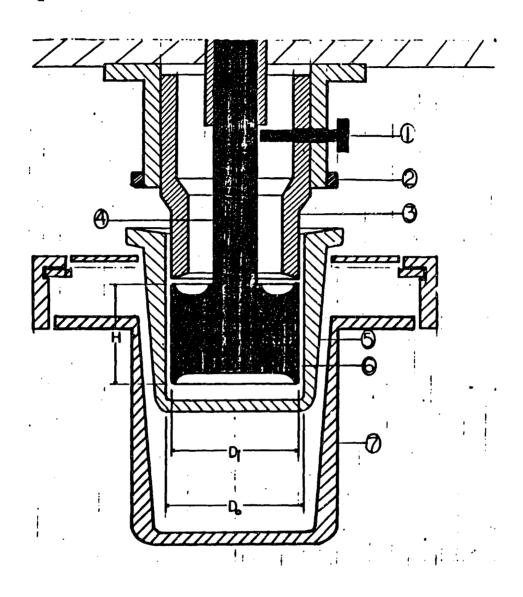


Figure 3-2: The Haake ZA30 sensor system, an example of a coaxial cylinder viscometer.

- 1. Knurled screw to hold inner cylinder. 2. Clamping ring to hold guard ring.
- 3. Guard ring. 4. Inner cylinder. 5. Outer cylinder (beaker).
- 6. Gap where sample is located. 7. Beaker housing

where ω is the angular velocity of the rotating cylinder in radians/sec, and R_o and R_i are the radii of the outer and inner cylinders, respectively. The torque across the gap is constant, so that if end effects are neglected, the shear stress in dyne/cm² exerted on the inner cylinder is given by

$$\tau = \frac{M}{2\pi h R_i^2} \tag{3.5}$$

where M is the torque exerted in g-cm and h is the length of the cylinder. Thus knowledge of ω , M, and the geometric parameters of the system leads to measurement of γ , τ , and hence, $\eta = \tau/\gamma$.

The interpretation of rheological data for blood is complicated by several effects, artifacts, and sources of error, some of which are common to all fluids while others are peculiar to blood. Included in the former are end and edge effects resulting from flows above and below the inner cylinder. These can be minimized by modification of the inner cylinder, either by recessing the ends or converting the bottom end into a conical configuration [Meiselman and Cokelet, 1973].

The air-fluid interface at the top of the viscometer can be a source of significant error. Even a simple Newtonian sample such as water exhibits surface effects from its high surface tension if a free meniscus develops in the gap. When plasma viscosities were intially measured [Copley et al., 1960; Wells and Merrill, 1961; Cerny et al., 1962] in viscometers without guard rings, shear-thinning behavior was reported due to the formation of a wax-like "skin" of lipids, lipoproteins, or denatured proteins. Employment of a guard ring such as that shown in Figure 3-2 eliminates the surface effects by preventing fluid which lies on the air-fluid interface from influencing the torque reading.

The presence of the walls of the cylinder necessarily introduces a inhomogeneity into the distribution of cells in the gap, since the center of any one

cell cannot lie closer to the wall than its radius. This wall exclusion effect was studied mathematically and experimentally by Vand [1948], who used glass spheres His model assumed a "rectangular" in coaxial and capillary viscometers. concentration profile of a layer of pure suspending fluid next to the walls and a bulk region of constant concentration which was later used by Quemada [1977] to derive his expression for blood viscosity, equation (2.11) (see Appendix C). monodisperse system, Vand found a particle-free layer with a width of 1.1 times the particle radius which resulted in a decrease in the measured wall shear stress below that expected for a homogeneous suspension. Cokelet et al. [1963] found that torque values of 2 to 5% higher could be obtained by the use of grooves 66µm deep in the walls of the cylinders. The necessity of the grooved surfaces is disputed by Chien et al. [1966], who note that their presence does not always prevent formation of the plasma layer [Merrill et al., 1963a]. Also, it is desirable to obtain data at conditions which represent flow systems of interest (e. g., blood vessels), and these do not have regularly grooved walls. The cylinders of the Haake viscometer used in this study had smooth surfaces.

The applicability of equations (3.4) and (3.5) depends on the maintenance of laminar, unidimensional (tangential) flow in the gap. If the inner cylinder is the rotor, centrifugal forces can introduce secondary flows and Taylor vortices and as the rotation rate increases, eventually lead to turbulent flow. For an annulus width of 1 mm and a outer radius of 2.5 cm, the shear rate at which secondary flow occurs for plasma at 37 °C is about 150 sec⁻¹ and for blood is about 300-450 sec⁻¹. When the outer cylinder is the rotor, as in the case of the present study, inertial forces tend to stabilize the flow and the shear rate at which secondary flow begins is around 10⁵ sec⁻¹ [Meiselman and Cokelet, 1973].

Other considerations are more specific to blood. The difference in density

between the erythroctes (approximately 1.09 g/cm³) and plasma (approximately 1.02 g/cm³) results in a tendency of red cells to settle in plasma solutions. A homogeneous sample can be maintained in the coaxial cylinder viscometer by having the region above the inner cylinder covered with a pool of blood [Meiselman and Cokelet, 1973].

The torque-time curves for blood show two regimes of behavior: At shear rates above 1 sec⁻¹ the torque reading rises quickly (on the order of a second) to a constant value which is maintained until the shear is stopped. At shear rates above 10 sec⁻¹ the time for this rise is negligible. At rates below 1 sec⁻¹ a more gradual rise to a maximum is observed followed by a decay to an equilibrium value. The time for this rise can be as long as a minute or more at shear rates of 0.01 sec-1. Direct visualization of the annulus shows that at low shear rates, the red cells migrate away from the outer and possibly from the inner walls, forming a substantial cell-free layer near the walls [Cokelet et al., 1963; Meiselman, 1965]. It has been hypothesized that the slow rise is due to transient effects from intiation of the shear and that the decay represents migration of the cells away from the cylinder walls, which can be represented mathematically as an exponential decay [Cokelet and Smith, 1973] (see Figure 3-3). The argument thus is that the correct torque is one which is extrapolated to zero time from the decaying exponential curve. As will be discussed in the next section, there was no torque decay at the lowest observable shear rate of the present study. A theoretical model for blood flow at low shear rates in a coaxial cylinder viscometer is given by Bloor [1982].

3.3.2 Viscometer

Rheological measurements were performed with a Haake Rotovisco RV100 with the CV100 measuring system (Haake, Inc., Saddle Brook, NJ). The instrument

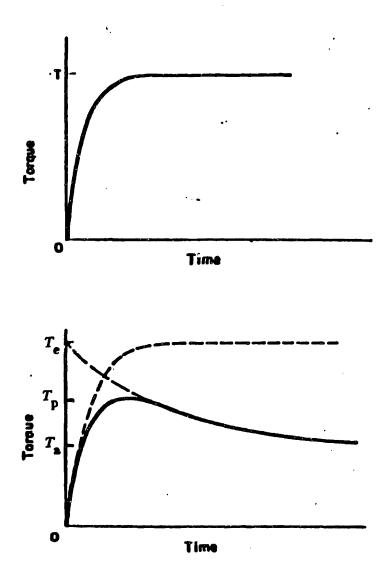


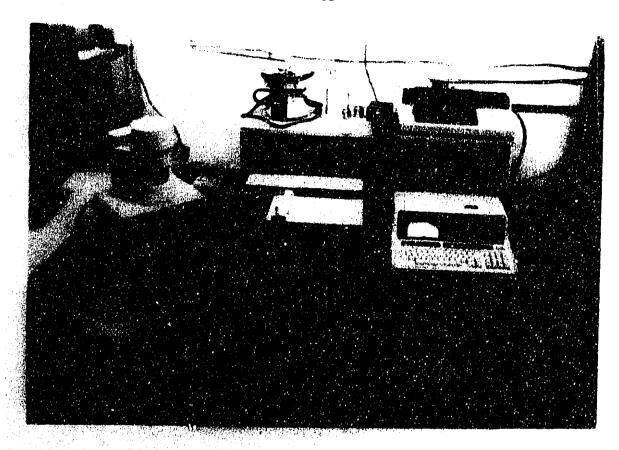
Figure 3-3: Torque-time curves for blood.

Top, shear rates greater than 1 sec⁻¹. Bottom, shear rates less than 1 sec⁻¹. $T_{\mathbf{a}}$ is the asymptotic equilibrium torque value measured, $T_{\mathbf{p}}$ is the peak torque, and $T_{\mathbf{e}}$ is the torque extrapolated to time zero. From Cokelet and Smith [1973].

is the property of the Ceramics Laboratory of the Department of Materials Science and Engineering at M.I.T. and is pictured in Figure 3-4. The ZA30 sensor system was used, which is a stainless steel coaxial cylinder system (see Figure 3-2, page 52). The outer cup is driven by a motor, which provides greater stabilization against secondary flows as described previously. The viscosity of the fluid being sheared causes a momentum flux which develops a torque on the inner cylinder, deflecting measuring springs in the drive unit and producing an electrical signal proportional to the torque. The relevant dimensions for the ZA30 are listed in Table 3-1. The inner cylinder slides into the measuring shaft of the unit and is held on the shaft by a knurled screw. It is mechanically positioned and centered by an air bearing in the measuring system which is supplied with compressed air from an air supply unit (Haake model LV100). The air pressure in the supply unit resevoir is maintained between 5.5 and 3.5 bar. The feed pressure to the bearing is 2.5 bar.

The top and bottom surfaces of the inner cylinder are not flat but are recessed from the outer edge to minimize end effects as shown in Figure 3-2. A guard ring, secured on the measuring shaft by a clamping ring, is employed in all measuremnets to minimize artifacts from the fluid-air interface. A refrigerated bath and circulator (Haake model F3-K) supplies a water jacket in the measuring system with a supply of distilled water, which is maintained at a constant temperature by a balance of controlled heating against continuous cooling. The water jacket is used to set sample temperature and to remove dissipated heat from the sample created by shearing.

The viscometer is linked to an HP-85 Desk Top Computer (Hewlett-Packard Corporation, Corvaillis, OR), which in turned is connected to an HP 7470A Graphics Plotter. The viscometer interface is a Haake DVM 7815 four-channel digital voltmeter with three control lines connected to an HP 82940A I/O interface.



Pigure 8-4: Haake Rotovisco RV100 viscometer with accesories as described in text.

- 1. CV100 measuring system
- 2. RV100 viscometer
- 3. Graphics Plotter
- 4. HP-85 computer
- 5. LV100 air supply unit



Inner cylinder diameter (D _i)	27.83 mm		
Inner cylinder length (h)	26.9 mm		
Outer cylinder diameter (D _o)	30 mm		
Gap width	1.085 mm		
Sample volume	5 ml		

Table 3-I: Geometric parameters for the ZA30 sensor sytem.

A Haake rotational software cartridge (part #1077922) is used to program the computer, which can then be used to set the viscometer parameters and control the measuring operation. The viscometer may be run in either a τ vs. time mode at constant shear rate, or in a τ vs. shear rate mode with a maximum range of 0 to 300 sec⁻¹. The software reads 100 data points evenly distributed over time or over the selected range of shear rates and can print digital values or plot data on the Graphics Plotter.

3.3.3 Viscometry Methods

Enough sample to cover the inner cylinder, about 5 to 7 ml in volume, is carefully mixed and poured into the cup, which is covered with a piece of Parafilm and placed into the measuring unit for about two minutes to allow temperature equilibration at 37 °C. While the sample is warming, the guard ring and inner cylinder are mounted following the procedure recommended by the instrument instructions: The clamping ring is loosened and the guard ring slides into the housing, resting at the upper stop, and is clamped into position. The inner cylinder slides into the measuring shaft and is secured by the knurled screw. The guard ring is now loosened and allowed to rest on the upper face of the cylinder. The clamping ring is again tightened, which lifts the guard ring to a level of 0.1 to 0.2 mm above the inner cylinder. For highly viscous samples it is necessary to elevate the guard ring slightly more.

The shaft is lowered into the cup and then briefly raised up to overcome surface tension effects in the annulus and to observe whether the sample covers the gap between the guard ring and the inner cylinder. The sample is just visible at the border of the outer cylinder, providing a small pool of blood to maintain homogeneity in the annulus [Meiselman and Cokelet, 1973]. The exposed shaft is

encased with a Plexiglas housing and then the entire measuring system is covered with a large cardboard box to eliminate artifacts from outside air currents.

A fresh piece of plotting paper is placed in the recorder and calibrated. The scale parameters for the recorder are set according to the particular sensor system used. For the ZA 30 these values are 0.3 Pa/scale division for the τ axis and 3 sec⁻¹/scale division for the γ axis. The mode of operation is set to automatic reversal, that is, to step up continuously from 0 to 300 sec⁻¹ over a period of one minute, to hold at 300 sec⁻¹ for six seconds, and then to step down back to 0 sec⁻¹. (There is an associated hysteresis that is reported on in Chapter 4.) The full-scale factor for the τ axis of the recorder was set to the minimum value possible. The run is intiated.

Upon completion, a hard copy of the data points is obtained from the HP-85. Repeat measurements are made from 0 to 30 sec⁻¹ and from 0 to 3 sec⁻¹ with appropriate modifications in the full-scale setting for the τ axis. The sample is then removed and discarded and the cup, inner cylinder, and guard ring are washed out with hot water.

In order to insure that the shear induced by the instrument would not cause hemolysis sufficient to affect the measurements, a series of samples had their viscosities measured first at a constant shear rate of 0.3 sec⁻¹, then were subjugated to constant shear rates of 300 sec⁻¹ for a period of a minute, and then viscosities were remeasured at 0.3 sec⁻¹. No significant change was noted in the values at the low shear rate. Secomb et al. [1983a], in the direct microscopic observation of concentrated red cells at shear rates up to 1585 sec⁻¹, did not report on any significant hemolysis.

An assessment of the torque-time curves for concentrated suspensions of blood showed no transient effects such as those seen in Figure 3-3 at shear rates of 0.3

sec⁻¹, which is the lowest constant shear rate at which the viscometer could be run. There was agreement between those viscosity values obtained in the constant shear rate mode and the corresponding value obtained with continuous variation of shear rates.

3.4 Data Analysis

The data was fitted to several functions, both linear and non-linear. A general optimization routine was written in FORTRAN and run on the VAX-11 computer of the Whitaker College Computer Facility. The program was adapted from one by Zydney [1985] and is given in Appendix D. The general principals behind the data analysis will be presented here, as developed by Zydney [1985].

Determination of the optimal set of parameters b_1, b_2, \ldots, b_P for a function Y which describes a set of data of N points can be equated to minimizing E, the value of the sum of squared residuals

$$E = \sum_{i=1}^{N} [y_i - y_{i,exp}]^2 \tag{3.6}$$

where y_i is the calculated value from the function Y at the same set of conditions as the experimental value $y_{i, exp}$.

Minimizing E is equivalent to finding values of b_i such that the gradient of E is zero. In mathematical terms, this is represented as a set of P coupled equations

$$F_{j}(b) = \frac{\partial E}{\partial b_{j}} = 2\sum_{i=1}^{N} [y_{i} - y_{i,exp}] \frac{\partial y_{i}}{\partial b_{j}} = 0$$
(3.7)

The method of steepest descent [Himmelblau, 1970] is used to find the set of parameters which minimize E. The set of equations represented by equation (3.7) can be solved by a Newton-Raphson iteration,

$$\mathbf{b}^{j+1} = \mathbf{b}^{j} - (\mathbf{A}^{j})^{-1} \mathbf{F}^{j}$$
 (3.8)

where A is the jacobian maxtrix with components

$$A_{ij} = \frac{\partial F_i}{\partial b_j} \tag{3.9}$$

The derivatives of y; are evaluated numerically as

$$\frac{\partial y_i}{\partial b_j} = \frac{y_i(b_j + \Delta b) - y_i(b_j)}{\Delta b} \tag{3.10}$$

The derivatives of F are found in a similar fashion.

After the data has been fit to the equation, various regression parameters are calculated from the covariance matrix:

$$\mathbf{cov}(\mathbf{b}) = \frac{E}{N-P} (\mathbf{X}^t \mathbf{X})^{-1}$$
 (3.11)

where X is the matrix whose elements are

$$X_{ij} = \frac{\partial y_i}{\partial b_j} \tag{3.12}$$

and X^t is the transpose of X. The variance of the fitted parameter b_i is given by the diagonal elements of the covariance matrix.

$$var(b_i) = cov(b_i, b_i)$$
(3.13)

The correlation coefficient between any two parameters b; and b; is

$$\rho_{ij} = \frac{\text{cov } (b_i, b_j)}{[\text{var } (b_i) \cdot \text{var } (b_j)]^{0.5}}$$
(3.14)

The 95% confidence limits for a function of the fitted parameters Y=Y(b) is evaluated first by finding the variance of Y from the variances and covariances of the R parameters [Freund and Minton, 1979]:

$$\operatorname{var}(Y) = \sum_{i=1}^{R} \left(\frac{\partial Y}{\partial b_i}\right)^2 \cdot \operatorname{var}(b_i) + 2 \sum_{i=2}^{R} \sum_{j=1}^{R-1} \left(\frac{\partial Y}{\partial b_j}\right) \left(\frac{\partial Y}{\partial b_j}\right) \operatorname{cov}(b_i, b_j)$$
(3.15)

where the second term on the right represents sums over all possible combinations of i and j such that i>j. The standard deviation σ_Y at any point on the function Y is given by the square root of the variance. The 95% confidence interval at any point on Y is given by

$$Y - t_{0.025}\sigma_Y < Y < Y + t_{0.025}\sigma_Y \tag{3.16}$$

where $t_{0.025}$ is the area under one tail of the Student t-distribution.

To avoid weighing the fits toward minimizing residuals at high values of η , the residuals were weighted by the reciprocal of the calculated value. The actual form of equation (3.6) used is

$$E = \sum_{i=1}^{N} \left[\frac{\eta_i - \eta_{i,exp}}{\eta_i} \right]^2$$
 (3.17)

Chapter 4

RESULTS

4.1 General comments

Examples of the raw data from the Haake viscometer as printed by the Graphics Plotter are shown in Figure 4-1. Each sample was run in three ranges of operation: high shear from 0 to 300 sec⁻¹, medium from 0 to 30 sec⁻¹, and low from 0 to 3 sec⁻¹. The plot of shear stress vs. shear rate in the lowest range shows two discernible artifacts: (a) a period in the step-up curve representing a start-up lag during which time the cylinder is rotating but the transducer as yet records no reading, and (b) a hysteresis between the step-up and step-down curves, with the step-down curve respresenting values on the order of 1 to 3 per cent higher than the step-up curve. This hysteresis, which existed to a smaller extent at higher shear rates, is caused by the time lag between the shear rate imposed and the shear rate Its magnitude diminished as the rate of change of shear rate was decreased, but it could never be completely eliminated. The HP-85 computer printed out a hard copy of 100 data points for each run, and a representative sampling of points were selected from these lists for fitting. Approximately every fifth point from both the up and the down curves was used, averaging twenty data points obtained per run. From the up curve, no points were obtained from the region of the start-up artifact, and in compensation there was a higher rate of selection of points from the down curve in this region.

Measurement of plasma and saline viscosities at 37 °C showed a small but significant shear-thickening behavior which could have resulted from the

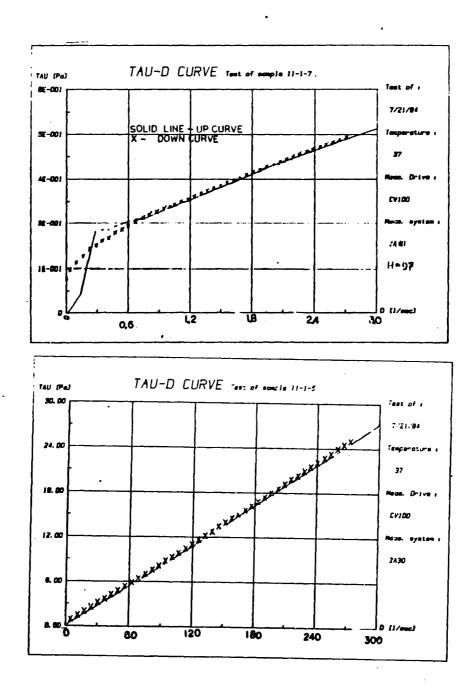


Figure 4-1: Plots of τ vs. γ from H-P Graphics Plotter interfaced with Haake viscometer, H=97.

Solid line=up curve. X=down curve.

development of secondary flows in the viscometer [Merrill, 1969]. The viscosity measured for Eagle's solution ranged from 0.85 to 0.9 cP. These values are somewhat higher than literature values of 0.69 cP for water at 37 °C, and the discrepancy is probably due to viscometer limitations in measurement of low-viscosity samples. In order to maintian consistency with other published data, 0.69 cP is used as the pure fluid viscosity for all saline solutions reported here. Plasma viscosities were more variable, ranging from 1.03 to 1.21 cP, which are comparable to typical literature values of 1.2 cP. For plasma suspensions the individual plasma values were used for calculating relative viscosity.

A series of measurements using freshly drawn blood obtained from a single source (the author) was used in order to check the reproducibility of the experimental method. Viscosity differences between different samples at the same hematocrit were on the order of 5% or less at hematocrits greater than 95. At hematocrits above 97 the sensitivity to concentration was enough to require that hematocrit be measured to the nearest tenth of a unit. At lower hematocrits it was sufficient to measure hematocrit to within a unit.

Tables of the data used in this work are presented in Appendix F. For definitional purposes, throughout the remainder of this work a unit of blood refers to all of the blood contained in the original bag obtained from the Red Cross. Each unit provided one or more batches of blood. A batch of blood is defined as an amount of blood removed from a unit and processed at one particular time, which is then divided into several samples of varying hematocrit. Sample identification is by the batch number followed by the sample number, e. g., 19-6. The unit identifications for each sample are given in Appendix F.

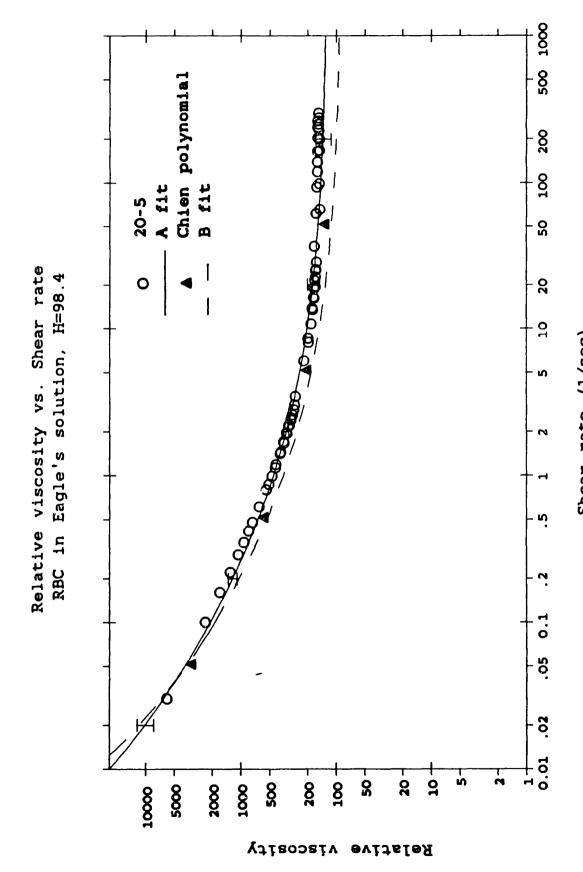
Variations in viscosity from batch-to-batch and from unit-to-unit were sheardependent, with the greatest differences at very low shear rates. Different batches from the same unit generally had comparable values at all shear rates, within 5% of each other. Samples from different units were within 5% at high shear rates, but could be separated by up to a factor of two or more at shear rates below 0.1 sec⁻¹. At shear rates above 0.1 sec⁻¹, viscosity differences were usually small. Some of the variability can be traced to the age of the blood samples, and this is expanded on later in this chapter.

4.2 Viscosity of RBC suspended in saline solution

The data for RBC suspensions in Eagle's solution are presented in Figures 4-2 to 4-25 (pages 69 to 92). Each plot is one of relative viscosity (η_r) versus shear rate (γ) at a different hematocrit. Hematocrits range from 98.4 to 7. Relative viscosities were calculated by dividing the measured viscosity by 0.88 cp, which was used as the pure Eagle's solution viscosity for all samples. On any one figure, data from different samples are represented by different symbols. Different samples from the same unit have the same designation with regard to the symbol being open or filled. Thus, in Figure 4-10, the two batches used are from the same unit, while in Figure 4-11, the two batches are from different units. There is no correlation of symbols between different figures.

The filled triangles in each figure are data values derived from the Chien et al. [1966] equation, (2.8), for Ringer's solution suspensions. Since the Chien et al. data are for viscosity and not relative viscosity, an estimate for η_f was made by taking the average values of the polynomials at zero hematocrit. In this manner, for Ringer's saline, η_f =0.692 cP. The solid curves with error bars and the dashed curves represent fits of the data to the Quemada equation, equation (2.11), and will be discussed in detail in Chapter 5.

On visual inspection, the points on each plot may appear to be segregated into



Shear rate (1/sec)
Figure 4-2: Eagle's solution data, H=98.4.

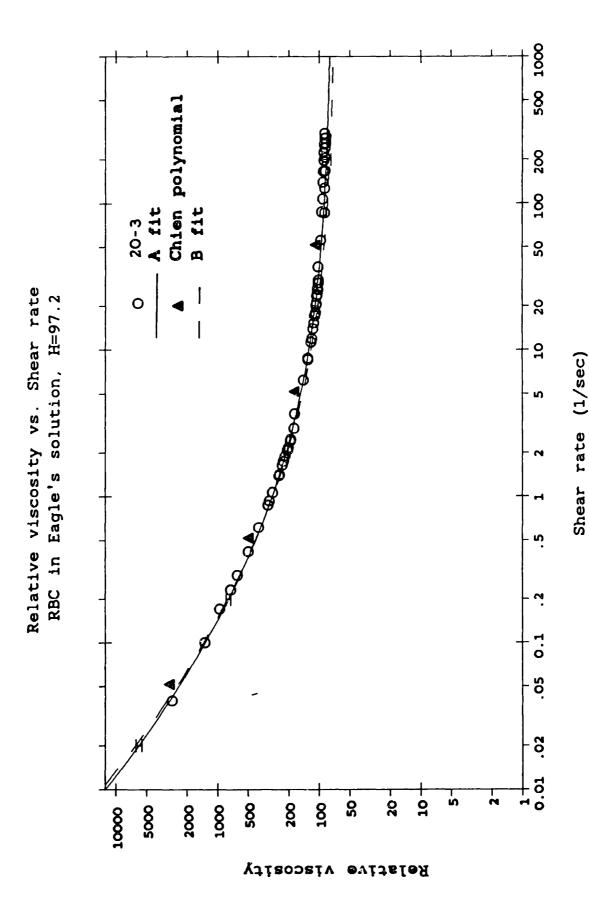


Figure 4-3: Eagle's solution data, H=97.2.

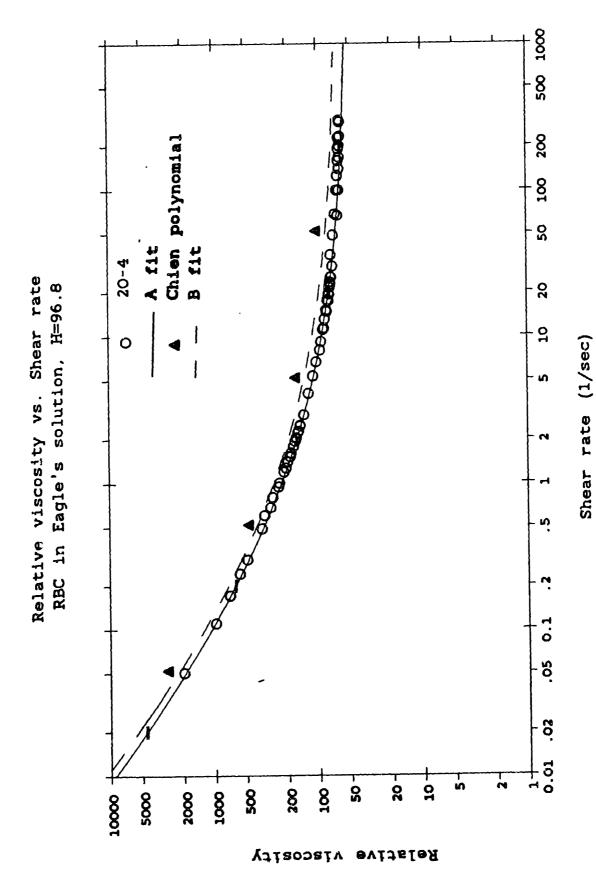


Figure 4-4: Eagle's solution data, H=96.8.

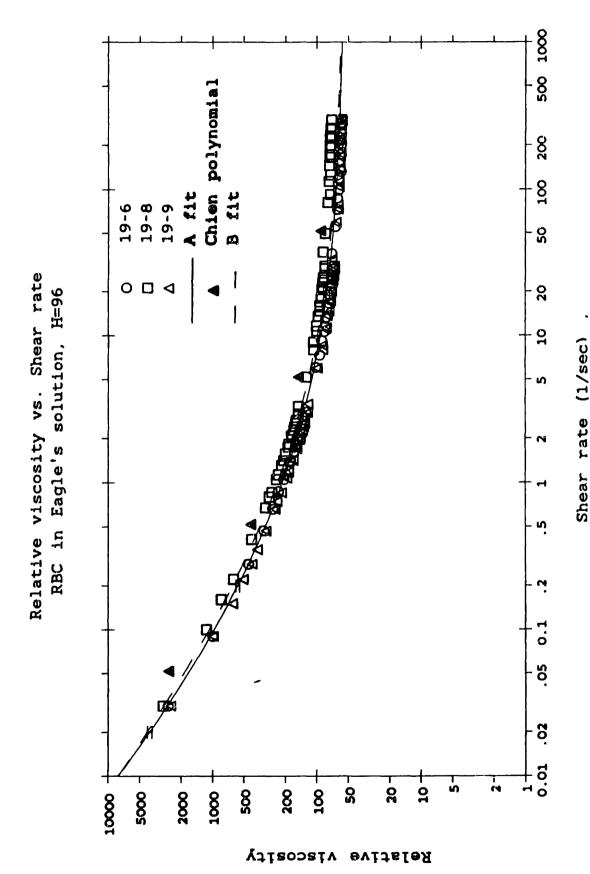


Figure 4-5: Eagle's solution data, H=96.

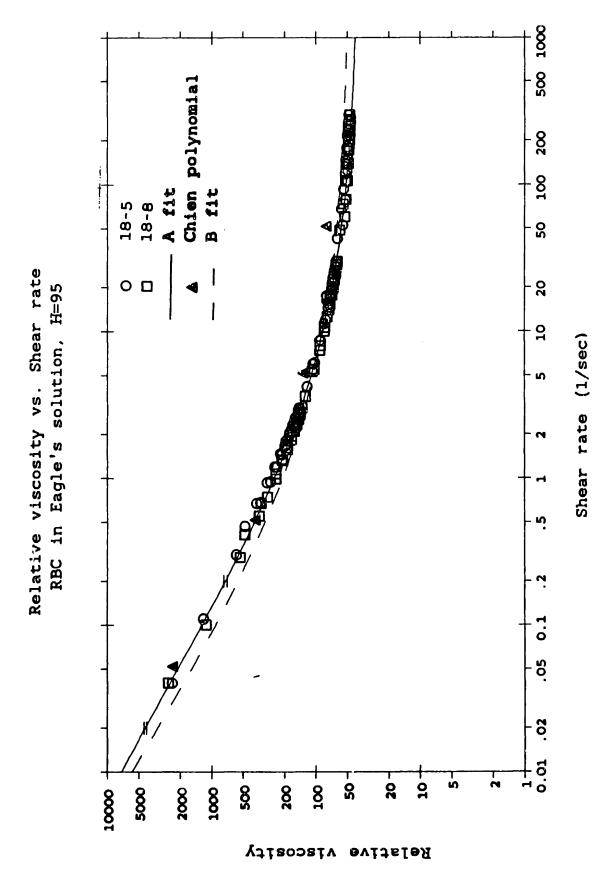


Figure 4-6: Eagle's solution data, II=95.

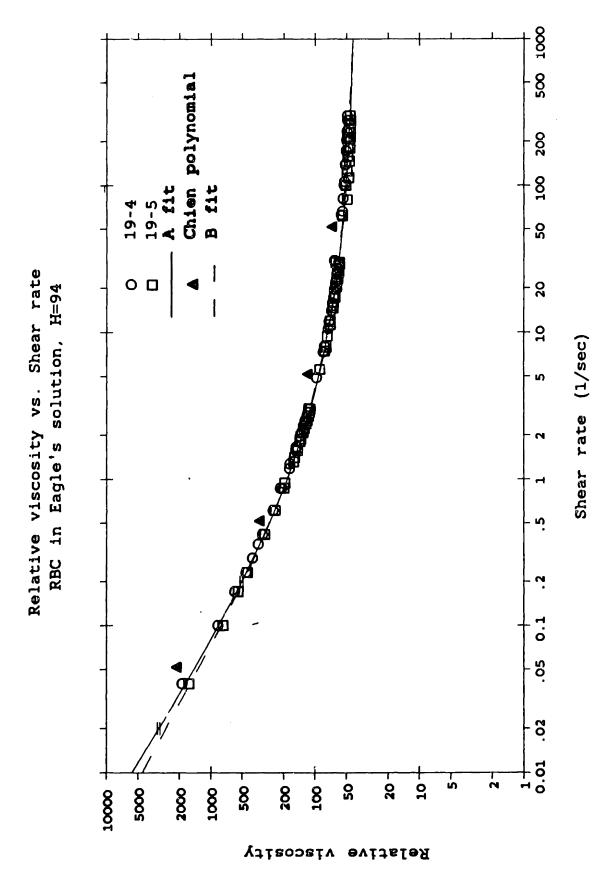


Figure 4-7: Eagle's solution data, H=94.

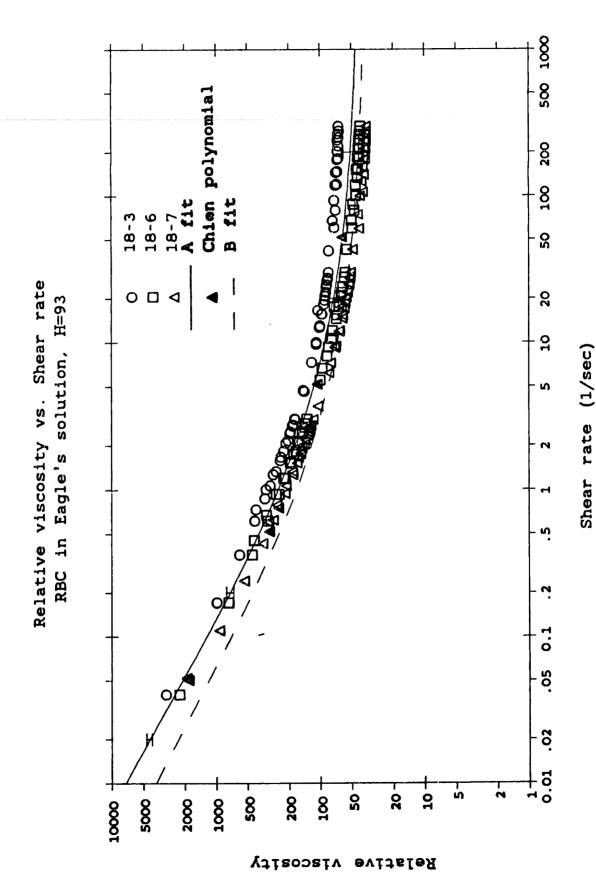


Figure 4-8: Eagle's solution data, H=93.

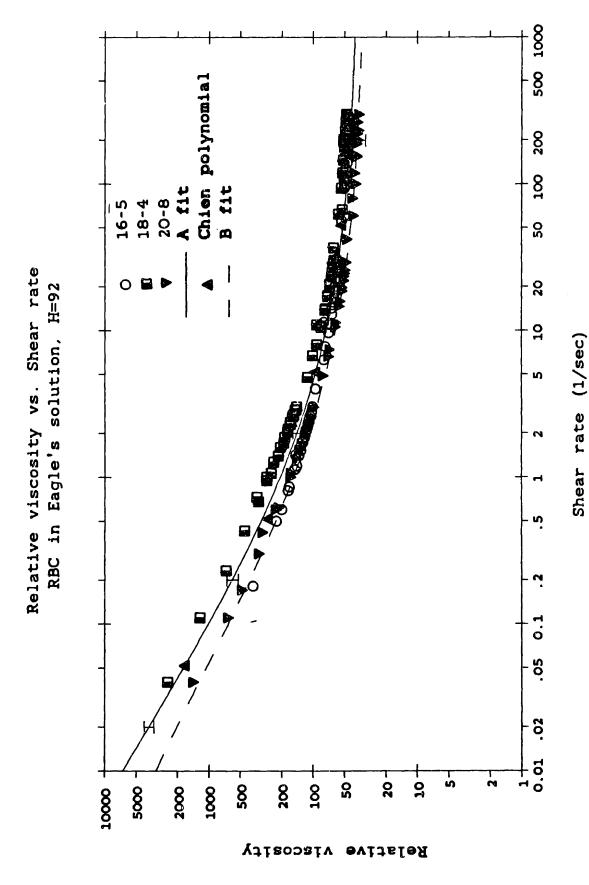


Figure 4-9: Eagle's solution data, H=92.

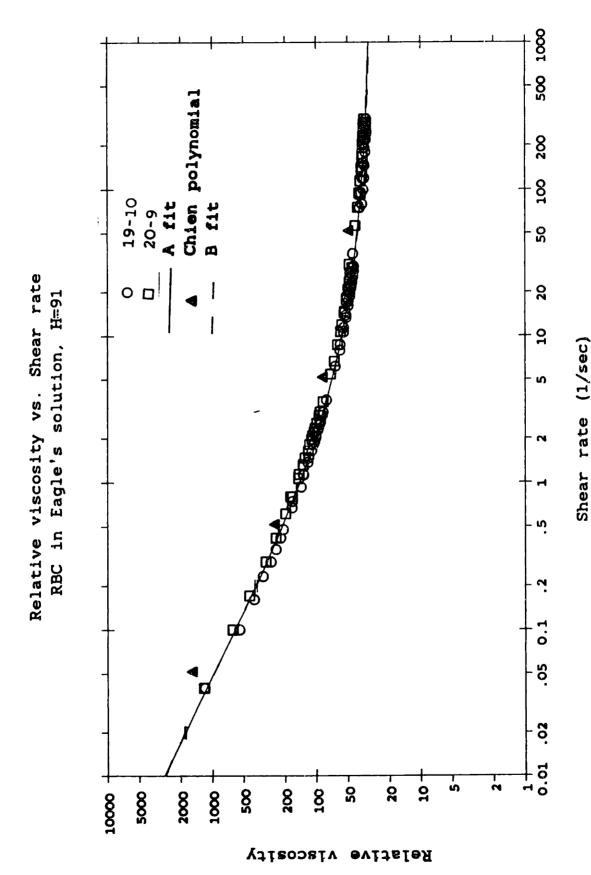


Figure 4-10: Eagle's solution data, H=91.

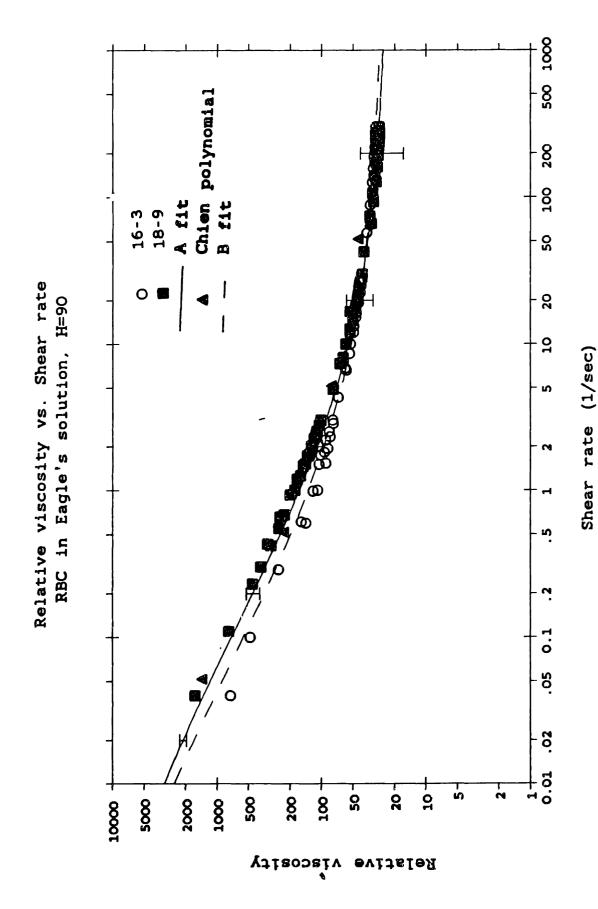


Figure 4-11: Eagle's solution data, H=90.

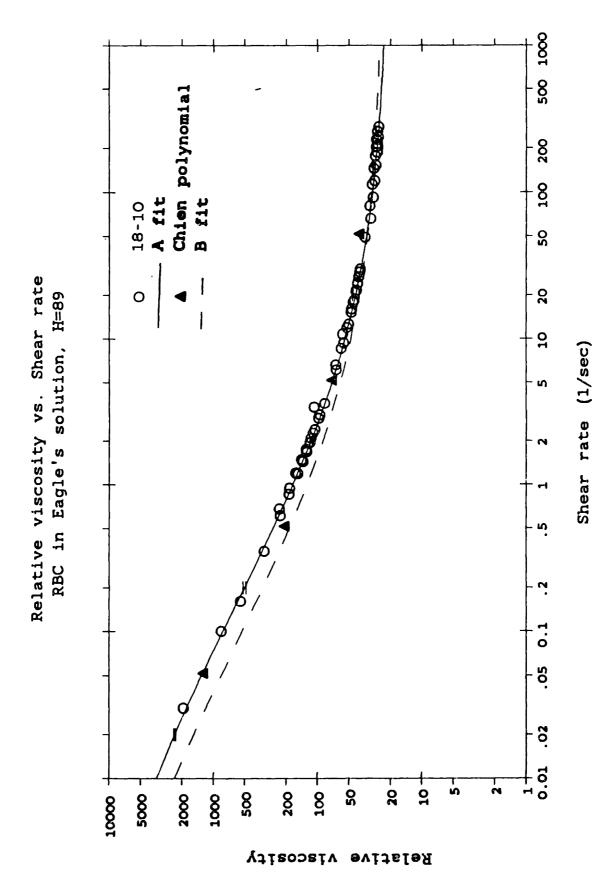
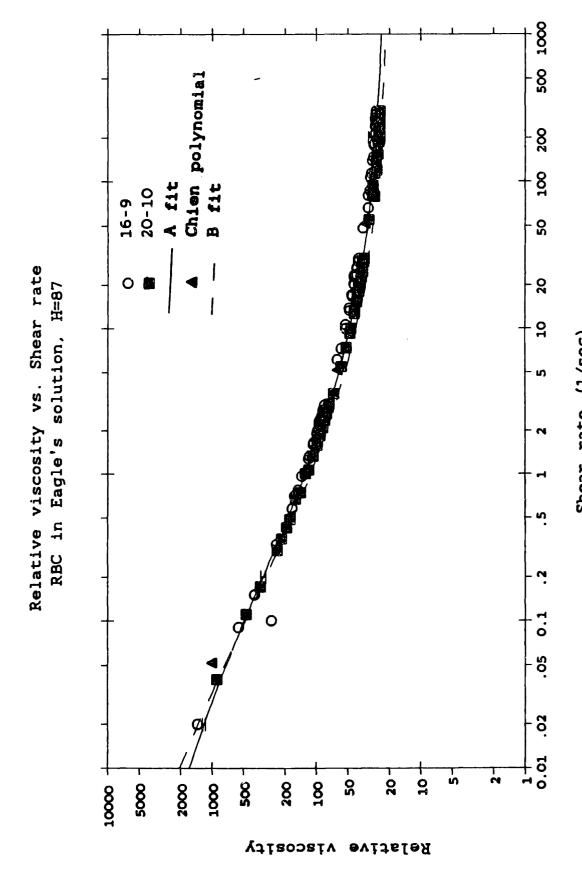
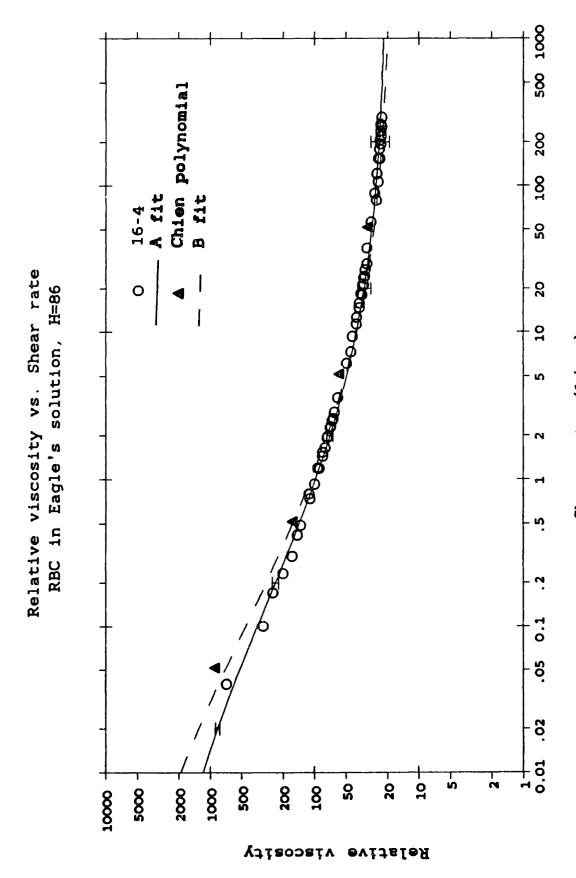


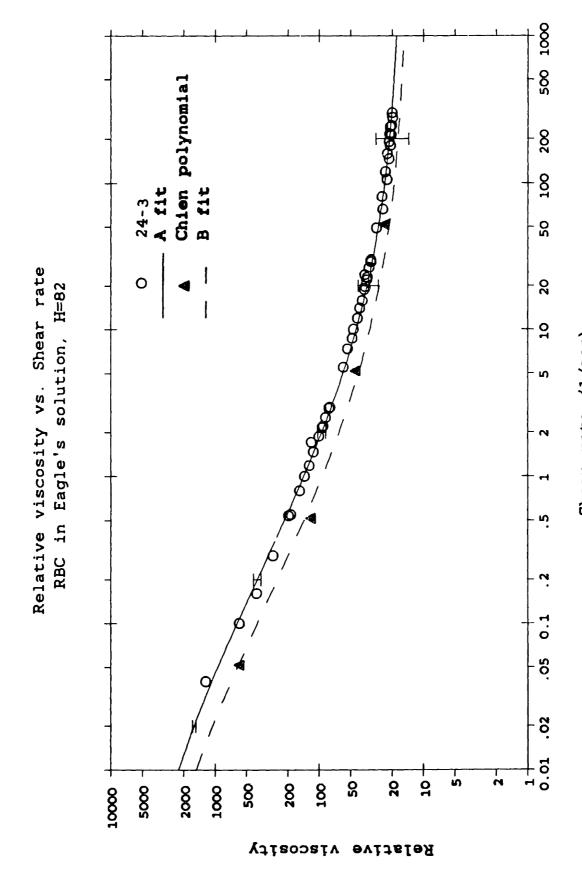
Figure 4-12: Eagle's solution data, H=89.



Shear rate (1/sec) Figure 4-13: Eagle's solution data, H==87.



Shear rate (1/sec) Figure 4-14: Eagle's solution data, H=86.



Shear rate (1/sec) Figure 4-15: Eagle's solution data, H=82.

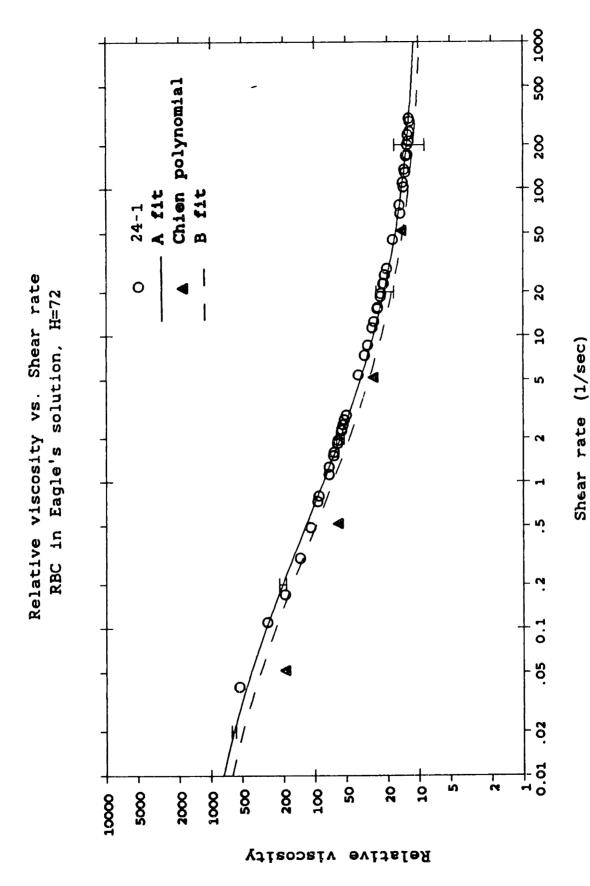


Figure 4-16: Eagle's solution data, H=72.

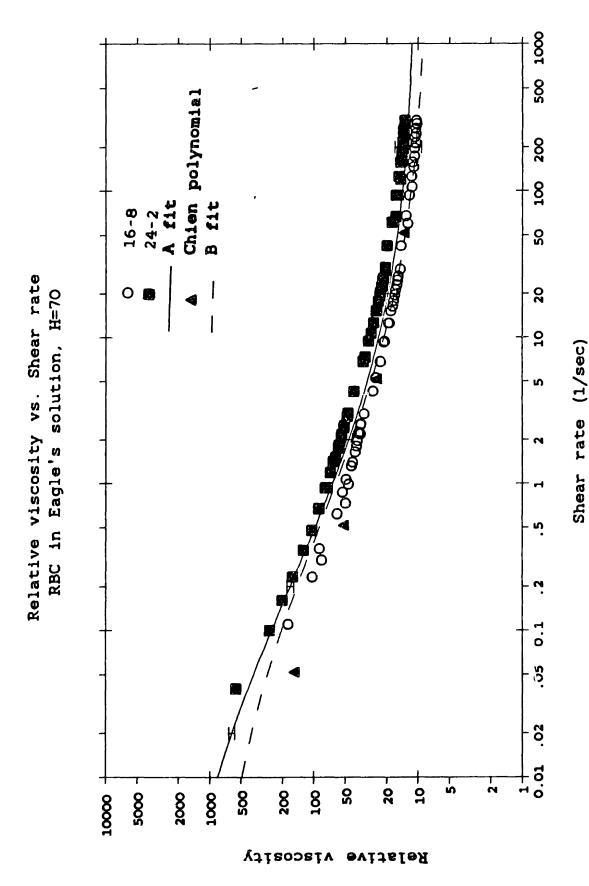
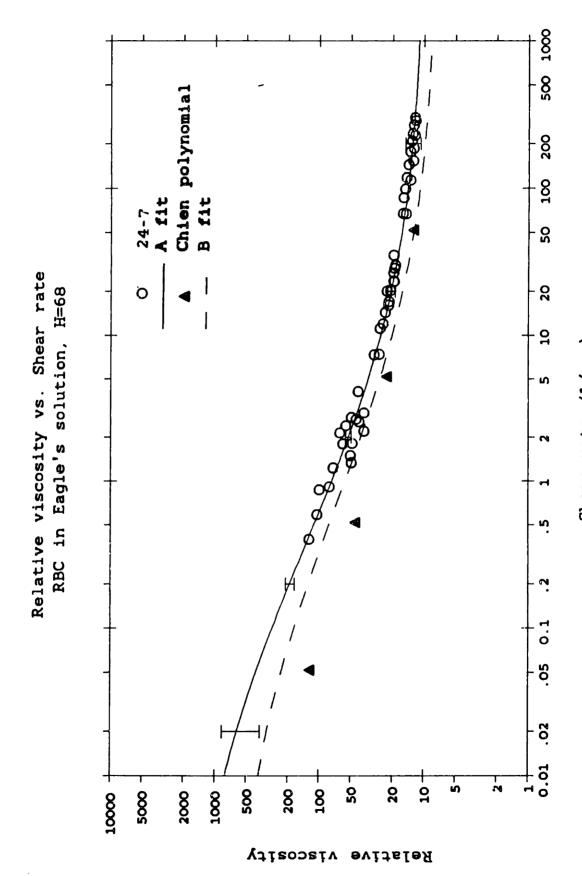


Figure 4-17: Eagle's solution data, il=70.



Shear rate (1/sec)
Figure 4-18: Eagle's solution data, H=68.

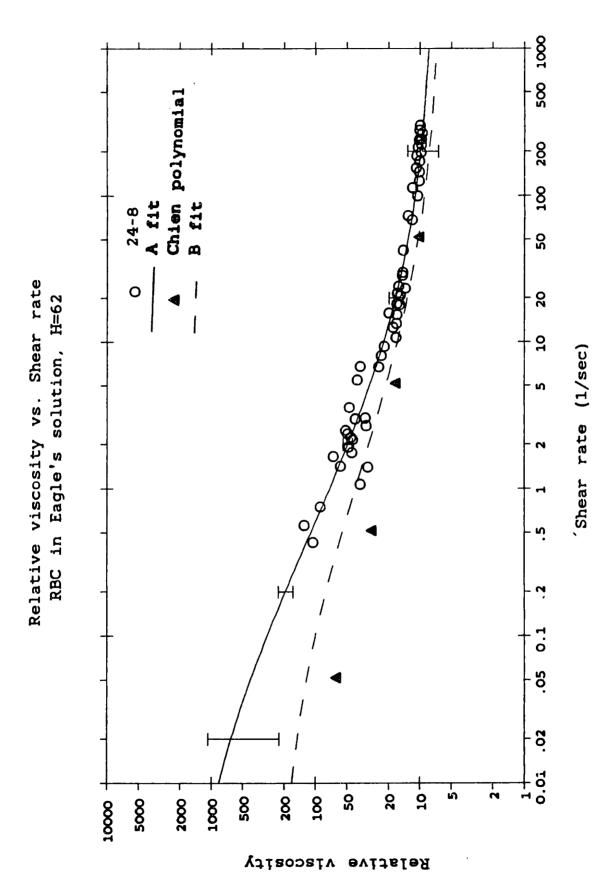


Figure 4-19: Eagle's solution data, H=62.

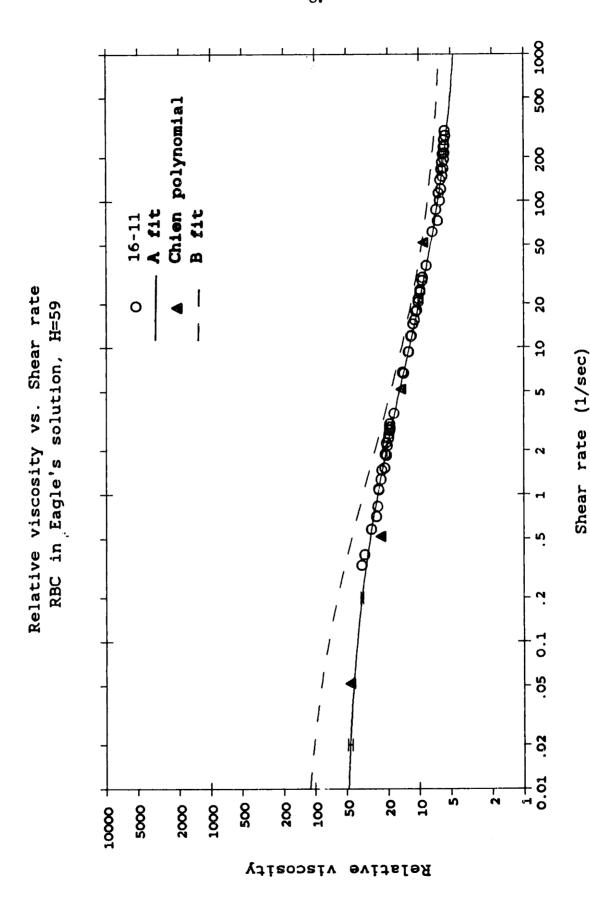


Figure 4-20: Eagle's solution data, H=59.

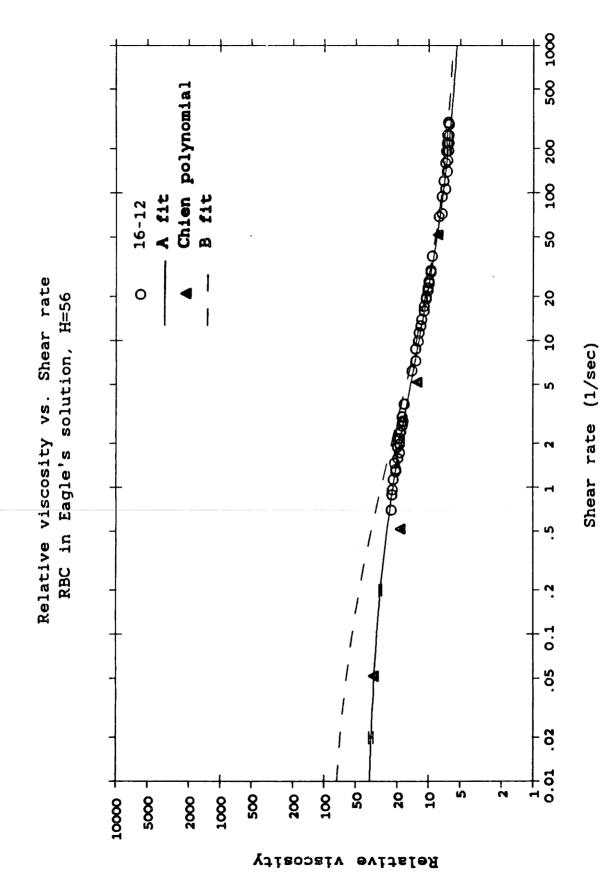
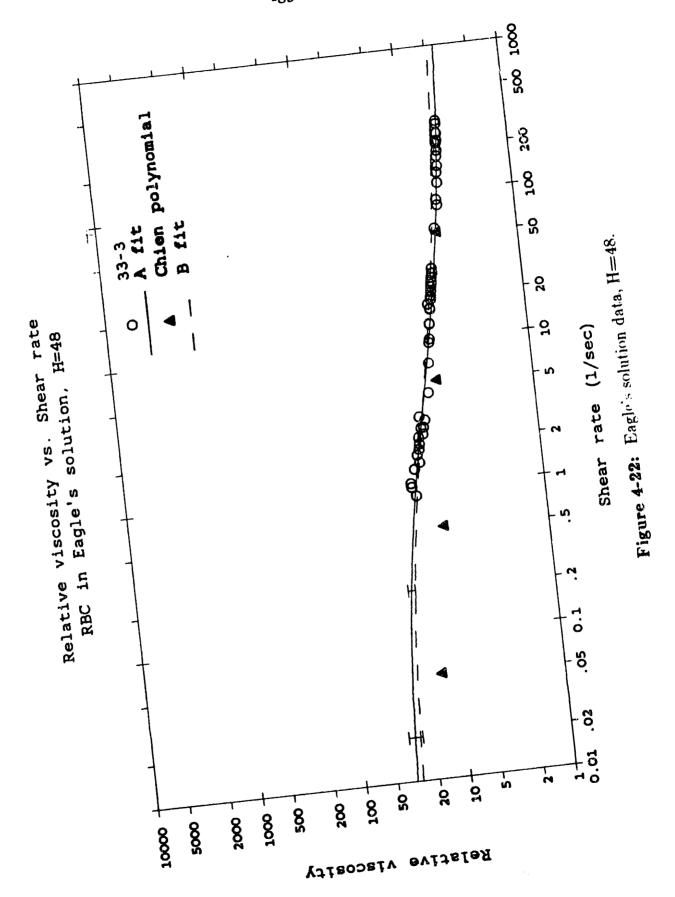


Figure 4-21: Eagle's solution data, H=56.



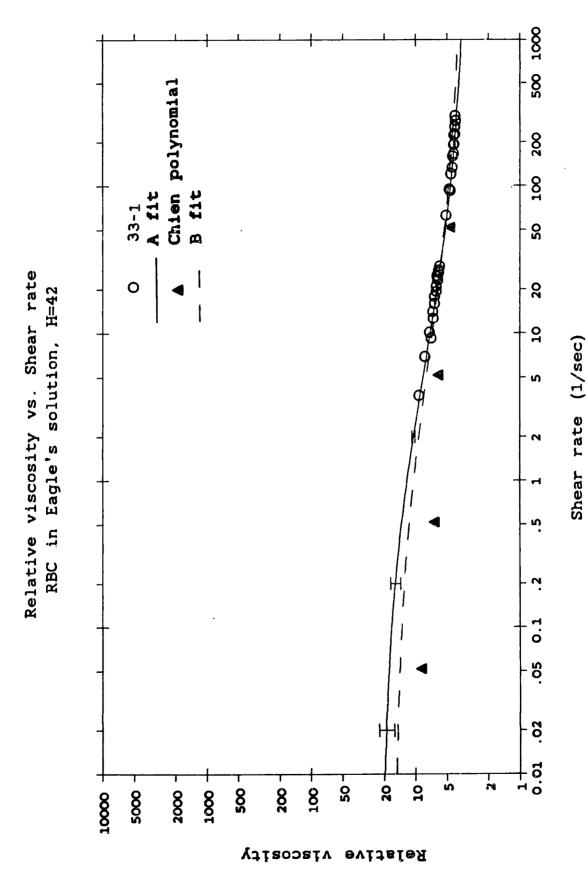
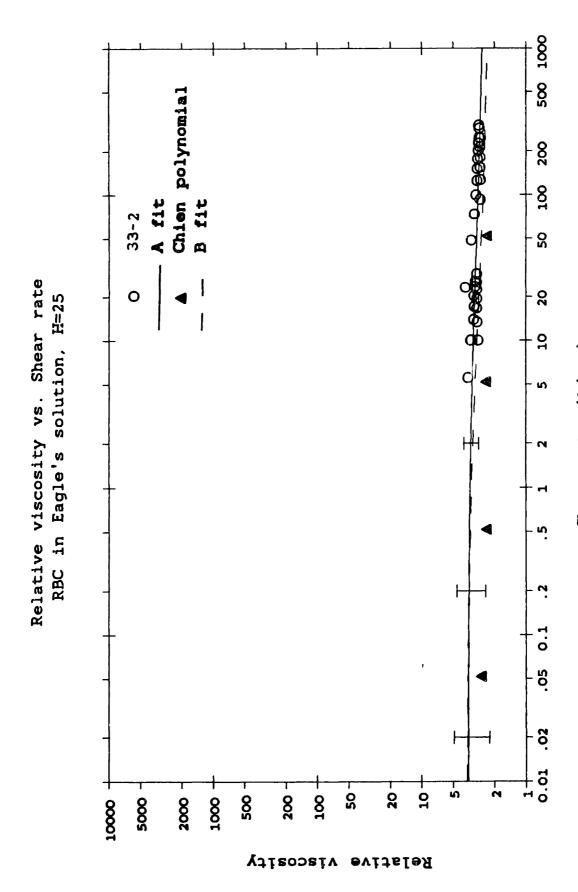


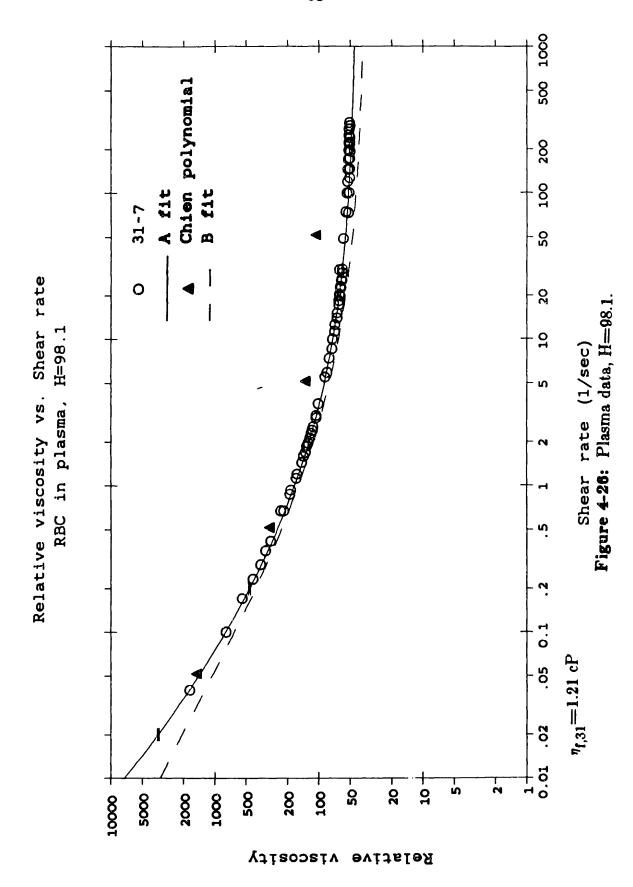
Figure 4-23: Eagle's solution data, H=42.

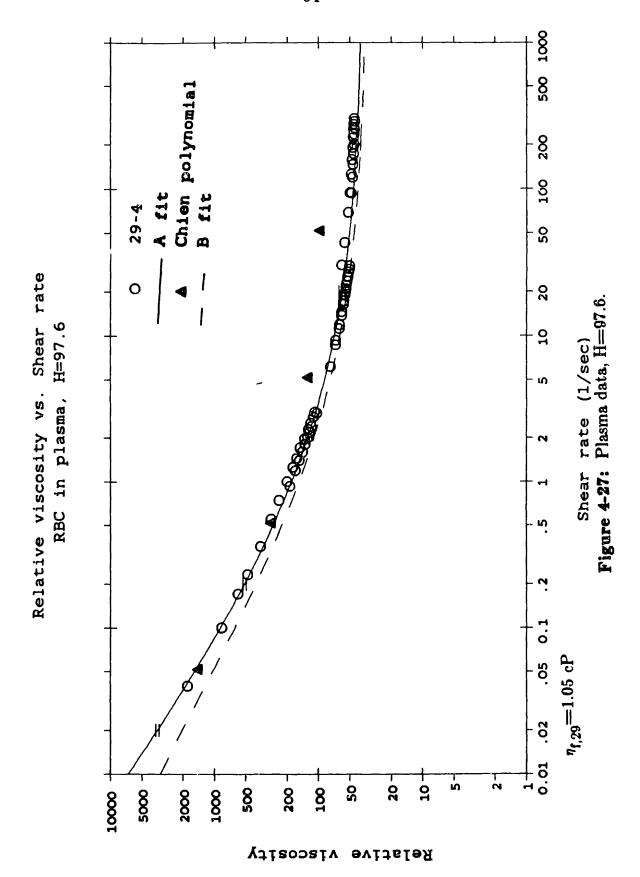


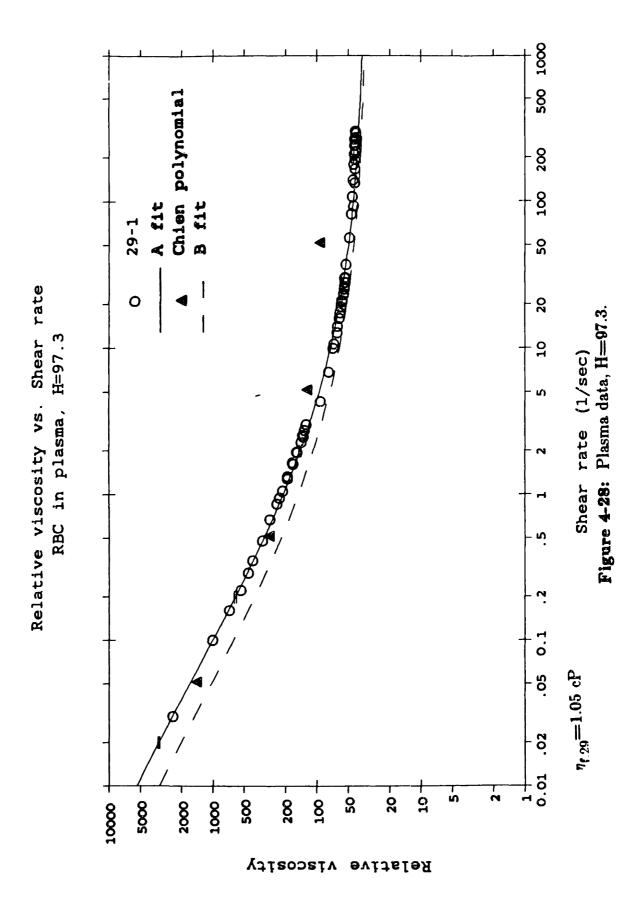
Shear rate (1/sec) Figure 4-24: Eagle's solution data, H=25.

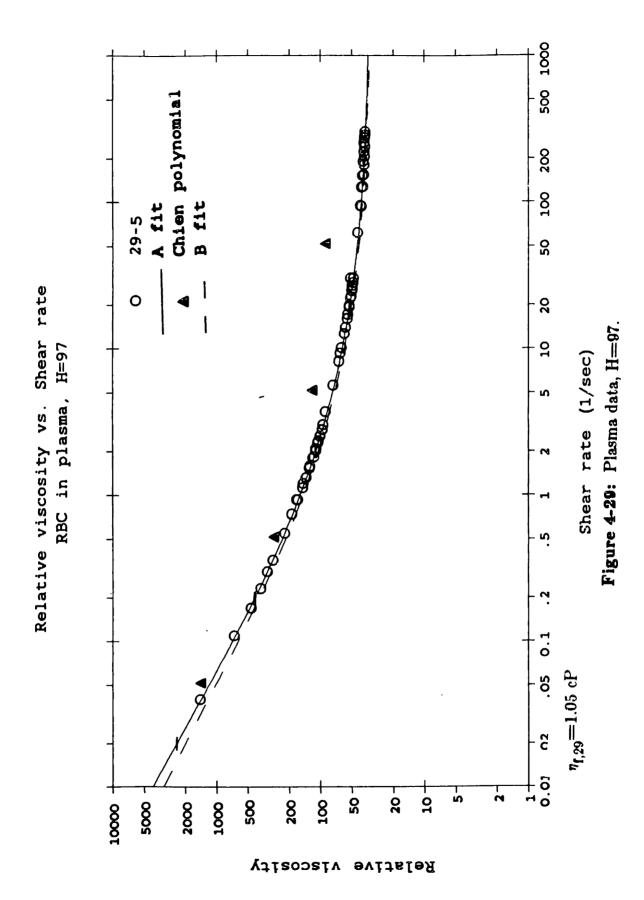
500 1000 Chien polynomial B fit 8 100 A fit 33-2 20 0 Relative viscosity vs. Shear rate 20 0 RBC in Eagle's solution, H=7 ဌ 0.1 .05 .02 0.01 10000 50 - 07 ្ន 5 88 188 1000 2000 200 2000 Relative viscosity

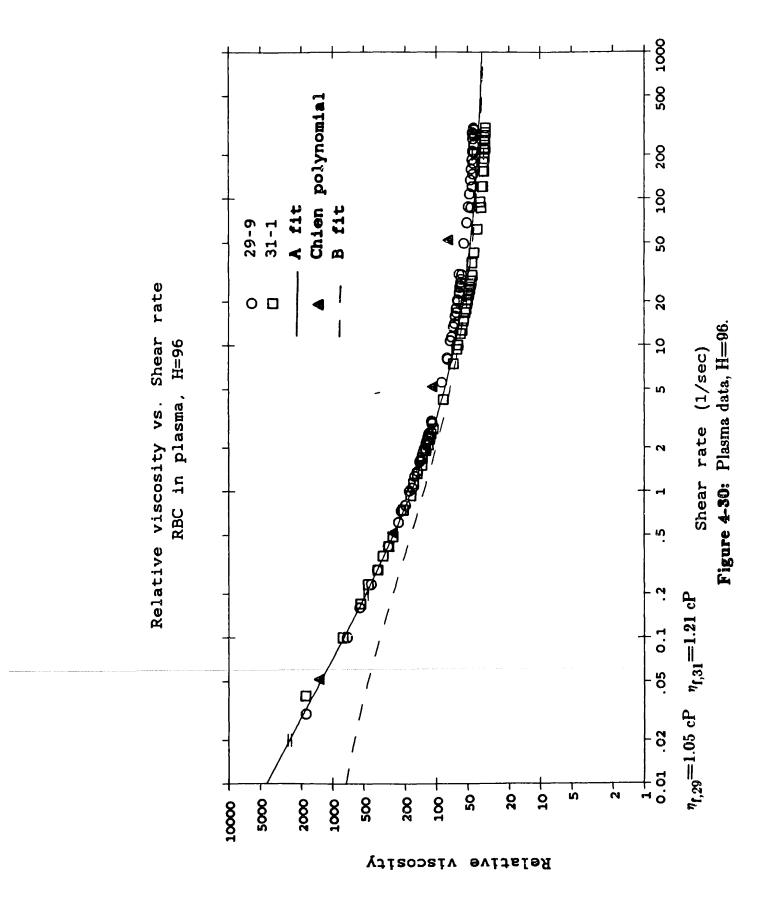
Shear rate (1/sec)
Figure 4-25: Eagle's solution data, H=7.

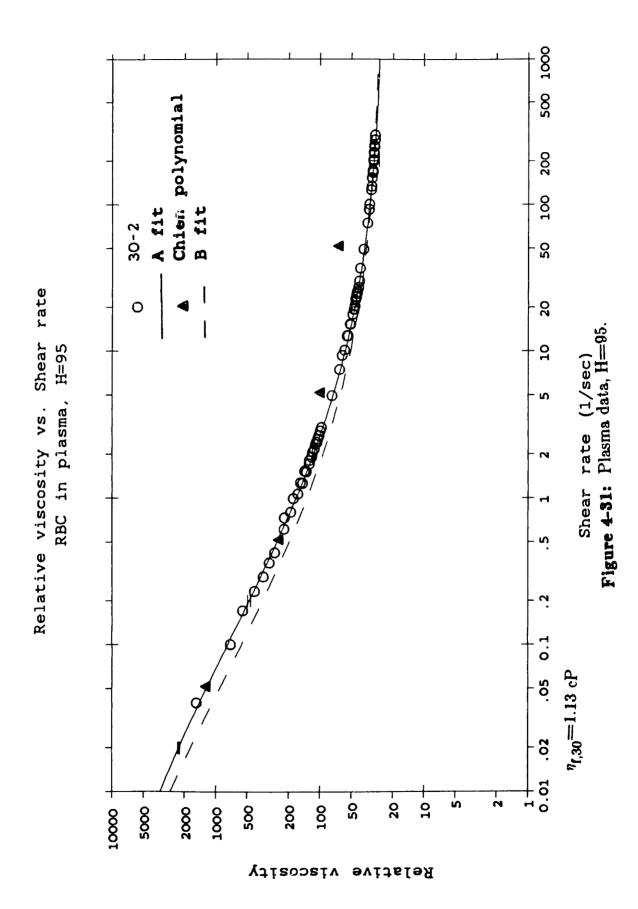


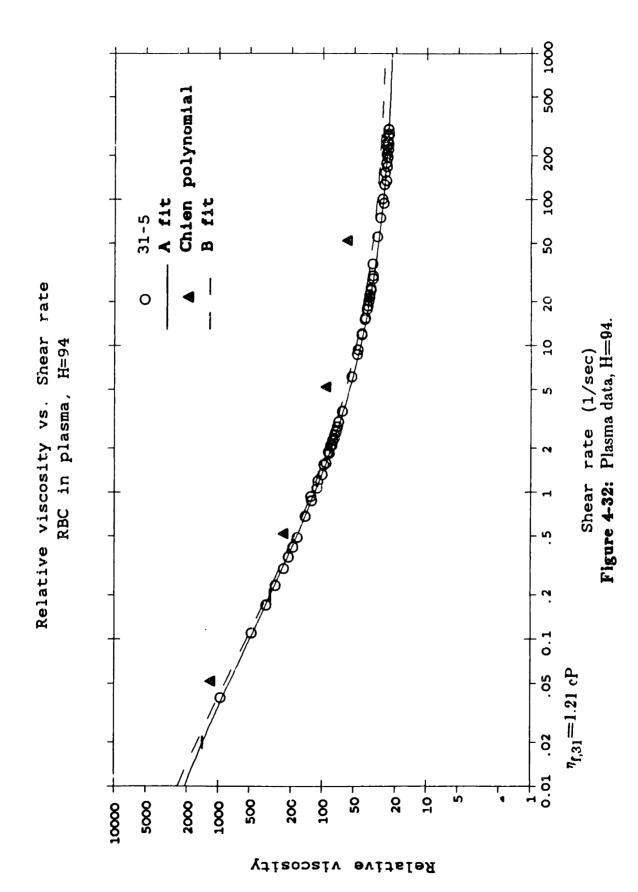


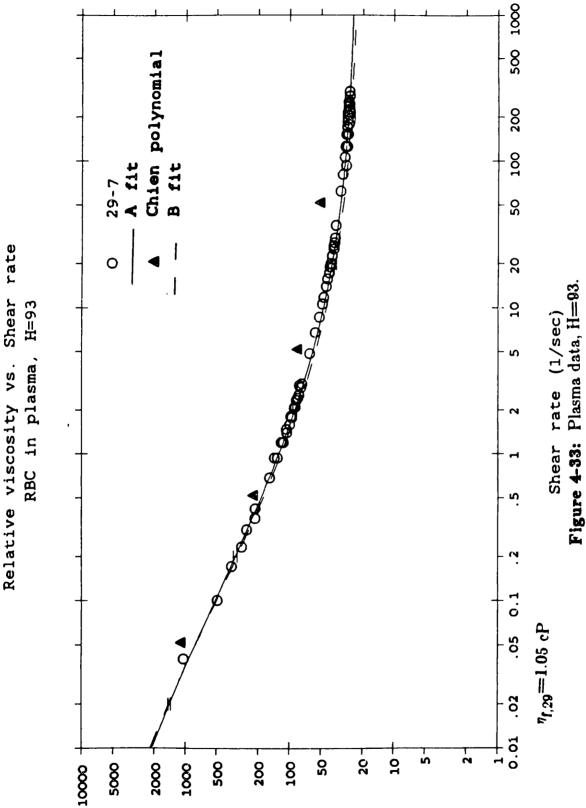




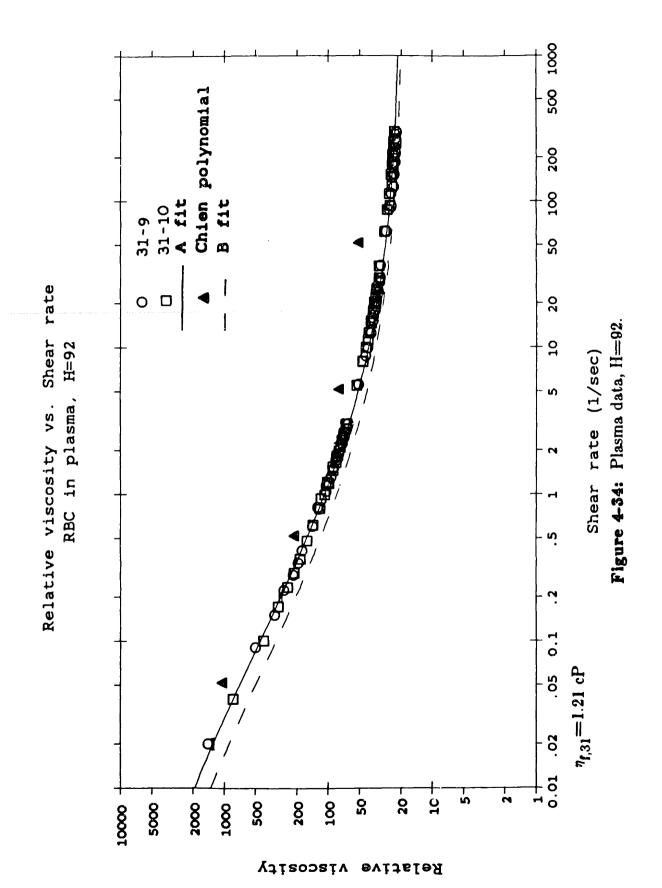


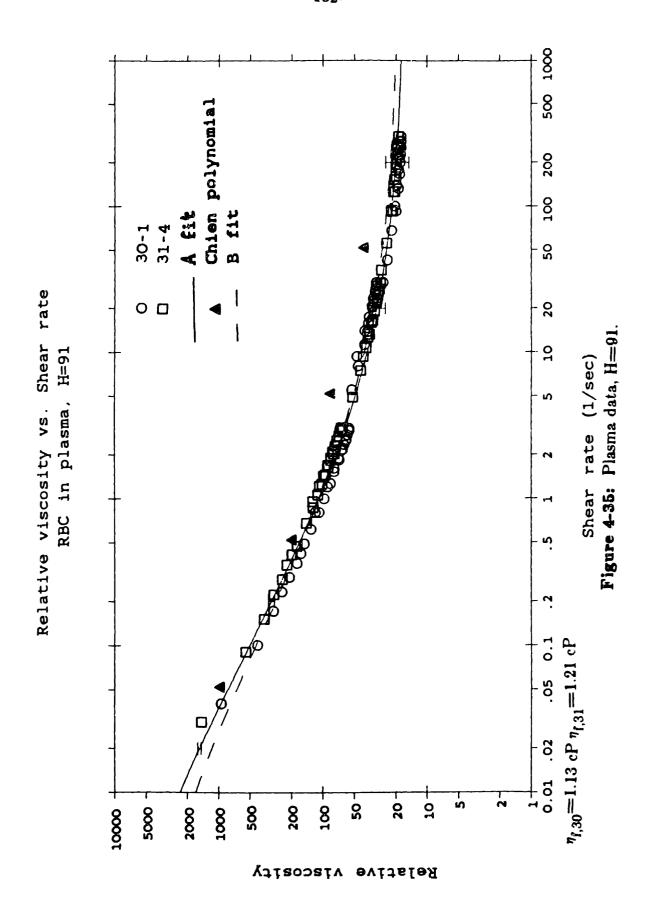


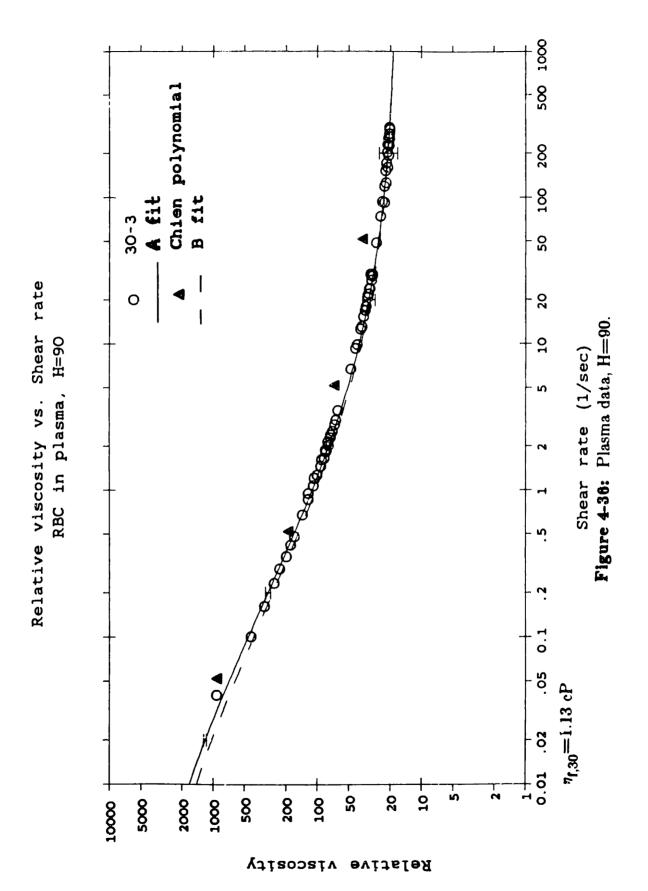


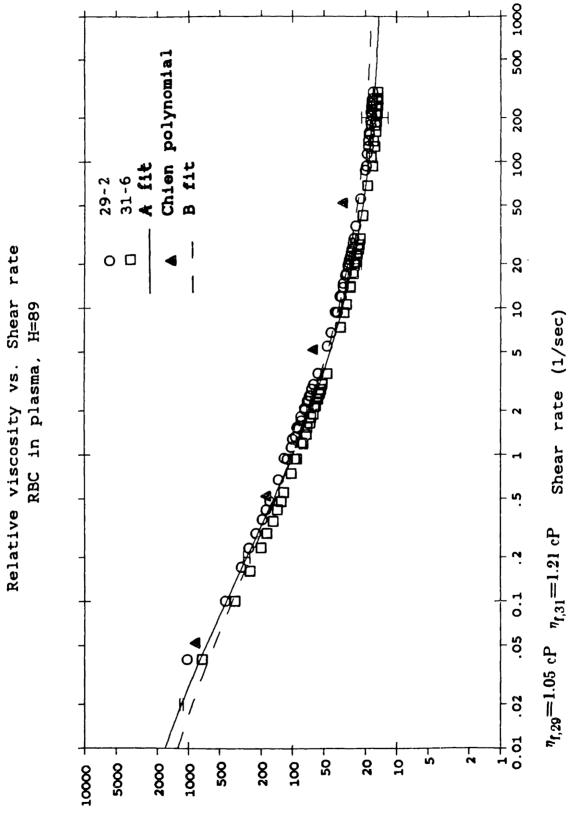


Relative viscosity



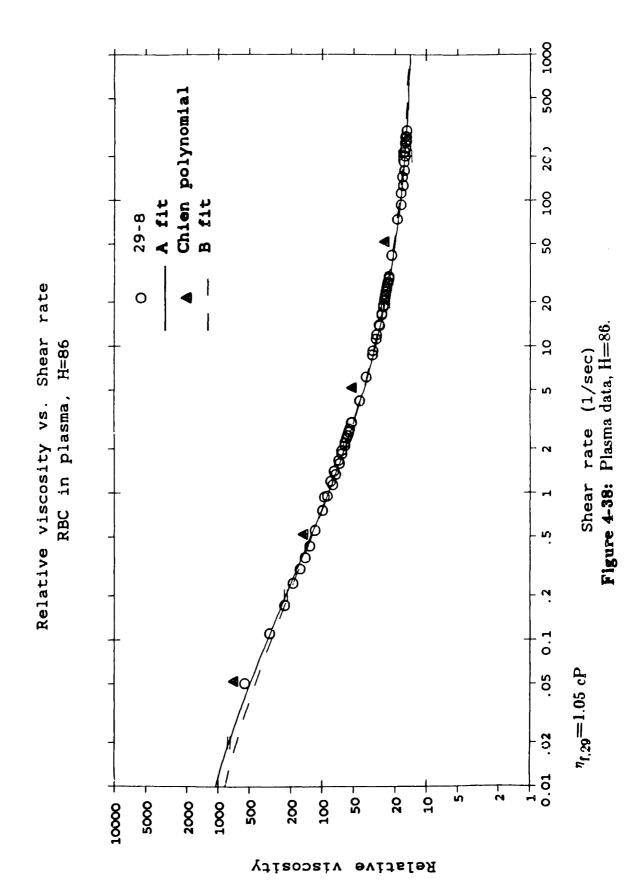


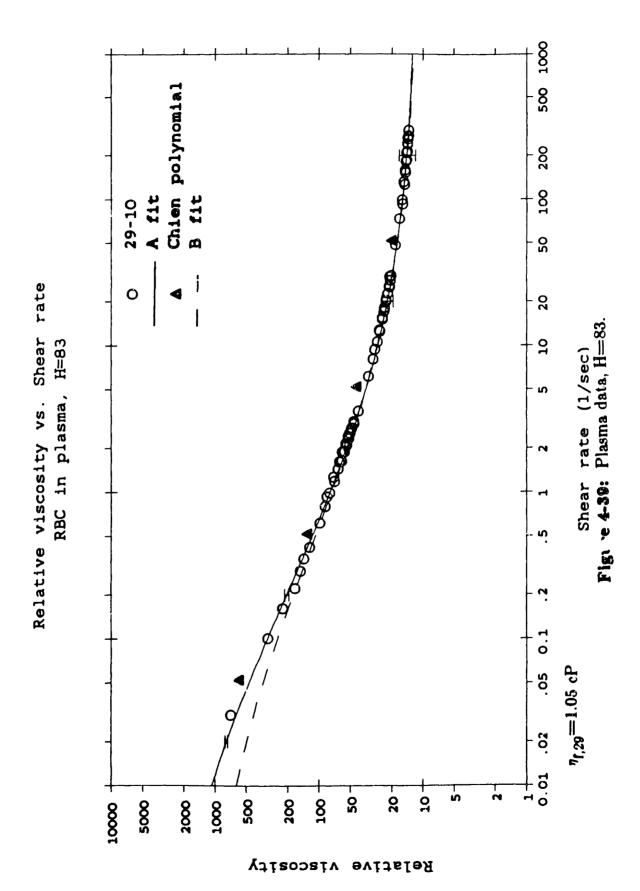


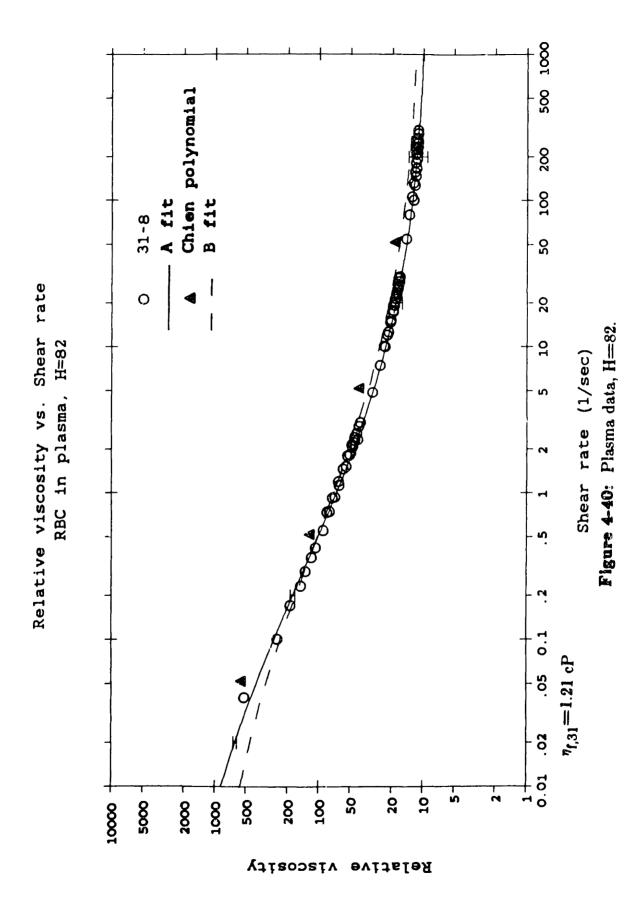


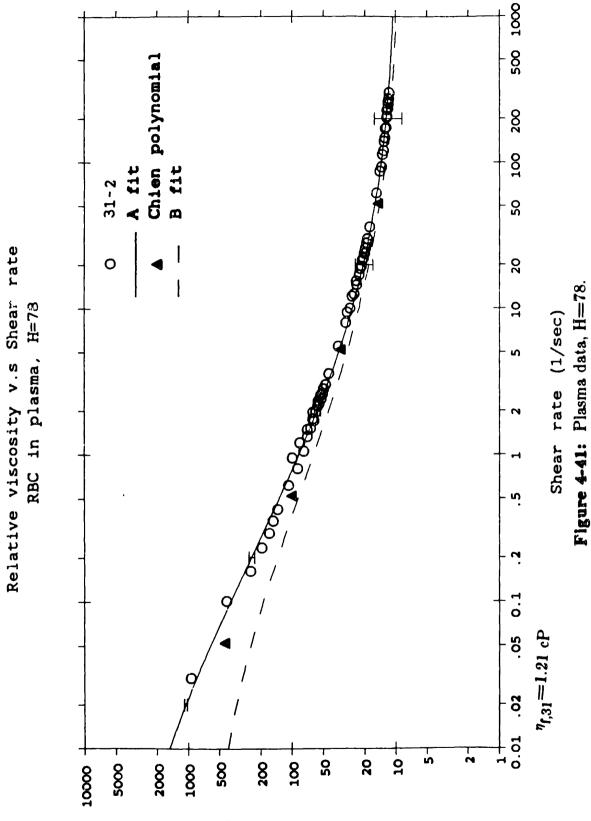
Relative viscosity

Figure 4-37: Plasma data, H=89.

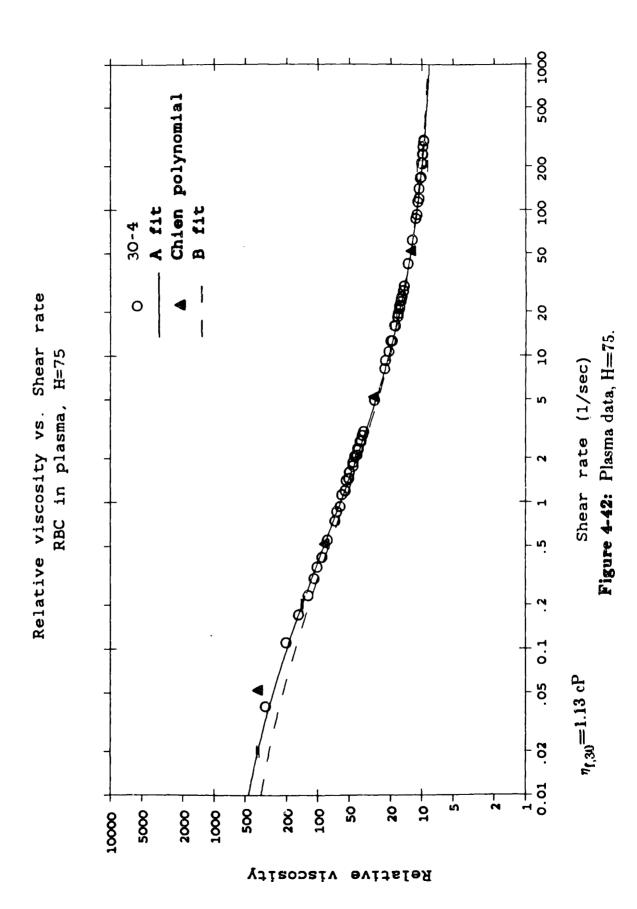


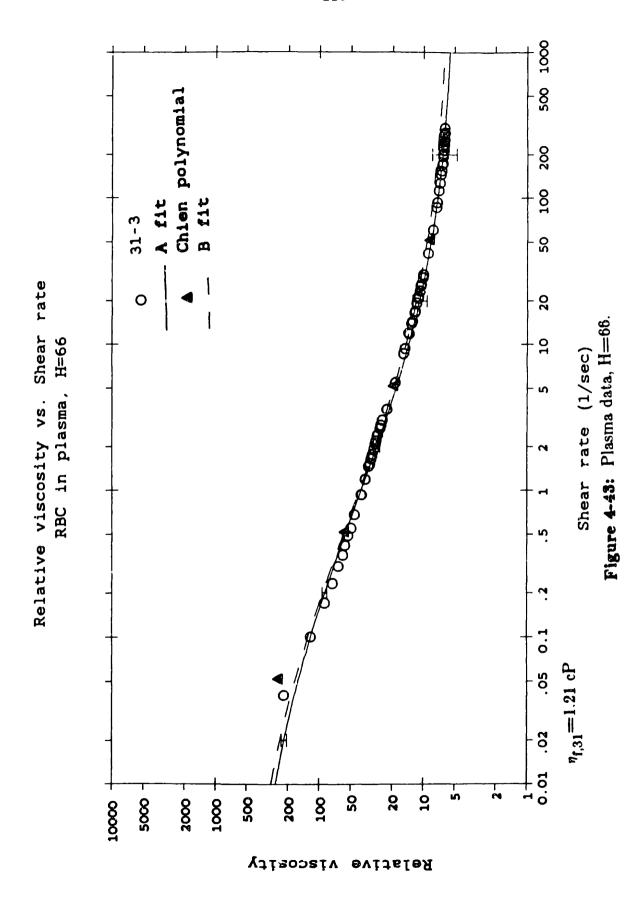


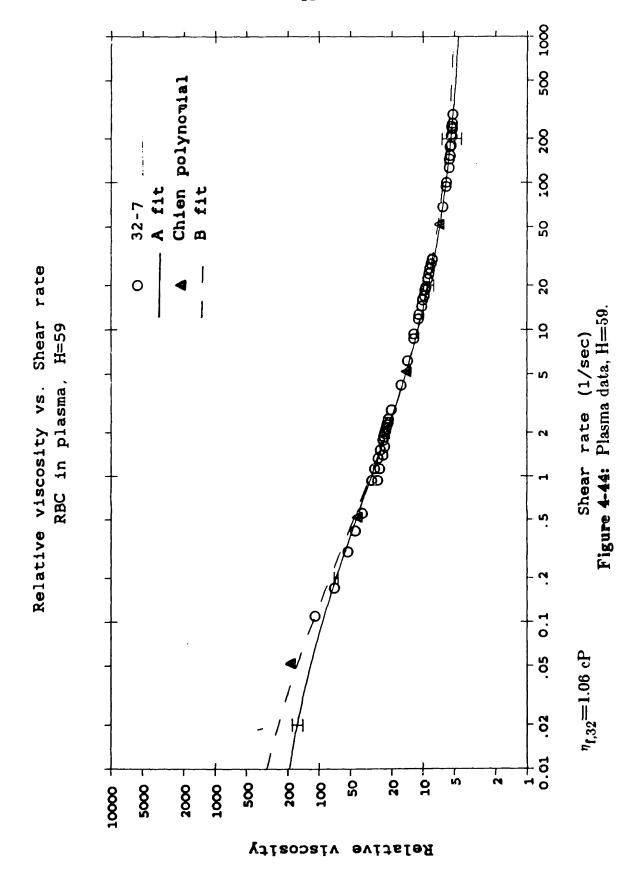


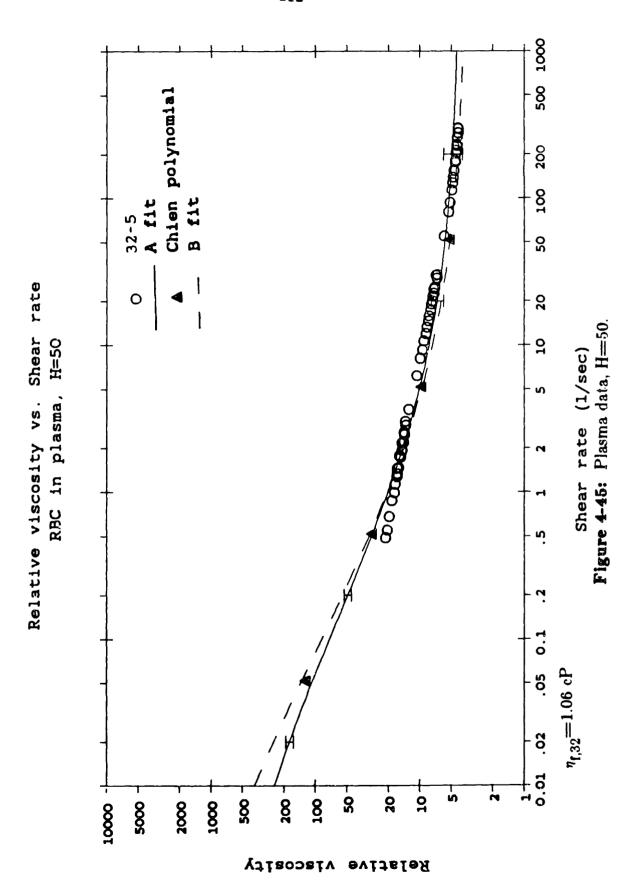


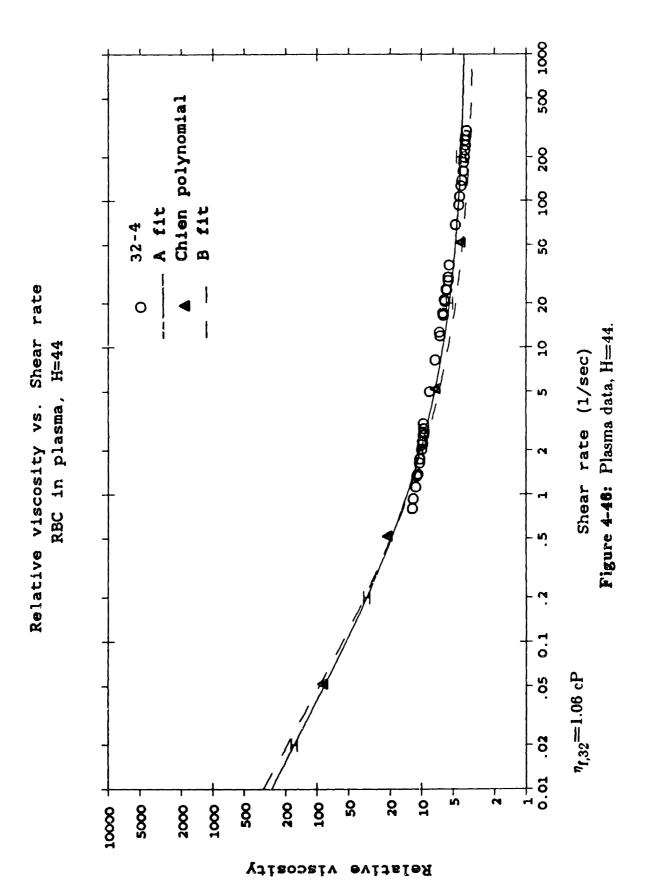
Relative viscosity



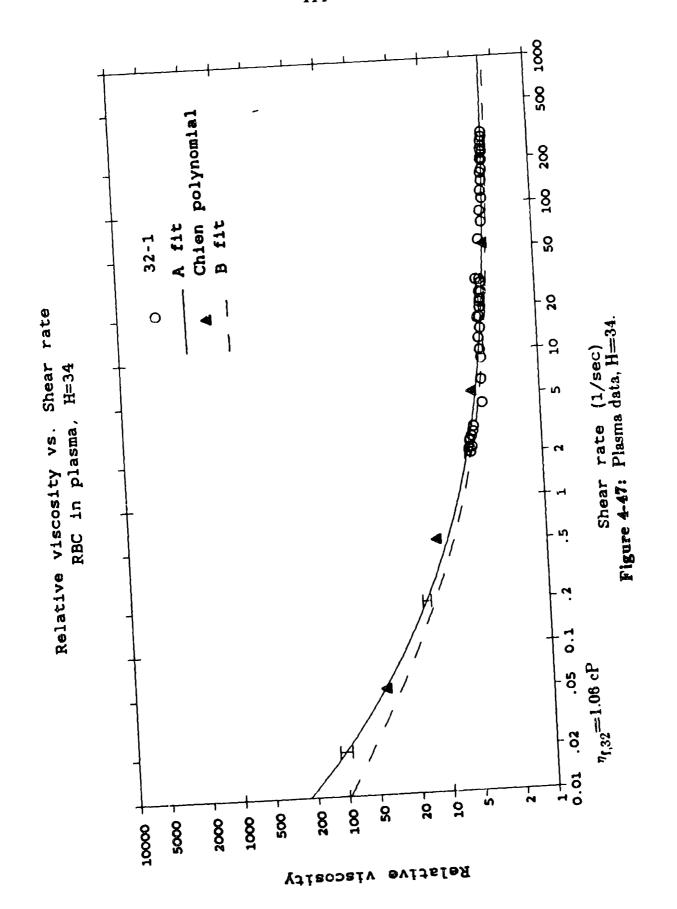


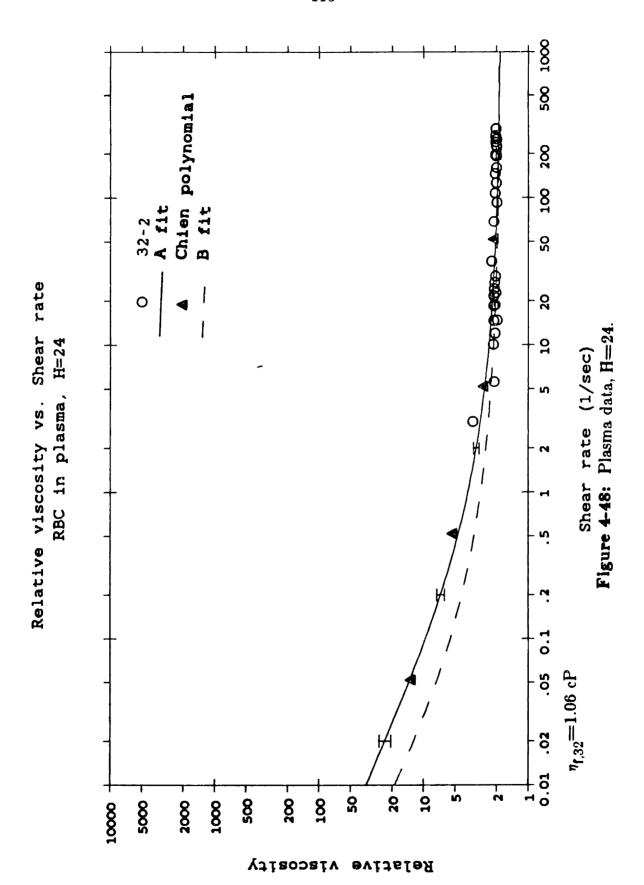


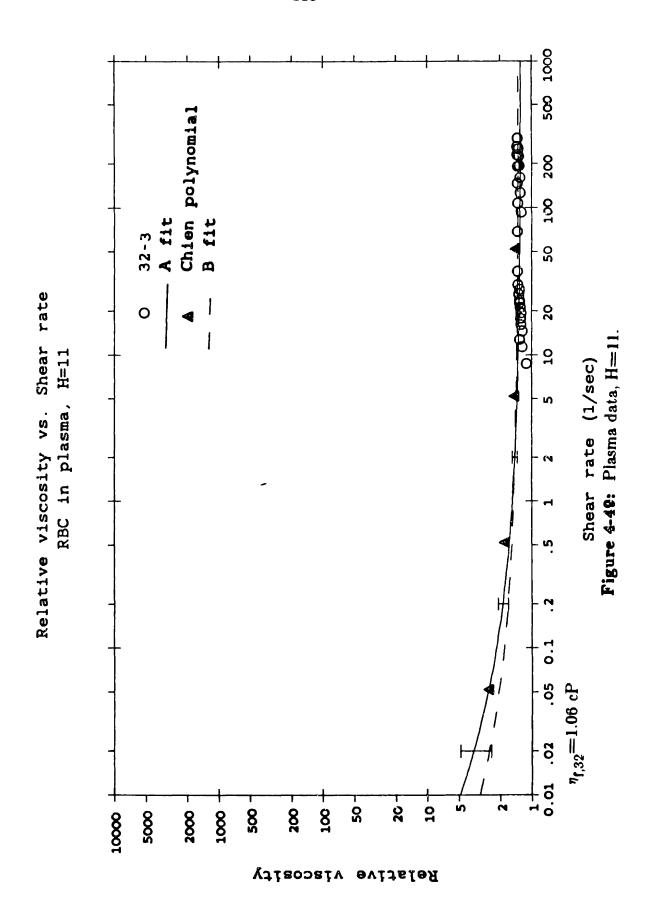




F







three groups along the x-axis. This is an artifact resulting solely from the choice of the ranges of operation used and the selection of data points.

The data follows the trends for blood viscosity reported in the literature and reviewed in Chapter 2. Shear-thinning behavior is observed in all cases. At low shear rates, the viscosity seems to approach infinity at hematocrits above 90 and seems to level to an asymptote at hematocrits below 60, but there is not sufficient data to make a judgement as to the existence of a yield stress. Asymptotic values for viscosity are approached at the highest obtainable shear rate (300 sec⁻¹) for all plots, but only in the most concentrated suspensions (H>94) do they actually appear to be reached. The sensitivity of the viscometer limits the minimum shear rate at which data can be obtained: Above H=70, this minimum γ is on the order of 0.1 sec⁻¹ or less; above H=50, it is between 0.1 and 1 sec⁻¹; below 40, the minimum is around 1 sec⁻¹.

A general pattern of increasing viscosity with increasing hematocrit is observed, with $\frac{d\eta}{dH}$ greatest at the highest concentrations. For example, at $\gamma=100$ sec⁻¹, an increase in hematocrit from 89 to 97 (a 6.7% increase) increases viscosity by over 70%; while increasing hematocrit from 42 to 48 (a 14% increase) increases viscosity by only about 15%. Even at hematocrits above 98, however, blood is very fluid.

4.3 Viscosity of RBC suspended in plasma

The data for RBC suspended in plasma solutions are shown in Figures 4-26 to 4-49 (pages 93 to 116). The range of hematocrits is from 98.1 to 11. Relative viscosities were calculated from the individual plasma viscosities for each sample, which are tabulated in Appendix F. The symbol conventions are the same as for the saline suspensions. For the data of Chien et al., η_f was calculated as 1.18 cP in a

manner analogous to that used for Ringer's saline. The descriptive comments applied to Eagle's solution suspensions in the previous section qualitatively apply to plasma suspensions. Because the plasma samples are for the most part more viscous than their corresponsing saline samples, data could be obtained at somewhat lower shear rates but again, below hematocrits of about 40 it was not possible to get data over a broad spectrum of shear rates.

4.4 Comparison of saline and plasma data

Data from the two types of RBC suspensions are plotted together as η_r vs. H in Figure 4-50 and as η vs. H in Figure 4-51. Values are shown at shear rates of 200, 20, 2, and 0.2 sec⁻¹. In order to express values for all hematocrits at precisely each of these shear rates, the points shown are not actual data but are values from the Quemada equation fits (Fit A on the individual data plots) for each hematocrit. These fits are close enough to the actual data values that there would be no discernible difference on Figures 4-50 and 4-51. For the absolute viscosity, plasma suspension η_r was multiplied by a value of 1.1 cP for average plasma viscosity. Points are shown only where data was actually taken, thus there is no representation in this figure of the low hematocrit, low shear rate regions.

There is a greater amount of scatter from a monotonic relationship with hematocrit at low shear rates, where the data is less reliable, and a greater scatter in the saline suspensions versus the plasma suspensions. The relative values for Eagle's suspensions are consistently higher than those for plasma, although on an absolute basis, the plasma suspension viscosities are higher. For example, at H=96, the ratio of the relative viscosity in saline to that in plasma is between 1.29 and 1.49 at the shear rates given. For H=94 the range is 1.87 to 1.56; for H=90, 1.38 to 1.40; H=86, 1.06 to 1.40. There is no clear trend of the ratios increasing or

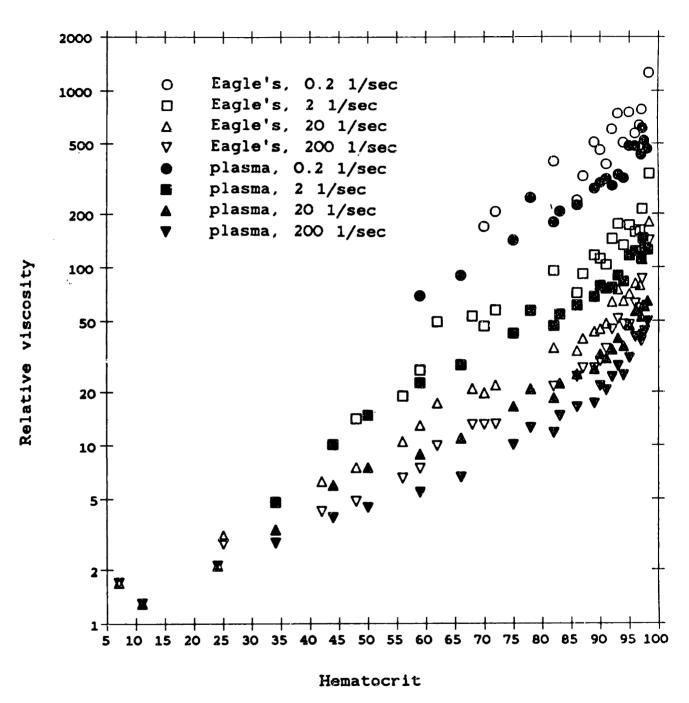


Figure 4-50: Relative viscosity vs. Hematocrit for Eagle's and plasma suspensions

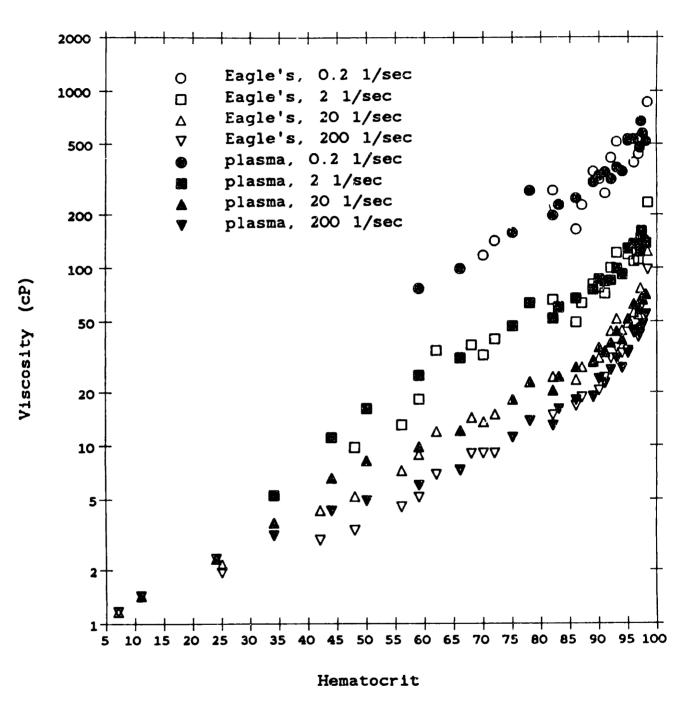


Figure 4-51: Absolute viscosity vs. Hematocrit for Eagle's and plasma suspensions

decreasing with shear rate. On a scale of absolute viscosities, the ratios just given would be decreased by a factor of about 0.6.

Figure 4-51 demonstrates how, on an absolute scale, the differences between saline and plasma suspensions decrease in the limit of high cell concentration. Above H=80, the data cannot be clearly distinguished between suspensions, particularly at high shear rates, and it appears at this point that an inversion phenomenon has taken place, with the cells behaving physically as the continuous phase. By an analysis of the behavior of the parameters for equation (2.11), Quemada [1981] has also suggested the importance of inversion, as will be discussed further in Chapter 5.

From Figures 4-50 and 4-51, it can be seen that, while the absolute viscosities become equal, the differences in relative viscosity are significant at high hematocrits. Viscosity becomes independent of η_f as the amount of suspending fluid becomes small, and the implication is that relative viscosity becomes a meaningless parameter in the limit of high hematocrits.

The decrease in relative viscosity with increasing viscosity of the continuous phase is a well-known aspect of the emulsion behavior of blood as described in Chapter 2. Dintenfass [1968b] suggests a modified form of the Taylor equation for emulsions, equation (2.5), to calculate the internal viscosity of the red cell:

$$\eta_r = \frac{1}{(1 - c \cdot T)^{2.5}} \tag{4.1}$$

where $T(\eta_i, \eta_f)$ is the Taylor parameter described for equation (2.5) on page 22 and c is the cell volume fraction. The shear rate dependence of equation (4.1) comes from the internal viscosity of the red cell, which represents not only the cytoplasmic viscosity but also includes the effects of the red cell membrane. As discussed previously in Section 2.4, this equation has limited applicability in that it is only valid when the shear rate is high enough to prevent rouleau formation. Fits of the

data at $\gamma = 52 \text{ sec}^{-1}$ yield values for η_i around 2 cP, which is comparable to values found in the literature [Dintenfass, 1971]. The Dintenfass equation is used in the next section to provide an evaluation of how viscosity is related to changes in the red cell properties.

4.5 Effect of erythrocyte age and anticoagulant

It has been known for some time that the viscosity of blood increases with age [Erslev and Atwater, 1963; Usami et al., 1971]. Erythrocytes have been shown to have increased hemoglobin concentration as they get older, and this along with possible loss of membrane deformability may increase the intrinsic viscosity of the cell.

The blood units obtained from the Red Cross were stored in a refrigerator at a temperature of about 40 °F. There was a noticeable increase in the viscosity of the samples with longer storage times. This effect was largest at low shear rates. For example, the plot of H=92 in Eagle's solution, Figure 4-9, page 76, shows data for three samples from three units: Two (16-5 and 20-8) had their viscosities measured 10 days before the expiration date (11 and 15 days after collection, respectively) and one (18-4) was measured 2 days before expiration (19 days after collection). At 300 sec⁻¹ the oldest sample has the highest viscosity, but its value is almost identical to that of one of the fresher samples and is 1.3 times that of the other. As shear rate decreases, the difference in viscosity increases substantially. At $\gamma = 0.3 \text{ sec}^{-1}$ the oldest sample has a viscosity 1.75 times that of the other two. This is not attributable to storage in the laboratory refrigerator because both samples 16-5 and 18-4 were measured two days after being obtained from the Red Cross.

Relevent samples which illustrate the effect of storage time are described in

sample	suspending fluid	anti- coagulant	Н	d.s.c.	d.b.e.	v.s.f. (cP)
16-5 20-8 18-4 19-10 20-9 16-3 18-9 16-9 20-10 16-8 24-2 29-9 31-1 30-1 31-4	Eagle's Eagles	CPD CPD-A1 CPD-A1 CPD-A1 CPD-A1 CPD CPD-A1 CPD CPD-A1 CPD CPD-A1 CPD CPD-A1 AS-1 AS-1 AS-1 AS-1	92 92 92 91 91 90 90 87 87 70 96 96 91	11 14 25 22 25 11 19 11 25 11 35 9 11 10	10 10 2 13 10 10 10 10 10 0 33 31 32 31	0.69 0.69 0.69 0.69 0.69 0.69 0.69 0.69
29-2 31-6	plasma plasma	AS-1 AS-1	89 89	-9 11	33 31	1.05 1.21

Table 4-I: Description of samples which illustrate effect of erythrocyte age.

d.s.c.--days since collection
d.b.e.--days before expiration
v.s.f.--viscosity of suspending fluid

sample	visc. (cP) @ 0.3 1/sec	rel. visc.	visc. (cP) @ 3 1/sec	rel. visc.	visc. (cP) @ 30 1/sec	rel. visc.
16-5	208	301.4		100.4	38.7	56.1
20-8 18-4	223 392	323.2	66.0 99.3	95.7 143.9	32.5 43.2	47.1 62.6
19-10	184	568.1 266.7	59.0	85.5	29.6	
20 -9	206	298.6	63.0	91.3	31.0	44.9
16-3 18-9	175 260	253.6	53.0 89.0	76.8 129.0	27.5 27.7	39.9
16-9	170	376.8 246.4	56.0	81.2	27.7 27.0	40.1 39.1
20-10	161	233.3	51.0	73.9	23.6	34.2
16-8 24-2	58 95	84.1	23 .0	33.3	10.2	14.8 20.3
29-9	382	137.7 363.8	114.0	46.4 108.6	14.0 59.2	20.3 56.4
31-1	438	362.0	126.0	104.1	54.0	44.6
30-1	233	206.2	62.0	54.9	34.0	30.1
31-4 29-2	293 232	242.1 221.0	65.0	66.1 61.9	33.6 26.6	
31-6	210	173.6	61.5	50.8	26.7	
sample	visc. (cP) @ 300 1/sec	VISC.	int. visc. (d 30 1/sec	P) @ 1	nt. visc. (cP)	•
sample	300 1/sec	VISC.	30 1/sec	3 2. 4 9	00 1/ sec 2	.08
16-5 20-8	31.2 24.7	45.2 35.8	30 1/sec	2. 49 2.15	2 1	.08 .70
16-5 20-8 18-4	31.2 24.7 32.5	45.2 35.8 47.1	30 1/sec	2.49 2.15 2.74	2 1 2	.08 .70 .15
16-5 20-8 18-4 19-10 20-9	31.2 24.7 32.5 22.5 23.5	45.2 35.8	30 1/sec	2.49 2.15 2.74 2.16 2.25	2 1 2 1 1	.08 .70 .15 .69
16-5 20-8 18-4 19-10 20-9 16-3	31.2 24.7 32.5 22.5 23.5 20.4	45.2 35.8 47.1 32.6 34.1 29.6	30 1/sec	2.49 2.15 2.74 2.16 2.25 2.20	2 1 2 1 1	.08 .70 .15 .69 .76
16-5 20-8 18-4 19-10 20-9 16-3 18-9	31.2 24.7 32.5 22.5 23.5 20.4 19.0	45.2 35.8 47.1 32.6 34.1 29.6 27.5	30 1/sec	2.49 2.15 2.74 2.16 2.25 2.20 2.21	2 1 2 1 1 1	.08 .70 .15 .69 .76 .67
16-5 20-8 18-4 19-10 20-9 16-3 18-9 16-9 20-10	31.2 24.7 32.5 22.5 23.5 20.4 19.0 18.0 16.7	45.2 35.8 47.1 32.6 34.1 29.6 27.5 26.1 24.2	30 1/sec	2.49 2.15 2.74 2.76 2.25 2.20 2.21 2.89 2.49	2 1 2 1 1 1 1 1	.08 .70 .15 .69 .76 .67 .56
16-5 20-8 18-4 19-10 20-9 16-3 18-9 16-9 20-10 16-8	31.2 24.7 32.5 22.5 23.5 20.4 19.0 18.0 16.7	45.2 35.8 47.1 32.6 34.1 29.6 27.5 26.1 24.2	30 1/sec	2.49 2.15 2.74 2.16 2.25 2.20 2.21 2.89 2.49 6.47	2 1 2 1 1 1 1 1 1	.08 .70 .15 .69 .76 .56 .86
16-5 20-8 18-4 19-10 20-9 16-3 18-9 16-9 20-10 16-8 24-2	31.2 24.7 32.5 22.5 23.5 20.4 19.0 18.0 16.7 7.0 9.1	45.2 35.8 47.1 32.6 34.1 29.6 27.5 26.1 24.2 10.1 13.2	can't calcula	2.49 2.15 2.16 2.16 2.25 2.20 2.21 2.89 2.49 6.47	2 1 2 1 1 1 1 1 1 1 2	.08 .70 .15 .69 .67 .56 .86 .72 .33
16-5 20-8 18-4 19-10 20-9 16-3 18-9 16-9 20-10 16-8 24-2 29-9 31-1	31.2 24.7 32.5 22.5 23.5 20.4 19.0 18.0 16.7 7.0 9.1 45.0 40.0	45.2 35.8 47.1 32.6 34.1 29.6 27.5 26.1 24.2 10.1 13.2 42.9 33.1	can't calcula	3 2.49 2.15 2.74 2.16 2.25 2.20 2.21 2.89 2.49 6.47 te 2.74 2.69	2 1 2 1 1 1 1 1 1 1 2 4 2 2 2	.08 .70 .15 .69 .76 .56 .86 .72 .33 .45 .16
16-5 20-8 18-4 19-10 20-9 16-3 18-9 16-9 20-10 16-8 24-2 29-9 31-1 30-1	31.2 24.7 32.5 22.5 23.5 20.4 19.0 18.0 16.7 7.0 9.1 45.0 40.0 20.0	45.2 35.8 47.1 32.6 34.1 29.6 27.5 26.1 24.2 10.1 42.9 33.1 17.7	can't calcula	3 2.49 2.15 2.74 2.16 2.25 2.20 2.21 2.89 2.49 6.47 te 2.69 2.58	2 1 2 1 1 1 1 1 1 2 4 2 2 1 1	.08 .70 .15 .69 .76 .56 .86 .72 .33 .45 .16 .59
16-5 20-8 18-4 19-10 20-9 16-3 18-9 16-9 20-10 16-8 24-2 29-9 31-1 30-1 31-4	31.2 24.7 32.5 22.5 23.5 20.4 19.0 18.0 16.7 7.0 9.1 45.0 40.0 20.0 22.6	45.2 35.8 47.1 32.6 34.1 29.6 27.5 26.1 24.2 10.1 13.2 43.9 33.1 17.7 18.7	can't calcula	3 2.49 2.15 2.74 2.16 2.25 2.20 2.21 2.89 2.49 6.47 te 2.69 2.58 2.58	2 1 2 1 1 1 1 1 2 4 2 2 1 1 1 1 1 1 1 1	
16-5 20-8 18-4 19-10 20-9 16-3 18-9 16-9 20-10 16-8 24-2 29-9 31-1 30-1	31.2 24.7 32.5 22.5 23.5 20.4 19.0 18.0 16.7 7.0 9.1 45.0 40.0 20.0	45.2 35.8 47.1 32.6 34.1 29.6 27.5 26.1 24.2 10.1 42.9 33.1 17.7	can't calcula	3 2.49 2.15 2.74 2.16 2.25 2.20 2.21 2.89 2.49 6.47 te 2.69 2.58	2 1 2 1 1 1 1 1 2 4 2 2 1 1 1 1 1 1 1 1	.08 .70 .15 .69 .76 .56 .86 .72 .33 .45 .16 .59

Table 4-II: Viscosities of samples from Table 4-I.

Table 4-I and their viscosities at selected shear rates are given in Table 4-II. A complete catalog of all sample ages and anticoagulants is given in Appendix F.

Similar age effects are observed in the Eagle's suspensions with H=91, 90 and 70. The samples for H=91 were obtained from the same unit, one measured 22 days after collection, the other 25 days after collection. For H=90, the difference is 11 days versus 19 days. At H=70, a sample 11 days after collection is compared to one measured on its date of expiration, 35 days after collection. In all of these cases the older blood had higher viscosity. These results are summarized graphically in Figure 4-52. The increases in viscosity at 0.3 sec⁻¹ suggest an increase in the aggregation of the red cells, since this is the major determinant of suspension viscosity at low shear rate. The data for H=92 and H=87, which show decrease in viscosity with age, are probably related to the type of anticoagulant-preservative solution, as CPD-A₁-preserved suspensions consistently have lower viscosities than CPD-preserved suspensions.

There are analogous increases in viscosity with age for plasma suspensions (see Figure 4-53), and these are compounded by the fact that the plasma iself grows more viscous with time. The plasma data at H=96, 91, and 89 all come from the same Red Cross unit and were measured over the course of three days, during which time the plasma viscosity increased from 1.05 to 1.13 to 1.21 cp. These samples were preserved in AS₁, which has a storage time of 42 days.

The Dintenfass equation, (4.1), was used to calculate the internal viscosity for the samples listed above for which age comparisons were made. These values are shown in Table 4-II. For saline suspensions they provide no additional information since η_f is a constant for all saline samples, but for plasma suspensions they provide an indication of the relative changes in the cell fluidity versus those in the plasma. The values for η_i in Table 4-II indicate either slight increases or no change in the

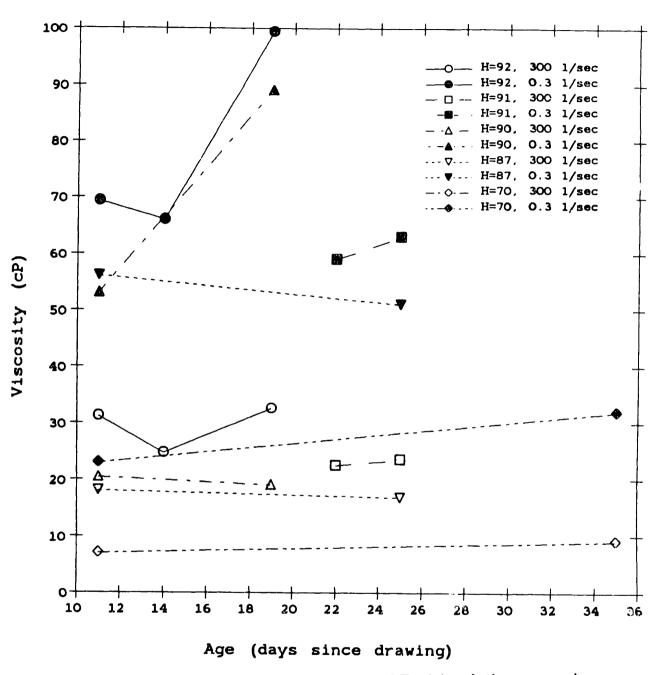


Figure 4-52: Effect of sample age on viscosity of Eagle's solution suspensions.

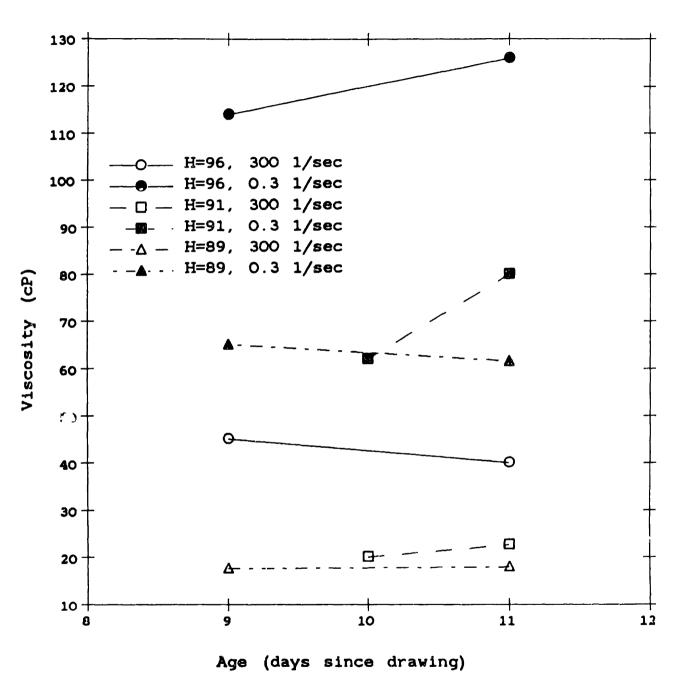


Figure 4-53: Effect of sample age on viscosity of plasma suspensions.

internal viscosity with time, but the Dintenfass equation is not applicable at low shear rates, where the age effects would be most noticeable.

To summarize, with all other things being equal, there is a rise in the viscosity of saline suspensions with erythrocyte age that is a reflection solely of the internal viscosity of the cell and which are more striking at low shear rates. Longer-lasting anticoagulant-preservative solutions appear to retard the age effects, to the extent that they are relatively insignificant. For plasma suspensions, the internal viscosity may rise slightly with storage in AS₁, and the plasma viscosity increases steadily with age.

4.6 Comparison to data of Chien et al., 1966.

The data from Figure 4-51 is replotted versus curves from the equations of Chien et al. [1966] in Figures 4-54 and 4-55. Since Chien et al. reports only absolute viscosities, the values for plasma suspensions in this study have been adjusted by multiplying them by a value of 1.1 cP for average plasma viscosity, which is an almost undetectable difference in these plots. The general trends of the two sets of datas are similar. It must be remembered that the data points in these figures which represent the work of this paper are actually derived values from the curve fits, and therefore in the case of the lower hematocrits (less than 59 for plasma, less than 70 for saline) at low shear rates (0.052 sec⁻¹ and 0.52 sec⁻¹) are only extrapolations of Filled symbols are used on Figures 4-54 and 4-55 to represent these The data for saline are comparable to each other at high extrapolations. hematocrits; below 85, the Chien data are consistently lower by factors of 2 or more. On Figures 4-20 to 4-23, the Chien values display a difference curvature with regards to shear rate dependence than the data of this work. The Chien points can be described as exhibiting a concavity, while the data shows convexity. More recent

Comparison of Chien data with this work RBC in saline solution

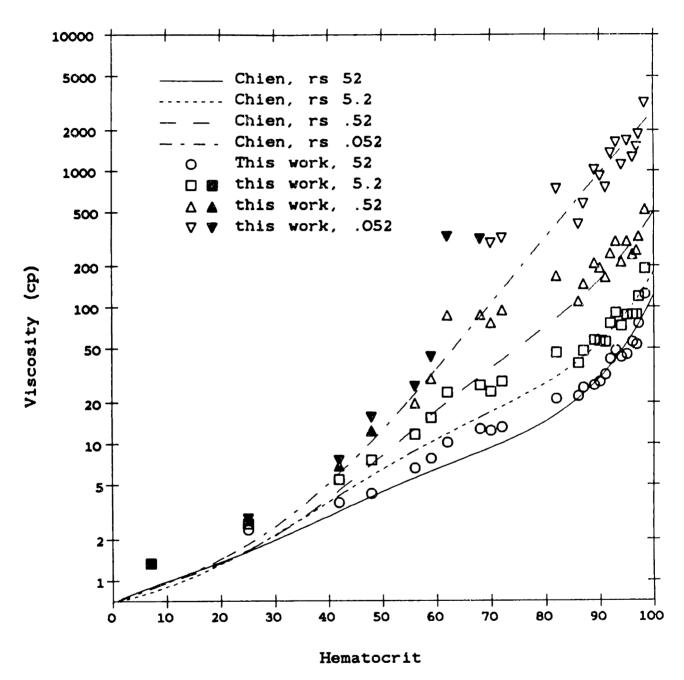


Figure 4-54: Comparison of data of this work to equations of Chien et al., 1966 for saline suspensions.

"rs"--Ringer's Solution

Numbers in legend represent shear rate in sec-1.

Comparison of Chien data with this work RBC in plasma

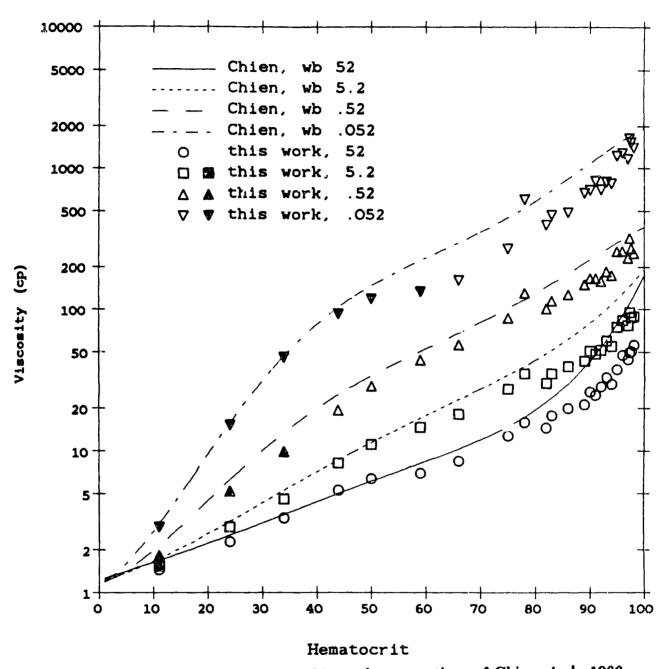


Figure 4-55: Comparison of data of this work to equations of Chien et al., 1966 for plasma suspensions.

wb --whole blood

Numbers in legend represent shear rate in sec-1.

-131data by Chien [1970], shown in Figure 2-3, also has a convex curvature. As will be discussed in Chapter 5, the convexity is the more physically reasonable behavior from the Quemada model. Perhaps by nature of their form, the Chien et al. [1966] equations, which model the hematocrit dependence by fifth-order polynomials, introduce a concavity artifact when plotted versus shear rate.

For plasma suspensions, the data of this work is lower than the Chien et al. values at the combination of high hematocrits and high shear rates. The magnitude of this difference ranges from 10-30% to factors of 2 or greater. This could be a reflection of the difference between the freshly drawn blood used by Chien et al. and the stored units used in this work, although the stored units would be expected to have a higher viscosity. Alternatively, dilution of plasma proteins by the anticoagulant-preservative could lower the viscosity, but this would have its largest impact at low shear rates. At hematocrits less than 80, the two sets of data are quite compatable with one another.

4.7 Global refitting of Chien et al. polynomials

It was desirable to examine whether the constants given in Table 2-I for equation (2.8) could be fitted to functions of shear rate, and thus the utility of the Chien polynomials expanded to a wider range. The values for saline suspensions oscillate greatly with shear rate (see Figure 4-56(a-f)) and can be best approximated by polynomials of $ln(\gamma)$ of the form:

$$a_{i} = \sum_{j=0}^{3} \alpha_{ij} [\ln(\gamma)]^{j}$$
ants α_{ij} for these equation are given in Table 4.73

The constants a_{ij} for these equation are given in Table 4-III. When such equations are plotted versus shear rate at a single hematocrit, they are seen to provide a good fit of data at high hematocrits (see Figure 4-57). As hematocrit decreases, the curve

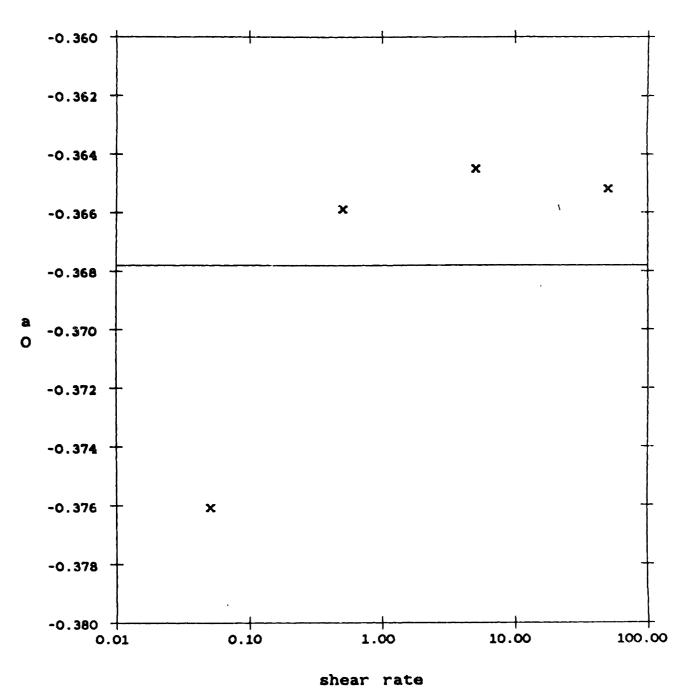


Figure 4-56: Plots of constants for Chien polynomial for saline versus shear rate.

(a) Plot for a₀ in Ringer's solution.

Chien's rs al

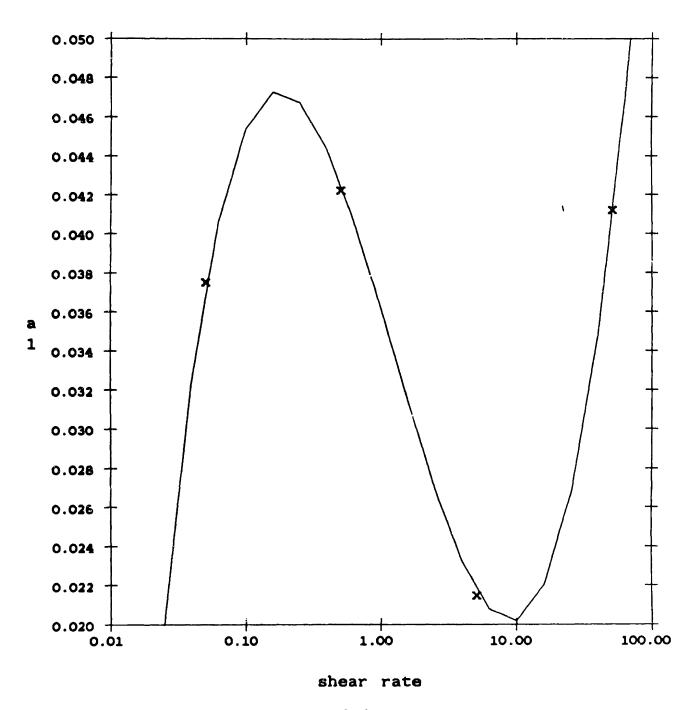


Figure 4-56(b) Plot for a₁ in Ringer's solution.

Chien's rs a2 x 10

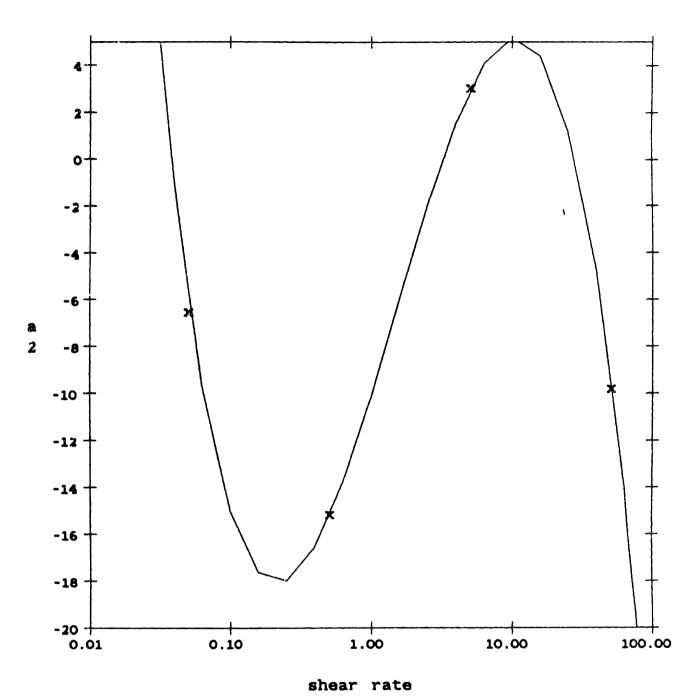


Figure 4-56(c): Plot for a₂ in Ringer's solution.

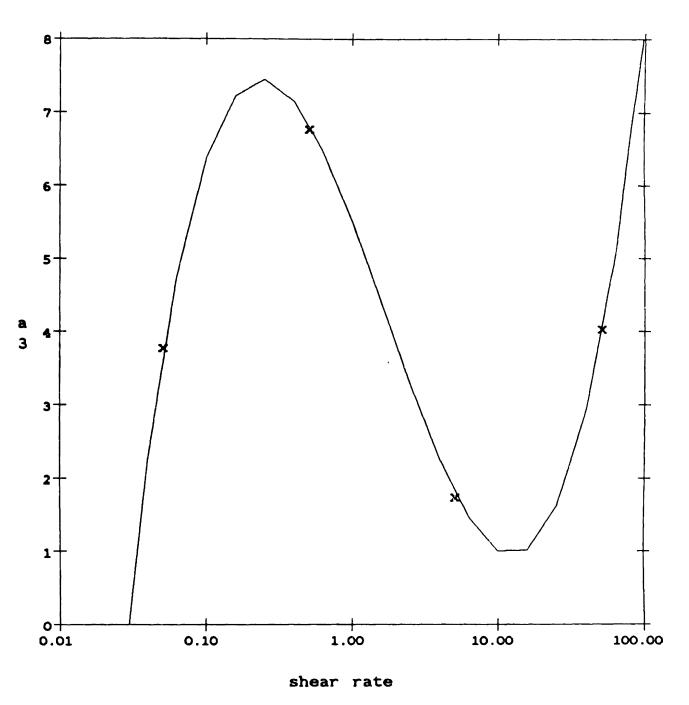


Figure 4-56(d): Plot for a₃ in Ringer's solution.

Chien's rs a4 \times 10⁷

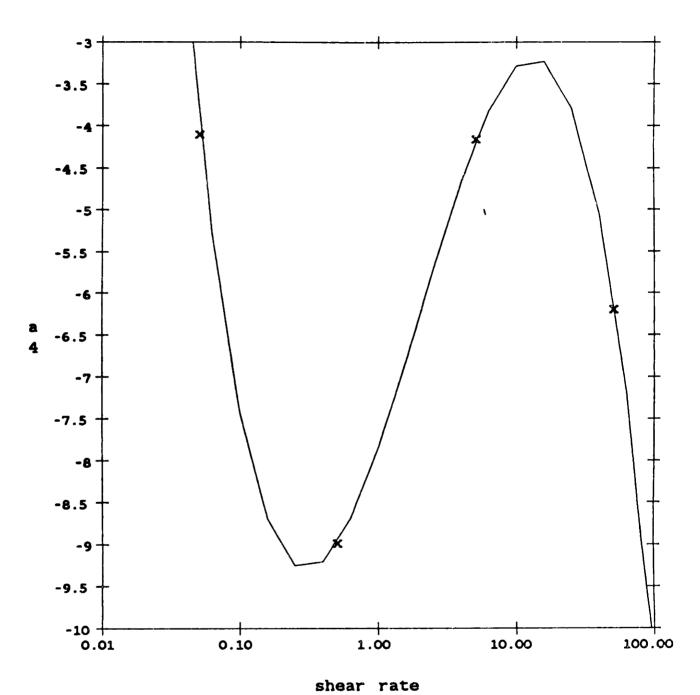


Figure 4-56(e): Plot for a₄ in Ringer's solution.

Chien's rs a5 \times 10

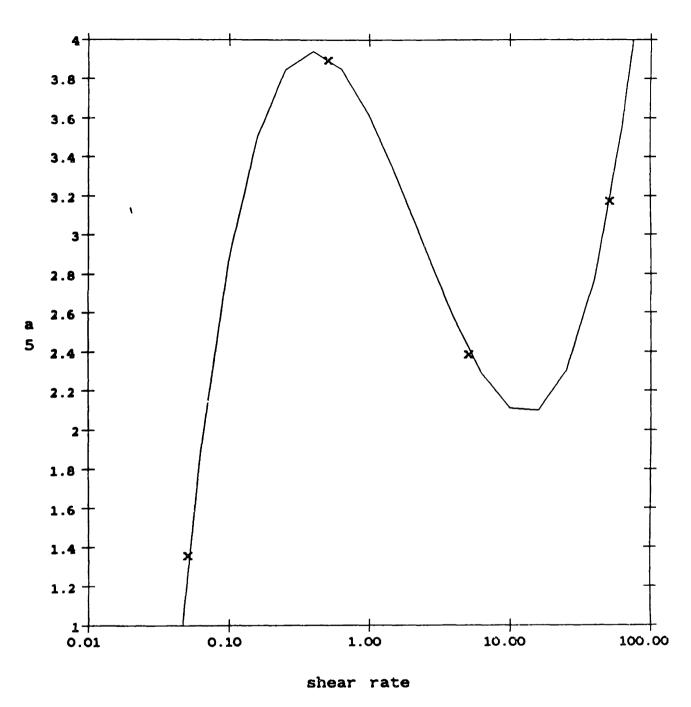
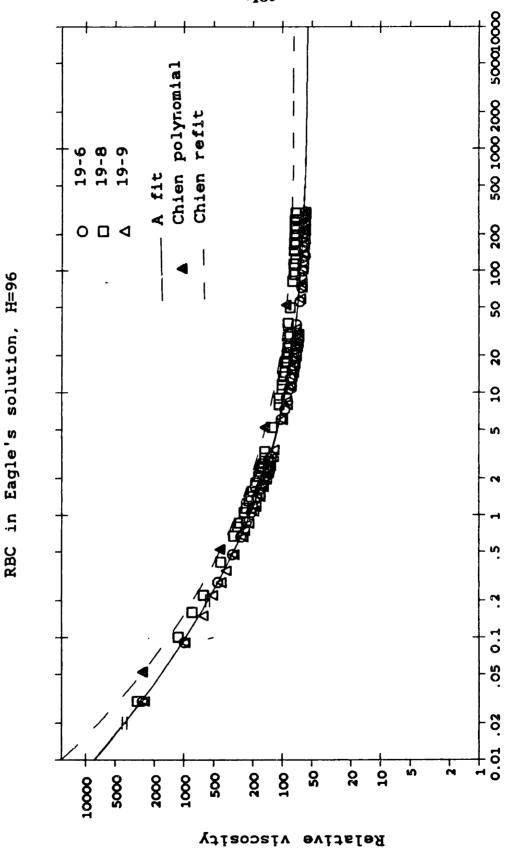


Figure 4-56(f): Plot for a_5 in Ringer's solution.

	j=0	j=1	j=2	j=3
i=0 i=1 i=2 i=3 i=4 i=5	-3.678e-O1 3.619e-O2 -1.012e-O3 5.514e-O5 -7.856e-O7 3.614e-O9	-1.025e-02 8.572e-04 -2.275e-05 2.095e-07 -6.247e-10	-6.384e-04 9.811e-05 -3.457e-06 4.721e-08 2.119e-10	9.009e-04 -7.906e-05 2.097e-06 -2.264e-08 8.669e-11

Table 4-III: Constants for refit saline Chien equation (4.2).

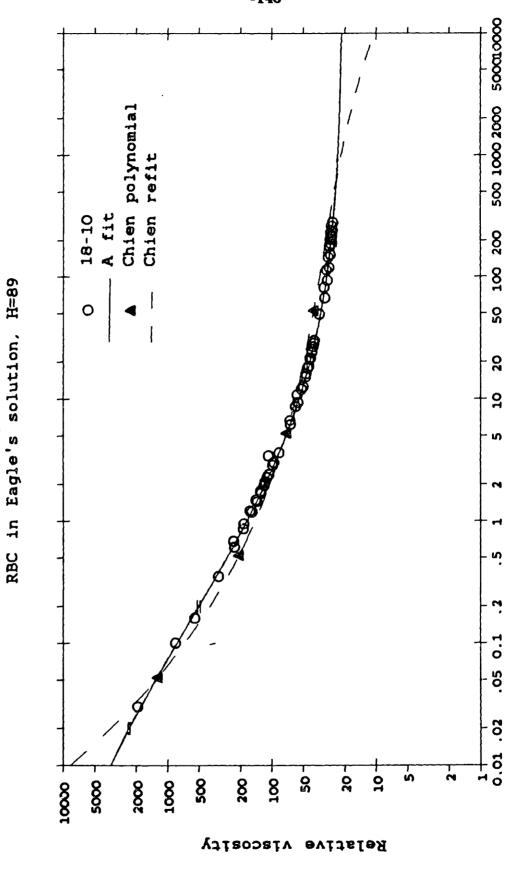




Relative viscosity vs. Shear rate

Figure 4-57: Plot of refit saline Chien equation versus shear rate at H=96.

Shear rate (1/sec)



Relative viscosity vs. Shear rate

Figure 4-58: Plot of refit saline Chien equation versus shear rate at H=89. Shear rate (1/sec)

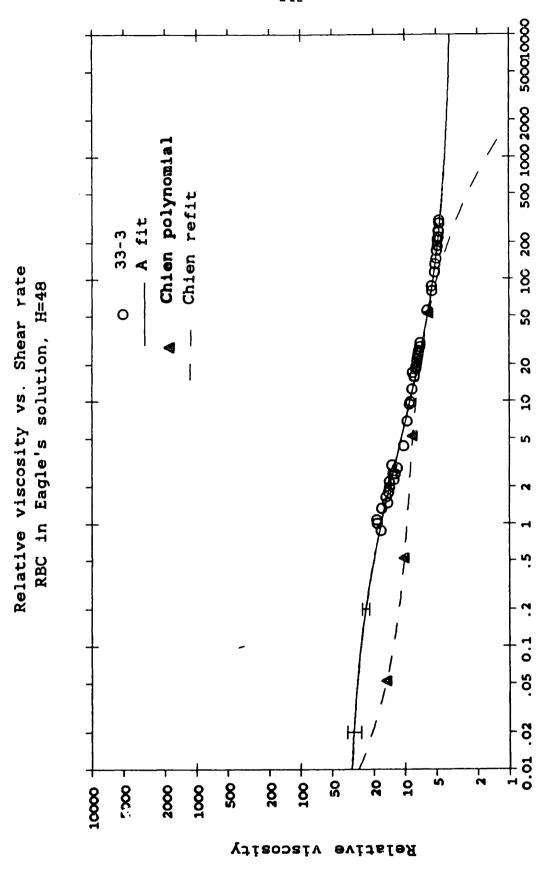


Figure 4-59: Plot of refit saline Chien equation versus shear rate at H=48. Shear rate (1/sec)

becomes less adequate, veering downward at high shear rates (see Figures 4-58 and 4-59). The constants for plasma suspensions actually suggest asymptotic values at high shear rates (see Figure 4-60(a-f)). The following equations are plotted in Figure 4-60(a-f) as providing a reasonable representation of the functional dependence of the constants:

$$a_0 = 0.1672 (4.3)$$

$$a_1 = \frac{8.513 \times 10^{-4}}{\gamma} + 0.02595 \tag{4.4}$$

$$a_2 = \frac{-6.243 \times 10^{-3} \gamma}{(0.8106 + \gamma)} + 6.153 \times 10^{-3}$$
(4.5)

$$a_3 = 1.732 \times 10^{-4} \exp(\frac{-0.4886}{\gamma}) - 1.639 \times 10^{-4}$$
 (4.6)

$$a_4 = \frac{1.238 \times 10^{-5}}{\ln (1000 \cdot \gamma)} - 1.326 \times 10^{-6}$$
 (4.7)

$$a_5 = 7.539 \times 10^{-9} \exp(\frac{-0.5584}{10^{-9}}) - 6.009 \times 10^{-9}$$
 (4.8)

These equations do not prove satisfactory, however, as it is not possible even to retrieve the original plots from them except at low hematocrits (see Figure 4-61). Once again the need is emphasized for a better representation of the data, in a more general form.

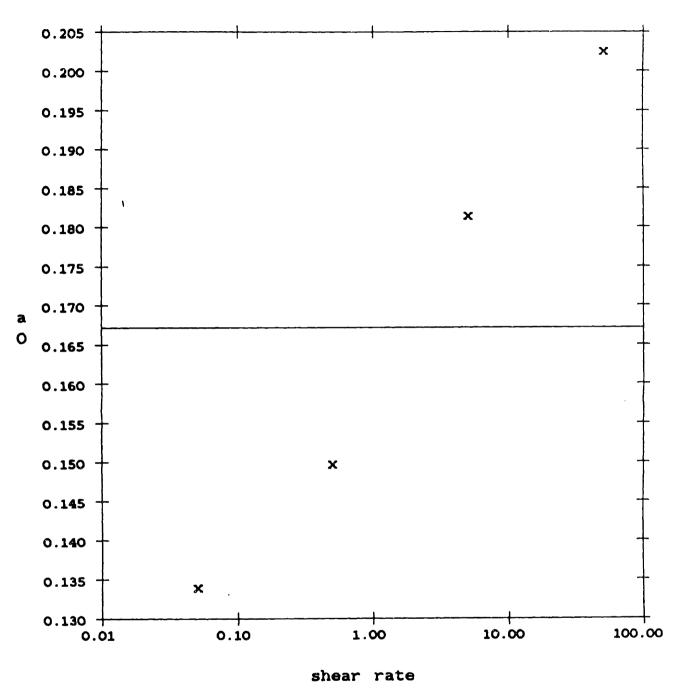


Figure 4-60: Plots of constants for Chien polynomial for plasma versus shear rate.

(a) Plot for a₀ in plasma.

Chien's wb al

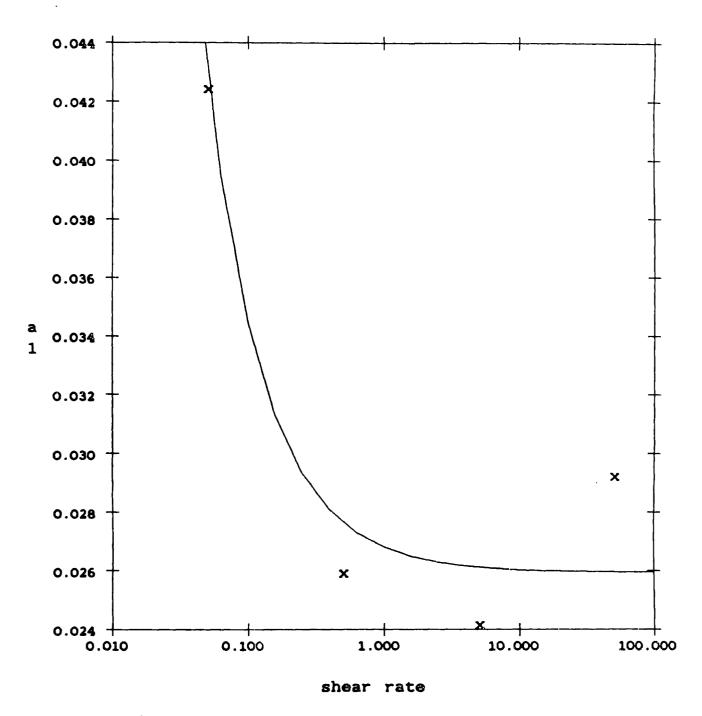


Figure 4-60(b): Plot for a₁ in plasma.

Chien's wb a2 x 10 4

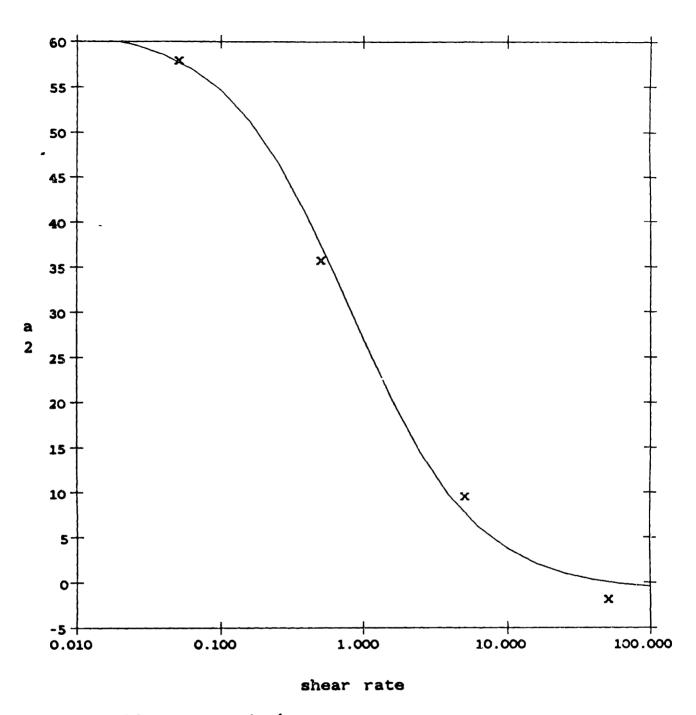


Figure 4-60(c): Plot for a_2 in plasma.

Chien's wb a3 x 10⁵

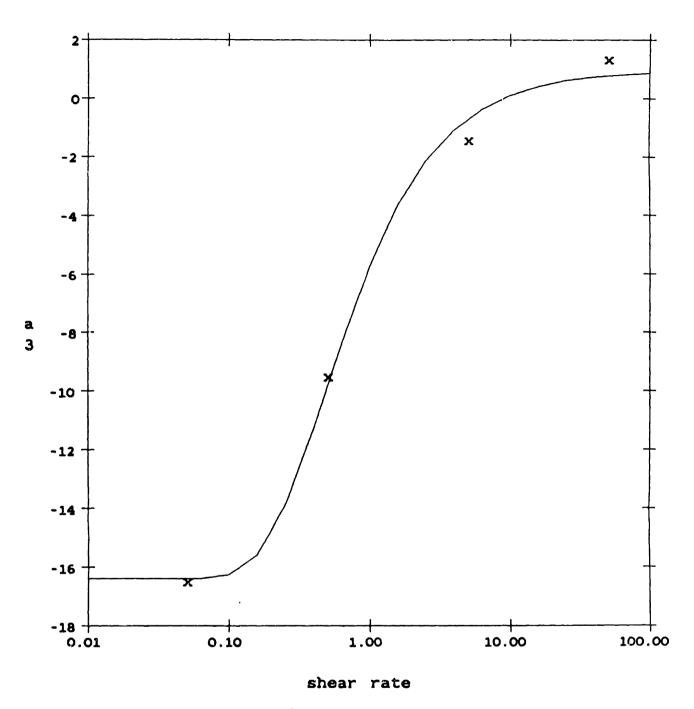


Figure 4-60(d): Plot for a₃ in plasma.

7

Chien's wb a4 x 10⁷

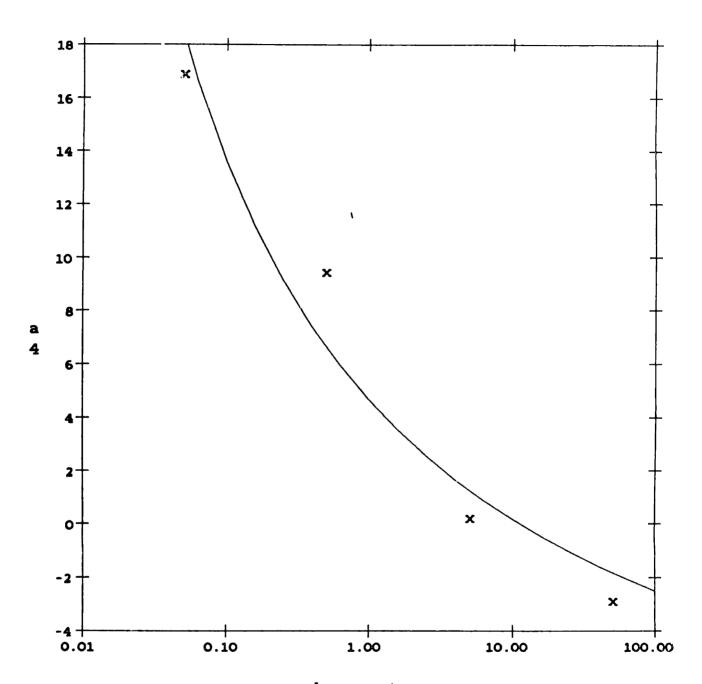


Figure 4-60(e): Plot for a₄ in plasma.

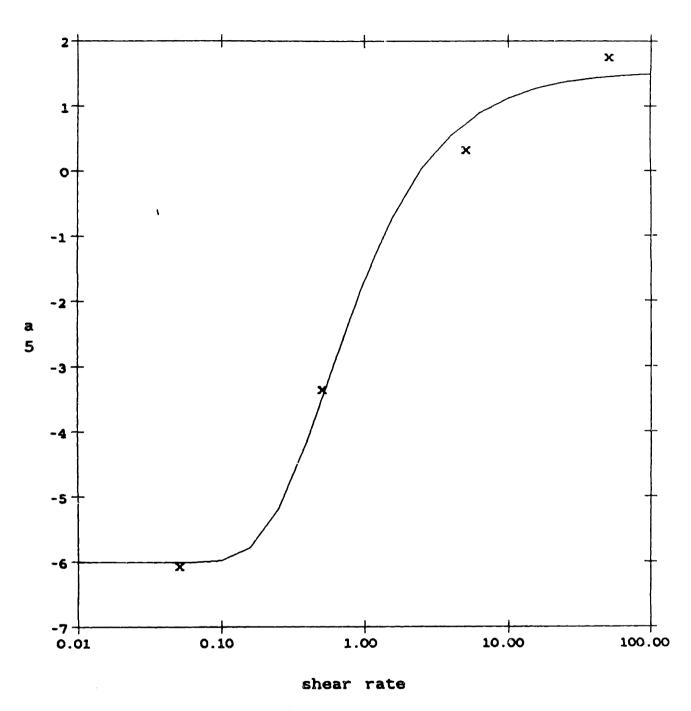


Figure 4-60(f): Plot for a₅ in plasma.

Global refitting of Chien polynomials for whole blood

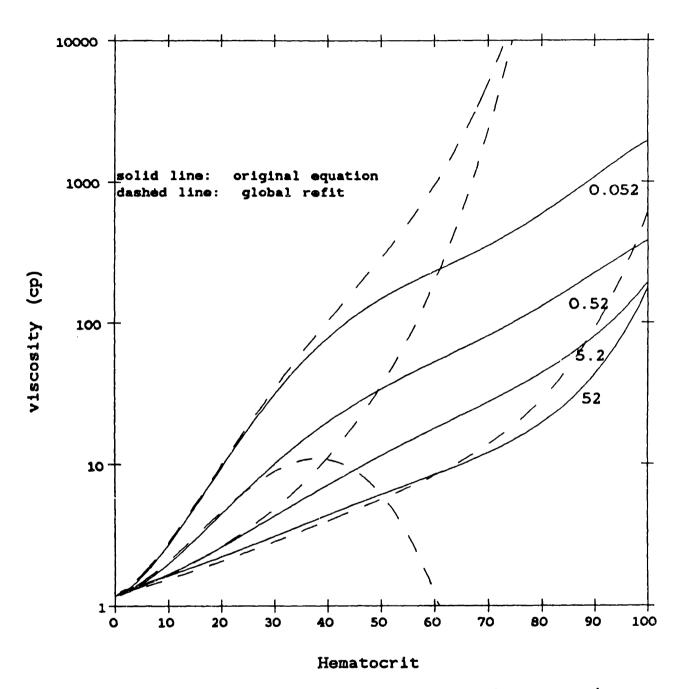


Figure 4-61: Plot of refit equations (4.3) to (4.8) for plasma suspensions.

Numbers represent shear rates in sec⁻¹.

Chapter 5

DISCUSSION

5.1 Curve fits to data

The data from the previous chapter was fitted to the three-parameter Quemada expression, equation (2.11), using the method and computer program given in Section 3.4 and Appendix D. Equation (2.11) was rearranged to the following form for ease in calculation:

$$\eta_r = \left[1 - \frac{c}{2} \left(k_{\infty} + \frac{k_0 - k_{\infty}}{1 + \sqrt{\gamma/\gamma_c}}\right)\right]^{-2} \tag{5.1}$$

This form of the equation minimizes the frequency of appearance of the shear rate term, whose fit, as will be seen, has the highest degree of uncertainty. It will be recalled that the term in parentheses is a general intrinsic viscosity $k(c,\gamma)$. The squared residuals were weighted by y_i^{-2} , where y_i is the predicted value of η_r from the equation, in order to assign equal relative weight to each point regardless of the magnitude of η_r . (When the term relative weighting is used henceforth, it will refer to a fit by this method. If there is additional weighting used, it will be so specified in each case.) In all cases the expression was able to provide a good representation of the data, and in almost every case the sum of squared weighted residuals using this equation was smaller than for any of several empirical equations attempted, the best of which were a fourth-order polynomial fit of $\ln(\eta)$ to $\ln(\gamma)$ and a fit of $\ln(\eta)$ to the form $b_1 + \frac{b_2}{b_3}$ where b_1 , b_2 and b_3 are constants.

The Quemada equation, when fitted to the low hematocrit plasma data from this work, often did not provide reasonable extrapolations to low shear rates where data was unavailable. In order to provide a better behavior in the low hematocrit-low shear rate regime, the data points from the Chien et al., [1966] equations were added to the plasma data where there was good agreement between the two sets. Therefore, for plasma suspension at H=50, 44, 34, 24, and 11 the fits are to this work plus the four points of Chien et al. at each hematocrit. In the case for Eagle's solution at H=7, the data was fit to a constant from which a value of k_{∞} was calculated.

Statistical parameters for the goodness-of-fit of the equations are given in Table 5-I. The standard weighted error of regression is defined as $\sqrt{\frac{E}{N-P}}$, where E is the sum of squared weighted residuals as defined by equation (3.17), N is the number of data points and P is the number of parameters. It will be noted that the absolute magnitude of the correlation coefficients involving the critical shear rate are all very close to 1, suggesting a relative insensitivity of the fit to the value of γ_c . As will be recalled from the analytical discussion of the Quemada equation in Chapter 2, γ_c does not change the overall shape of the Quemada curve but instead acts as a scaling factor for the x-axis. Thus, for data that is relatively constant or that expresses asymptotic behavior at only one end, it will be more difficult to pinpoint the value of γ_c , as seen by the ρ_{23} values for plasma at low and high hematocrits (ρ_{13} values are practically constant for all cases because asymptotic approach to k_{∞} is always seen). This uncertainty in γ_c will be expressed in relatively higher standard deviations for the value of its fit.

The high magnitudes of the correlation coefficients might also suggest an overspecification of the problem for any one curve. It is quite possible that a data at one hematocrit may be effectively represented by a two parameter equation, but three parameters are needed to model behavior over a large range of hematocrits.

The rheological parameters k_{∞} , k_0 , and γ_c generated by the fits are given

Hematocrit	number of data points	std. wghtd. regress. err.	corr. coeff. 12	corr. coef. 13	corr. coeff. 23
98.4	60	7.651e-02	0.7437	-0.9413	-0.9225
97.2	55	3.342e-02	0.6890	-0.9251	-0.9075
96.8	60	2.879e-02	0.7147	-0.9379	-0.9069
96.0	170	1.013e-01	0.6957	-0.9301	-0.9065
95.0	129	4.210e-02	0.7297	-0.9573	-0.8901
94.0	112	3.153e-02	0.6876	-0.9382	~O.8893
93.0	181	2.096e-01	0.7366	-0.9544	-0.8986
92.0	161	1.757e-01	0.7166	-0.9506	-0.8905
91.0	122	4.011e-02	0.6809	-0.9410	-0.8776
90.0	118	1.212e-01	0.7102	-0.9610	-0.8678
89.0	54	3.829e-02	0.7056	-0.9721	-0.8443
87.0	120	7.18 4e -02	0.6203	-0.9541	-0.8067
86.0	57	5.163e-02	0.6543	-0.9385	-0.8587
82.0	47	5.303e-02	0.6715	-0.9692	-0.8235
72.0	46	5.949e-02	0.6517	-0.9658	-0.8091
70.0	107	1.789e-01	0.6385	-0.9513	-0.8261
68.0	48	9.703e-02	0.6850	-0.9142	-0.9127
62.0	53	1.638e-01	0.7176	-0.9397	-0.9046
59.0	57	3.020e-02	0.6533	-0.9307	-0.8642
56.0	54	2.435e-02	0.7450	-0.9321	-0.9233
48.0	46	4.270e-02	0.7650	-0.9269	-0.9 4 06
42.0	30	1.689e-02	0.7872	-0.9131	-0.96 44
25.0	32	6.469e-02	0.9061	-0.9740	-0.9745
7.0	14	4.355e-03			
Hematocrit	number of	std. wahtd.	corr. coeff.	corr. coef.	corr. coeff.
	data points	regress. err.	12	13	23
	data points	regress. err.	12	13	23
98.1	data points	regress. err. 2.584e-02	0.6980	-0.9283	-0.9085
98.1 97.6	data points 65 63	regress. err. 2.584e-02 6.425e-02	0.6980 0.6985	-0.9283 -0.9423	23
98.1 97.6 97.3	data points 65 63 59	regress. err. 2.584e-02	0.6980	-0.9283	-0.9085 -0.8919
98.1 97.6 97.3 97.0	data points 65 63 59 60	2.584e-02 6.425e-02 4.792e-02 1.471e-02	0.6980 0.6985 0.7018	-0.9283 -0.9423 -0.9659	-0.9085 -0.8919 -0.8550
98.1 97.6 97.3 97.0 96.0	data points 65 63 59 60 122	2.584e-02 6.425e-02 4.792e-02	0.6980 0.6985 0.7018 0.7015	-0.9283 -0.9423 -0.9659 -0.9463	-0.9085 -0.8919 -0.8550 -0.8859
98.1 97.6 97.3 97.0	data points 65 63 59 60 122 63 62	2.584e-02 6.425e-02 4.792e-02 1.471e-02 9.660e-02	0.6980 0.6985 0.7018 0.7015 0.6694	-0.9283 -0.9423 -0.9659 -0.9463 -0.9489	-0.9085 -0.8919 -0.8559 -0.8604 -0.8541 -0.8545
98.1 97.6 97.3 97.0 96.0 95.0 94.0 93.0	data points 65 63 59 60 122 63 62 62	2.584e-02 6.425e-02 4.792e-02 1.471e-02 9.660e-02 2.514e-02	0.6980 0.6985 0.7018 0.7015 0.6694 0.7077 0.6850 0.6732	-0.9283 -0.9423 -0.9659 -0.9463 -0.9489 -0.9673 -0.9572 -0.9492	-0.9085 -0.8919 -0.8550 -0.8859 -0.8604 -0.8541 -0.8545 -0.8590
98.1 97.6 97.3 97.0 96.0 95.0 94.0 93.0	data points 65 63 59 60 122 63 62 62 122	2.584e-02 6.425e-02 4.792e-02 1.471e-02 9.660e-02 2.514e-02 2.112e-02 2.943e-02 3.445e-02	0.6980 0.6985 0.7018 0.7015 0.6694 0.7077 0.6850 0.6732 0.6610	-0.9283 -0.9423 -0.9463 -0.9463 -0.9489 -0.9673 -0.9572 -0.9492 -0.9590	-0.9085 -0.8919 -0.8550 -0.8654 -0.8541 -0.8545 -0.8590 -0.8322
98.1 97.6 97.3 97.0 96.0 95.0 94.0 93.0 92.0	data points 65 63 59 60 122 63 62 62 122 124	2.584e-02 6.425e-02 4.792e-02 1.471e-02 9.660e-02 2.514e-02 2.112e-02 2.943e-02 3.445e-02 8.631e-02	0.6980 0.6985 0.7018 0.7015 0.6694 0.7077 0.6850 0.6732 0.6610 0.7064	-0.9283 -0.9423 -0.9659 -0.9463 -0.9489 -0.9673 -0.9572 -0.9492 -0.9590 -0.9699	-0.9085 -0.8919 -0.8550 -0.8859 -0.8604 -0.8541 -0.8545 -0.8590 -0.8322 -0.8479
98.1 97.6 97.3 97.0 96.0 95.0 94.0 93.0 92.0 91.0	data points 65 63 59 60 122 63 62 62 122 124 62	2.584e-02 6.425e-02 4.792e-02 1.471e-02 9.660e-02 2.514e-02 2.112e-02 2.943e-02 3.445e-02 8.631e-02	0.6980 0.6985 0.7018 0.7015 0.6694 0.7077 0.6850 0.6732 0.6610 0.7064 0.6788	-0.9283 -0.9423 -0.9659 -0.9463 -0.9489 -0.9673 -0.9572 -0.9590 -0.9699 -0.9642	-0.9085 -0.8919 -0.8550 -0.8859 -0.8604 -0.8545 -0.8545 -0.8590 -0.8322 -0.8479 -0.8361
98.1 97.6 97.3 97.0 96.0 95.0 94.0 93.0 92.0 91.0 90.0 89.0	data points 65 63 59 60 122 63 62 122 124 62 124	2.584e-02 6.425e-02 4.792e-02 1.471e-02 9.660e-02 2.514e-02 2.112e-02 2.943e-02 3.445e-02 8.631e-02 3.614e-02	0.6980 0.6985 0.7018 0.7015 0.6694 0.7077 0.6850 0.6732 0.6610 0.7064 0.6788 0.6931	-0.9283 -0.9423 -0.9659 -0.9463 -0.9489 -0.9572 -0.9572 -0.9590 -0.9699 -0.9642 -0.9694	-0.9085 -0.8919 -0.8550 -0.8859 -0.8604 -0.8541 -0.8545 -0.8590 -0.8322 -0.8479 -0.8361 -0.8378
98.1 97.6 97.3 97.0 96.0 95.0 93.0 92.0 91.0 90.0 89.0	data points 65 63 59 60 122 63 62 122 124 62 124 65	2.584e-02 6.425e-02 4.792e-02 1.471e-02 9.660e-02 2.514e-02 2.112e-02 2.943e-02 3.445e-02 8.631e-02 3.614e-02 1.004e-01 3.351e-02	0.6980 0.6985 0.7018 0.7015 0.6694 0.7077 0.6850 0.6732 0.6610 0.7064 0.6788 0.6931 0.6708	-0.9283 -0.9423 -0.9659 -0.9463 -0.9489 -0.9572 -0.9572 -0.9492 -0.9699 -0.9642 -0.9694 -0.9573	-0.9085 -0.8919 -0.8550 -0.8859 -0.8604 -0.8541 -0.8545 -0.8590 -0.8322 -0.8479 -0.8361 -0.8378 -0.8418
98.1 97.6 97.3 97.0 96.0 95.0 93.0 92.0 91.0 90.0 89.0 86.0	data points 65 63 59 60 122 63 62 122 124 62 124 65 65	2.584e-02 6.425e-02 4.792e-02 1.471e-02 9.660e-02 2.514e-02 2.112e-02 2.943e-02 3.445e-02 8.631e-02 3.614e-02 1.004e-01 3.351e-02 3.515e-02	0.6980 0.6985 0.7018 0.7015 0.6694 0.7077 0.6850 0.6732 0.6610 0.7064 0.6788 0.6931 0.6708	-0.9283 -0.9423 -0.9659 -0.9463 -0.9673 -0.9572 -0.9590 -0.9699 -0.9642 -0.9694 -0.9573 -0.9638	-0.9085 -0.8919 -0.8550 -0.8859 -0.8604 -0.8541 -0.8545 -0.8590 -0.8322 -0.8479 -0.8361 -0.8378 -0.8418
98.1 97.6 97.3 97.0 96.0 95.0 91.0 91.0 90.0 89.0 86.0 83.0	data points 65 63 59 60 122 63 62 122 124 62 124 65 65 68	2.584e-02 6.425e-02 4.792e-02 1.471e-02 9.660e-02 2.514e-02 2.112e-02 2.943e-02 3.445e-02 8.631e-02 3.614e-02 1.004e-01 3.351e-02 3.697e-02	0.6980 0.6985 0.7018 0.7015 0.6694 0.7077 0.6850 0.6732 0.6610 0.7064 0.6788 0.6931 0.6608 0.6661	-0.9283 -0.9423 -0.9659 -0.9463 -0.9673 -0.9572 -0.9590 -0.9699 -0.9694 -0.9638 -0.9631	-0.9085 -0.8919 -0.8550 -0.8859 -0.8604 -0.8541 -0.8545 -0.8322 -0.8479 -0.8361 -0.8378 -0.8418 -0.8251 -0.8161
98.1 97.6 97.3 97.0 96.0 95.0 91.0 91.0 90.0 89.0 86.0 82.0 78.0	data points 65 63 59 60 122 63 62 122 124 62 124 65 65 65	2.584e-02 6.425e-02 4.792e-02 1.471e-02 9.660e-02 2.514e-02 2.112e-02 2.943e-02 3.445e-02 8.631e-02 3.614e-02 1.004e-01 3.351e-02 3.515e-02 3.697e-02 5.593e-02	0.6980 0.6985 0.7018 0.7070 0.6694 0.7077 0.6850 0.6732 0.6610 0.7064 0.6788 0.6981 0.6708 0.6518 0.6518	-0.9283 -0.9423 -0.9659 -0.9463 -0.9673 -0.9572 -0.9590 -0.9699 -0.9642 -0.9644 -0.9573 -0.9631 -0.9631	-0.9085 -0.8919 -0.8559 -0.8859 -0.8604 -0.8541 -0.8545 -0.8590 -0.8322 -0.8479 -0.8361 -0.8361 -0.8251 -0.8251
98.1 97.6 97.3 97.0 96.0 95.0 93.0 92.0 91.0 90.0 86.0 83.0 78.0	data points 65 63 59 60 122 63 62 122 124 62 124 65 65 65 68	2.584e-02 6.425e-02 4.792e-02 1.471e-02 9.660e-02 2.514e-02 2.112e-02 2.943e-02 3.445e-02 8.631e-02 3.614e-02 1.004e-01 3.351e-02 3.515e-02 3.697e-02 5.593e-02 2.728e-02	0.6980 0.6985 0.7018 0.7077 0.6694 0.7077 0.6850 0.6732 0.6610 0.7064 0.6788 0.6931 0.6708 0.6661 0.6518 0.6997	-0.9283 -0.9423 -0.9463 -0.9463 -0.9572 -0.9572 -0.9590 -0.9699 -0.9642 -0.9694 -0.9573 -0.9631 -0.9631 -0.9662	-0.9085 -0.8919 -0.8550 -0.8550 -0.8604 -0.8541 -0.8545 -0.8590 -0.8322 -0.8479 -0.8361 -0.8378 -0.8418 -0.8251 -0.8225
98.1 97.6 97.3 97.0 96.0 95.0 93.0 92.0 91.0 90.0 86.0 83.0 75.0 66.0	data points 65 63 59 60 122 63 62 122 124 62 124 65 65 68 64 59 65	2.584e-02 6.425e-02 4.792e-02 1.471e-02 9.660e-02 2.514e-02 2.112e-02 2.943e-02 3.445e-02 8.631e-02 3.614e-02 1.004e-01 3.351e-02 3.515e-02 3.697e-02 5.593e-02 5.593e-02	0.6980 0.6985 0.7018 0.7077 0.6694 0.7077 0.6850 0.6732 0.6610 0.7064 0.6788 0.6931 0.6708 0.66518 0.6518 0.6997 0.6263	-0.9283 -0.9423 -0.9659 -0.9463 -0.9572 -0.9572 -0.9590 -0.9699 -0.9642 -0.9694 -0.9573 -0.9631 -0.9631 -0.9631 -0.9662 -0.9662	-0.9085 -0.8919 -0.8550 -0.8550 -0.8604 -0.8541 -0.8545 -0.8590 -0.8322 -0.8479 -0.8361 -0.8378 -0.8418 -0.8251 -0.8225 -0.7654
98.1 97.6 97.3 97.0 96.0 95.0 93.0 92.0 91.0 90.0 86.0 83.0 82.0 78.0 75.0 66.0	data points 65 63 59 60 122 63 62 122 124 62 124 65 65 68 64 59 65 54	regress.err. 2.584e-02 6.425e-02 4.792e-02 1.471e-02 9.660e-02 2.514e-02 2.112e-02 2.943e-02 3.445e-02 8.631e-02 3.614e-02 1.004e-01 3.351e-02 3.515e-02 3.515e-02 5.593e-02 5.593e-02 5.786e-02	0.6980 0.6985 0.7018 0.7018 0.7077 0.6694 0.6732 0.6610 0.7064 0.6788 0.6788 0.6661 0.6518 0.6518 0.6518 0.6519 0.6519	-0.9283 -0.9423 -0.9463 -0.9463 -0.9572 -0.9572 -0.9590 -0.9699 -0.9642 -0.9694 -0.9631 -0.9631 -0.9631 -0.9631 -0.9634 -0.9634	-0.9085 -0.8919 -0.8550 -0.8859 -0.8604 -0.8545 -0.8545 -0.8590 -0.8322 -0.8479 -0.8361 -0.8378 -0.8418 -0.8251 -0.8161 -0.8225 -0.7654 -0.7654
98.1 97.6 97.3 97.0 96.0 95.0 93.0 92.0 91.0 90.0 86.0 83.0 82.0 78.0 75.0 66.0 59.0	data points 65 63 59 60 122 63 62 122 124 62 124 65 65 65 68 64 59 65 54	2.584e-02 6.425e-02 4.792e-02 1.471e-02 9.660e-02 2.514e-02 2.112e-02 2.943e-02 3.445e-02 8.631e-02 3.614e-02 1.004e-01 3.351e-02 3.515e-02 3.515e-02 5.593e-02 5.786e-02 1.437e-02	0.6980 0.6985 0.7018 0.7015 0.6694 0.7077 0.6850 0.6732 0.6610 0.7064 0.6788 0.6931 0.6708 0.6661 0.6518 0.6997 0.6263 0.5921 0.6677	-0.9283 -0.9423 -0.9659 -0.9463 -0.9673 -0.9572 -0.9572 -0.9590 -0.9699 -0.9642 -0.9631 -0.9631 -0.9631 -0.9631 -0.9631 -0.9631 -0.9631	-0.9085 -0.8919 -0.8550 -0.8859 -0.8604 -0.8541 -0.8545 -0.8590 -0.8322 -0.8479 -0.8361 -0.8378 -0.8418 -0.8251 -0.8161 -0.8251 -0.8161 -0.8225 -0.7654 -0.7654 -0.9028
98.1 97.6 97.3 97.0 96.0 95.0 93.0 92.0 91.0 90.0 89.0 86.0 83.0 78.0 75.0 75.0 50.0	data points 65 63 59 60 122 63 62 122 124 62 124 65 65 68 64 59 65 54	2.584e-02 6.425e-02 4.792e-02 1.471e-02 9.660e-02 2.514e-02 2.112e-02 2.943e-02 3.445e-02 8.631e-02 3.614e-02 1.004e-01 3.351e-02 3.515e-02 3.515e-02 3.597e-02 5.593e-02 2.728e-02 5.786e-02 1.437e-02 1.193e-02	0.6980 0.6985 0.7018 0.7015 0.6694 0.7077 0.6850 0.6732 0.6610 0.7064 0.6788 0.6931 0.6708 0.6661 0.6518 0.6977 0.6267 0.6273	-0.9283 -0.9423 -0.9659 -0.9463 -0.9673 -0.9572 -0.9572 -0.9590 -0.9699 -0.9642 -0.9631 -0.9631 -0.9631 -0.9631 -0.9631 -0.9631 -0.9631 -0.9631 -0.9632 -0.9632 -0.9614 -0.9543 -0.9543 -0.9382 -0.9162	-0.9085 -0.8919 -0.8550 -0.8859 -0.8604 -0.8541 -0.8545 -0.8590 -0.8322 -0.8479 -0.8361 -0.8378 -0.8418 -0.8251 -0.8161 -0.8251 -0.8161 -0.8251 -0.9608
98.1 97.6 97.3 97.0 96.0 95.0 93.0 92.0 91.0 90.0 89.0 86.0 83.0 82.0 78.0 75.0 66.0 59.0 59.0	data points 65 63 59 60 122 63 62 122 124 65 65 68 64 59 65 54 59 45	2.584e-02 6.425e-02 4.792e-02 1.471e-02 9.660e-02 2.514e-02 2.112e-02 2.943e-02 3.445e-02 8.631e-02 3.614e-02 1.004e-01 3.351e-02 3.515e-02 3.697e-02 5.593e-02 2.728e-02 5.593e-02 1.437e-02 1.193e-02 4.518e-02	0.6980 0.6985 0.7018 0.7015 0.6694 0.7077 0.6850 0.6732 0.6610 0.7064 0.6788 0.6931 0.6708 0.6661 0.6518 0.6997 0.6263 0.7276 0.7276 0.7276	-0.9283 -0.9423 -0.9659 -0.9463 -0.9489 -0.9572 -0.9572 -0.9590 -0.9699 -0.9642 -0.9631 -0.9631 -0.9631 -0.9662 -0.9614 -0.9543 -0.9543 -0.9543 -0.9543 -0.9543 -0.9543 -0.9543 -0.9543 -0.9543	-0.9085 -0.8919 -0.8550 -0.8859 -0.8604 -0.8541 -0.8545 -0.8590 -0.8322 -0.8479 -0.8361 -0.8378 -0.8418 -0.8251 -0.8251 -0.7654 -0.7654 -0.7654 -0.9608 -0.9608
98.1 97.6 97.3 97.0 96.0 95.0 93.0 92.0 91.0 90.0 89.0 86.0 83.0 78.0 75.0 75.0 50.0	data points 65 63 59 60 122 63 62 122 124 62 124 65 65 68 64 59 65 54	2.584e-02 6.425e-02 4.792e-02 1.471e-02 9.660e-02 2.514e-02 2.112e-02 2.943e-02 3.445e-02 8.631e-02 3.614e-02 1.004e-01 3.351e-02 3.515e-02 3.515e-02 3.597e-02 5.593e-02 2.728e-02 5.786e-02 1.437e-02 1.193e-02	0.6980 0.6985 0.7018 0.7015 0.6694 0.7077 0.6850 0.6732 0.6610 0.7064 0.6788 0.6931 0.6708 0.6661 0.6518 0.6977 0.6267 0.6273	-0.9283 -0.9423 -0.9659 -0.9463 -0.9673 -0.9572 -0.9572 -0.9590 -0.9699 -0.9642 -0.9631 -0.9631 -0.9631 -0.9631 -0.9631 -0.9631 -0.9631 -0.9631 -0.9632 -0.9632 -0.9614 -0.9543 -0.9543 -0.9382 -0.9162	-0.9085 -0.8919 -0.8550 -0.8859 -0.8604 -0.8541 -0.8545 -0.8590 -0.8322 -0.8479 -0.8361 -0.8378 -0.8418 -0.8251 -0.8161 -0.8251 -0.8161 -0.8251 -0.9608

Table 5-I: Standard weighted error of regression and correlation coefficients for Quemada fits to data.

Top, values for saline suspensions. Bottom, values for plasma suspensions.

For correlation coefficients: $1=k_{\infty}$, $2=k_{0}$, $3=\gamma_{c}$

Hematocrit	k-inf. A fit	st. dev. k-inf.	k-O A fit	st. dev. k-0	gamcrit. A fit	st. dev. gam. crit.
98.4 97.2 96.8 96.0 95.0 94.0 92.0 90.0 87.0 86.0 72.0 70.0 68.0 42.0 77.0	1.849 1.819 1.774 1.800 1.764 1.794 1.815 1.796 1.752 1.806 1.807 1.829 1.884 1.969 2.005 2.014 1.853 1.896 1.947 2.099 2.096 6.605	1.081e-02 7.028e-03 3.090e-03 7.707e-03 8.821e-03 8.269e-03 1.881e-02 3.395e-02 8.140e-03 6.705e-02 1.739e-02 2.802e-02 3.368e-02 6.995e-02 9.638e-02 6.995e-01 3.547e-02 2.604e-02 7.059e-02 2.987e-02 4.546e-01 1.489e-01	2.039 2.063 2.069 2.087 2.100 2.126 2.146 2.171 2.268 2.231 2.268 2.289 2.412 2.709 2.802 2.874 3.155 2.983 3.004 3.476 3.730 3.787	2.085e-03 1.582e-03 6.329e-04 1.346e-03 8.093e-04 1.321e-03 2.033e-03 4.001e-03 1.148e-03 5.263e-03 7.749e-04 1.940e-03 4.791e-03 3.550e-03 5.382e-03 8.218e-03 2.499e-02 4.397e-02 7.337e-03 9.297e-03 3.734e-02 5.228e-02 4.281e-01	0.7572 0.8711 1.2130 0.9387 2.6770 1.3300 2.3230 1.9850 1.7760 3.3170 4.4220 2.8530 2.0640 5.1660 6.1900 3.3140 4.9410 7.5150 23.4500 22.0800 13.7800 14.5500 52.8800	1.873e-01 1.123e-01 5.526e-02 1.064e-01 2.519e-01 1.337e-01 4.980e-01 7.161e-01 1.442e-01 1.715e+00 4.876e-01 5.700e-01 5.662e-01 1.898e+00 2.276e+00 1.146e+00 1.767e+00 4.714e+00 3.234e+00 2.836e+00 4.065e+00 2.937e+00 2.248e+02
Hematocrit	k-inf. A fit		k-O A fit	st. dev. k-0	gamcrit. A fit	st. dev. gam. crit.
98.1 97.6 97.3 97.0 96.0 95.0 94.0 93.0 91.0 90.0 86.0 83.0 82.0 78.0 75.0 66.0 59.0 50.0	1.728 1.711 1.700 1.698 1.724 1.678 1.651 1.684 1.684 1.682 1.630 1.674 1.696 1.625 1.722 1.688 1.653 1.653 1.653 2.181 2.219 2.150 2.023	3.730e-03 9.668e-03 8.846e-03 3.011e-03 1.395e-02 1.495e-02 7.985e-03 1.909e-02 1.435e-02 4.420e-02 3.542e-02 2.977e-02 4.127e-02 5.459e-02 8.138e-02 3.757e-02 1.266e-01 1.245e-01 7.282e-02 7.624e-02 9.283e-02 1.434e-01	2.045 2.050 2.048 2.056 2.076 2.108 2.130 2.154 2.181 2.221 2.284 2.370 2.391 2.532 2.577 2.880 3.265 4.484 6.092 7.913 17.410	8.178e-04 1.387e-03 5.806e-04 4.183e-04 1.456e-03 1.084e-03 7.744e-04 2.149e-03 1.012e-03 2.759e-03 2.781e-03 3.682e-03 2.885e-03 2.621e-03 3.734e-03 3.734e-03 3.734e-03 3.734e-03 2.414e-02 2.987e-02 1.265e-01 2.719e-01 1.087e+01	0.91790 1.48300 2.56200 1.59300 1.80500 3.26600 2.55200 2.33000 2.21600 3.11400 3.29200 3.88700 3.75000 4.38000 5.30400 6.30400 6.99900 6.80300 2.07700 0.95380 0.30890 0.23780 0.01124	4.823e-02 1.663e-01 2.110e-01 5.226e-02 2.566e-01 3.905e-01 1.575e-01 3.797e-01 2.241e-01 8.285e-01 7.587e-01 1.208e+00 6.440e-01 7.088e-01 1.013e+00 1.556e+00 8.458e-01 2.291e+00 2.108e+00 6.568e-01 1.924e-01 8.253e-02 7.731e-02 2.345e-02

Table 5-II: Quemada parameters for data of present study.

Top, values for saline suspensions. Bottom, values for plasma suspensions.

along with their standard deviations in Table 5-II for Eagle's solution and plasma suspensions. The curves generated by these parameters are plotted as solid lines designated as "Fit A" in the results graphs of Chapter 4. The hematocrit dependence of the parameters, to be discussed in the sections to follow, are used to generate the dashed lines designated as "Fit B" in Chapter 4. For comparison, fits were also made of the Quemada equation to the polynomials of Chien et al. for both saline and plasma at intervals of five hematocrit units. The values obtained from these fits are shown in Table 5-III.

As discussed in Chapter 2, the potential for singular points of infinite viscosity exists as the cell volume fraction approaches unity, dependent on the magnitude of $\frac{c}{2} \cdot k_0$. Some of the fits obtained had singular shear rates, and these are documented in Table 5-IV, although in all of these cases they occur well out of the limits of the data.

The standard deviations in Tables 5-II and 5-III are notable in that those for the critical shear rate are large relative to the value itself. At low hematocrits, the standard deviation may be several times the parameter value for γ_c and it is also larger for k_0 . These observations underscore the fact that data at very low shear rates is needed to accurately fit these two constants.

5.2 Dependence of k_{∞} on hematocrit and plasma proteins

The A fit values for k_{∞} range from 1.752 to 6.605 for saline and 1.625 to 2.219 for plasma. On the whole, these values are compatible with the values around 1.8 fit by Quemada to other data (see Table 2-II, page 42), but lower because the data from this work extended to higher shear rates. The saline values for the A fit are plotted versus hematocrit along with the values obtained from the Ringer solution Chien polynomials in Figure 5-1. Since the data of Chien et al. does not

Hematourit	k-infinity	st. dev. k-infinity	k-0	st. dev. k-0	gamma. crit.	st. dev. gamma. crit.
100 95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15	1.829 1.834 1.836 1.847 1.872 1.915 2.098 2.131 2.219 2.313 2.525 2.653 2.750 2.867 2.867 2.867 2.884 2.963 3.162	3.85e-03 3.38e-03 1.33e-02 2.50e-02 3.77e-02 5.15e-02 6.72e-02 8.61e-02 1.09e-01 1.38e-01 1.71e-01 2.02e-01 2.11e-01 1.69e-01 1.10e-01 7.05e-02 6.61e-02 9.72e-02 1.71e-01 2.90e-01	2.005 2.112 2.227 2.348 2.474 2.604 2.736 2.865 2.985 3.091 3.175 3.234 3.280 3.389 5.054	2.74e-03 1.84e-03 6.17e-02 1.62e-02 2.34e-02 3.34e-02 4.75e-02 6.74e-02 9.48e-02 1.31e-01 1.80e-01 2.57e-01 5.33e-01 1.82e+01	0.763400 1.049000 1.321000 1.534000 1.672000 1.770000 1.779000 1.785000 1.786000 1.745000 1.545000 0.972800 0.219800 0.002042	1.37e-01 9.23e-02 3.05e-01 5.01e-01 6.83e-01 1.08e+00 1.35e+00 2.23e+00 2.23e+00 2.87e+00 3.40e+00 2.90e+00 9.26e-01 4.21e-02
Hematocri:	Medinity	st. dev. k-infinity	k-0	st. dev. k-0	gamma. crit.	st. dev. gamma. crit.
100 95 90 85 80 75 70 65 60 55 50 45 40 35 30 25	1.822 1.818 1.794 1.764 1.741 1.735 1.747 1.775 1.813 1.856 1.898 1.938 1.974 2.010 2.052	8.00e-03 1.00e-03 1.60e-02 3.70e-02 5.80e-02 7.70e-02 9.00e-02 9.30e-02 8.70e-02 4.60e-02 1.10e-02 3.00e-02 7.50e-02 1.21e-01	2.054 2.110 2.210 2.328 2.463 2.618 2.798 3.009 3.257 3.551 3.902 4.324 4.835 5.458 6.222	4.00e-02 1.00e-03 7.00e-03 1.00e-02 1.40e-02 2.00e-02 2.30e-02 2.30e-02 2.10e-02 4.00e-03 1.40e-02 4.50e-02 9.78e-02	0.079000 0.656100 1.725000 2.897000 3.745000 4.086000 3.993000 3.647000 3.203000 2.746000 2.307000 1.891000 1.494000 1.122000 0.790000	6.70e-02 2.44e-02 4.36e-01 1.05e+00 1.59e+00 1.85e+00 1.76e+00 1.46e+00 1.05e+00 6.53e-01 3.12e-01 5.70e-02 1.06e-01 1.85e-01 1.99e-01

Table 5-III: Quemada parameters for data of Chien et al., [1966].

Top, values for saline suspensions. Bottom, values for plasma suspensions.

Fit	Suspension	Н	$\gamma(\sec^{-1})$
A	saline	98.4	1.25 x 10 ⁻³
A	saline	97.2	5.70 x 10 ⁻⁴
A	saline	96.8	9.75 x 10 ⁻⁵
A	saline	96	1.67 x 10 ⁻⁴
A	plasma	98.1	3.73 x 10 ⁻⁴
A	plasma	97.6	8.71 x 10 ⁻⁶
В	saline	98.4	2.68 x 10 ⁻³
В	saline	97.2	5.17 x 10 ⁻⁴
В	saline	96.8	2.33 x 10 ⁻⁴
В	saline	96	7.88 x 10 ⁻⁶

Table 5-IV: Singular shear rates of curve fits.

k-infinity vs. hematocrit saline suspensions

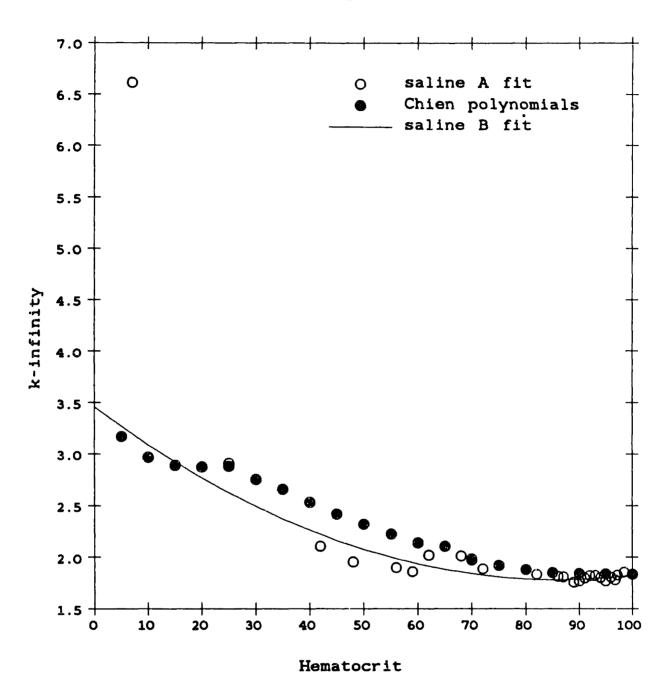


Figure 5-1: Plot of k_{∞} versus hematocrit for saline suspensions.

extend to high shear rates, it is to be expected that the derived k_{∞} values from that work will be of higher magnitude than those from the A fit. Similar behavior is shown by the k_{∞} values for plasma suspensions in Figure 5-2.

The B fits in Figures 5-1 and 5-2 represent fits of the open symbols to function of cell concentration. For both saline and plasma suspensions the fits are to second-order polynomials:

$$k_{\infty} = \sum_{i=1}^{3} k_{\infty i} c^{(i-1)}$$
 (5.2)

where $k_{\infty i}$ are constants and c is the volume concentration of cells. The values for the best fits of equation (5.2) and their standard deviations are, for saline,

$$\begin{aligned} k_{\infty 1} &= 3.458 {\pm} 0.251 \\ k_{\infty 2} &= -3.894 {\pm} 0.730 \\ k_{\infty 3} &= 2.260 {\pm} 0.500 \end{aligned}$$

and for plasma,

$$\begin{aligned} k_{\infty 1} &= 2.688 \pm 0.117 \\ k_{\infty 2} &= -2.300 \pm 0.433 \\ k_{\infty 3} &= 1.314 \pm 0.353. \end{aligned}$$

Both fits were relatively weighted, and the values at hematocrits of 95 and above were triple weighted to provide better correlation at high hematocrit. For the same reason, the saline k_{∞} value at H=7 was not included in the fit. The importance of accuracy at high hematocrit is seen by the sensitivity of the asymptotic relative viscosity at high shear rates, where $k=k_{\infty}$. The sensitivity is much greater at higher cell volume fractions because the magnitude of k_{∞} does not change a great deal with H. For example, at c=0.95, $k_{\infty}\approx1.7$, and $\frac{\partial\eta_r}{\partial k}=\frac{c}{(1-k\cdot c/2)^3}=133$. At c=0.45, $k_{\infty}\approx2.0$, and $\frac{\partial\eta_r}{\partial k}=2.7$.

The saline and plasma fits are plotted together on Figure 5-3. Plasma values are consistently lower than those for saline. This is not due to cell-protein

k-infinity vs. hematocrit plasma suspensions

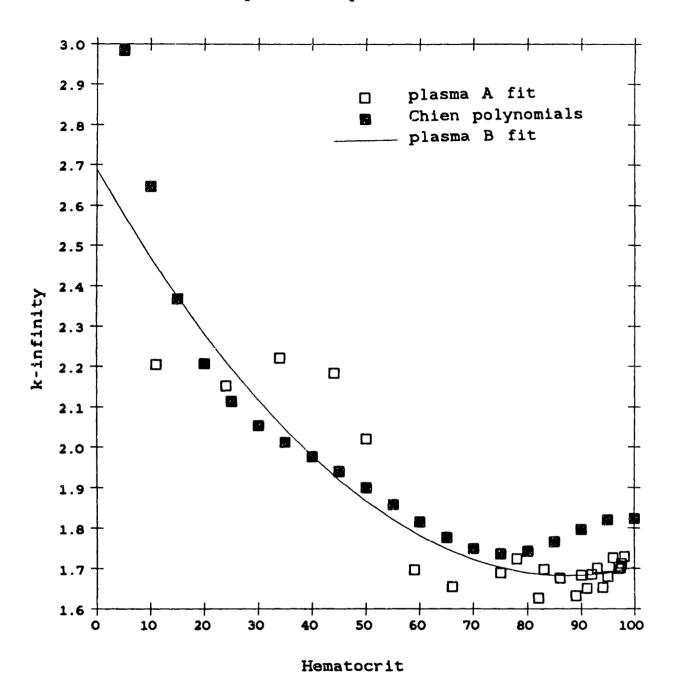


Figure 5-2: Plot of k_{∞} versus hematocrit for plasma suspensions.

k-infinity vs. hematocrit saline vs. plasma suspensions

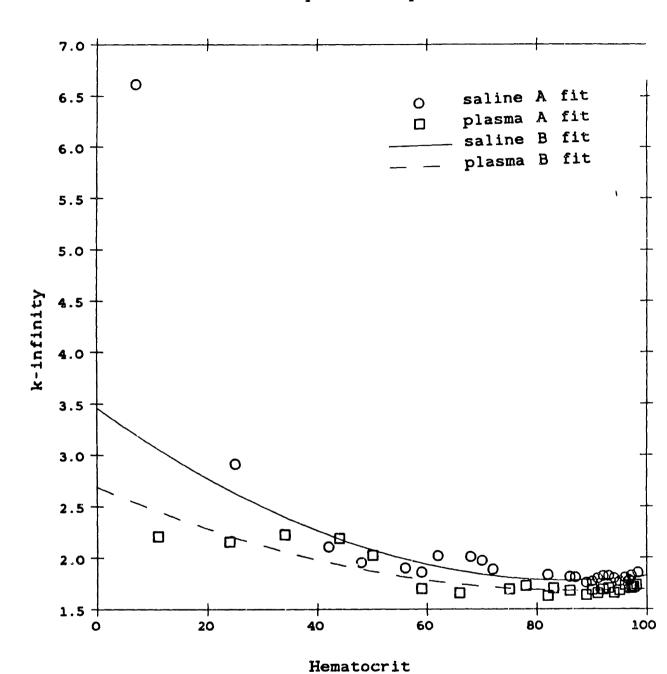


Figure 5-3: Comparison of k_{∞} values for saline and plasma suspensions.

interactions, because at high shear rates aggregation effects are not important, but results directly from the differences in η_f and the emulsive properties of the erythrocytes. For rigid particles, k_{∞} is independent of η_f ; but for emulsions, the intrinsic viscosity will clearly have a functional dependence on the internal viscosity, and if η_i is lowered in more viscous media, then k_{∞} will also be lowered. Quemada [1978b] obtained no difference in k_{∞} from data [Chien, 1970] for erythrocytes in plasma and Ringer's albumin solution (see Figure 2-3 and Table 2-II), but these solutions all had the same η_f , which is not the case here.

As noted in Chapter 4, as $c \to 1$, the absolute viscosities of plasma and saline solutions become equal, and, barring the apparently negligible differences in cell properties from saline washing, the definition of the relative viscosity leads to contrived distinctions. These distinctions are manifested in the difference in k_{∞} values at high hematocrits, as they are in the values for k_0 at high hematocrits. Thus k_{∞} , saline and k_{∞} , plasma can be related as a function of η_f . Since $\eta_{\text{saline}} = \eta_{\text{plasma}}$ at high H:

$$\frac{\eta_{f, \text{ plasma}}}{\eta_{f, \text{ saline}}} = \frac{\left(1 - \frac{c}{2} k_{\infty, \text{ plasma}}\right)^2}{\left(1 - \frac{c}{2} k_{\infty, \text{ saline}}\right)^2}$$
(5.3)

This reduces to

$$k_{\infty, \text{ plasma}} = k_{\infty, \text{ saline}} \cdot \left(\frac{\eta_{f, \text{ plasma}}}{\eta_{f, \text{ saline}}}\right)^{0.5} - \frac{2}{c} \cdot \left(\left(\frac{\eta_{f, \text{ plasma}}}{\eta_{f, \text{ saline}}}\right)^{0.5} - 1\right)$$
The values at high hematocrit comply with this relationship. (5.4)

Quemada [1981], in fitting the plasma data of Chien et al. [1966], noted that k_{∞} reached a minimum at about H=75 and proposed that this represented the point of inversion of the emulsion, where the erythrocytes begin to behave physically as a continuous phase. Using the first-order approximation that the intrinsic viscosity scales as effective particle volume (see Appendix C), a physical

picture may be constructed in which the effective particle volume at low concentration and high shear rate is the hydrodynamic volume of a single red cell. The effective volume is reduced by crowding as hematocrit increases, and eventually a point is reached where the effective particle is no longer a single cell, but a volume of sterically interacting cells. At this point inversion takes place. With further crowding, the volume of this effective particle no longer changes, but the number of cells it contains increases, leading to increases in intrinsic viscosity. There is not clear-cut evidence of a minimum k_{∞} in the results (Fit A) of this work, but there is a trend at hematocrits above 90 of k_{∞} increasing with H. The polynomial curve fits to the data (Fit B) reach minimums at about H=86-87.

The Quemada equation demonstrates a better approach to an asymptotic value at high shear rate than any of the empirical fits attempted, but the curves continue to descend after 300 sec⁻¹. Comparison of data values at 300 sec⁻¹ versus the limiting high shear rate asymptote for the Quemada equation, $(1-\frac{c}{2}\cdot k_{\infty})^{-2}$, are shown in Table 5-V for both the A and B fits. The average difference between data and equation values is on the order of 15-20%, although in some cases can be greater than 40%. These results are shown graphically in Figures 5-4 and 5-5. From these figures it can be seen that the difference between the Chien et al. values at 52 sec⁻¹ and the data at 300 sec⁻¹ is large enough to bring into question any use of the Chien values as the limiting viscosity. For saline, ratio of the Chien value to the data at 300 sec⁻¹ is about 1.1 to 1.2 over most of the hematocrits. For plasma, the ratio is greater than 2 for the most concentrated suspensions and about 1.1 at physiologic hematocrit.

Mematocrit	Rel. viscosity at 300 1/sec	A fit asymptote	% change from data	B fit asymptote	% change from data
98.4 97.2 96.8 96.0 95.0 94.0 93.0 92.0 91.0 90.0 87.0 86.0 82.0 72.0 70.0 68.0 62.0 59.0 56.0 48.0 42.0 42.0 42.0	151.3 86.7 59.3 57.3 47.6 47.1 47.2 43.6 33.4 27.5 25.8 22.3 19.8 12.1 11.2 12.1 9.8 7.1 6.4 4.6 4.1 2.8 1.7	122.7 74.4 50.0 54.1 38.1 40.7 41.6 36.7 29.0 23.2 20.6 21.8 20.1 16.0 9.7 10.3 9.9 7.1 4.9 4.5 3.5 3.5 3.7	-18.9 -14.2 -15.6 -5.6 -20.0 -13.7 -11.9 -15.9 -15.6 -20.2 -14.0 -9.8 -19.3 -20.2 -7.6 -18.4 -27.7 -31.5 -29.0 -11.9 -0.5	87.0 68.1 63.2 55.1 47.1 40.8 35.8 31.8 28.5 25.7 23.4 19.7 18.2 13.9 7.3 6.5 7.3 6.5 5.1 4.1 3.5 21.3	-42.5 -21.5 -6.6 -3.9 -1.2 -13.4 -24.1 -27.1 -14.7 -6.5 -9.4 -22.2 -18.3 -29.9 -29.6 -39.4 -38.4 -22.2 -20.7 -10.8 -14.3 -20.9 -25.4
98.1 97.6 97.3 97.0 96.0 95.0 94.0 93.0 91.0 89.0 89.0 86.0 83.0 66.0 59.0 50.0	49.8 44.6 41.8 36.8 39.6 29.5 23.2 26.5 21.3 18.2 20.0 15.9 15.3 13.6 11.1 11.5 9.5 6.2 5.1	43.0 36.7 33.4 32.1 33.6 24.3 19.9 22.7 19.7 16.0 16.9 13.3 12.7 11.4 9.0 9.3 7.4 4.8 4.0 4.1 3.7 2.6 1.8	from data	35.4 33.5 32.3 31.3 28.2 25.6 23.3 21.4 19.7 18.2 16.9 15.8 13.1 11.0 10.5 8.7 7.6 5.5 3.5 3.0 2.4 1.9	7 cnange from data

Table 5-V: High shear rate asymptotes.

Top, saline suspensions. Bottom, plasma suspensions.

Average change from data for saline=-16.7%±7.3 (A fit)

$$=-20.0\%\pm12.2$$
 (B fit)

Average change from data for plasma=-13.9%±6.3 (A fit)

$$=-13.9\%\pm9.1$$
 (B fit)

High shear rate asymptotes for saline fits

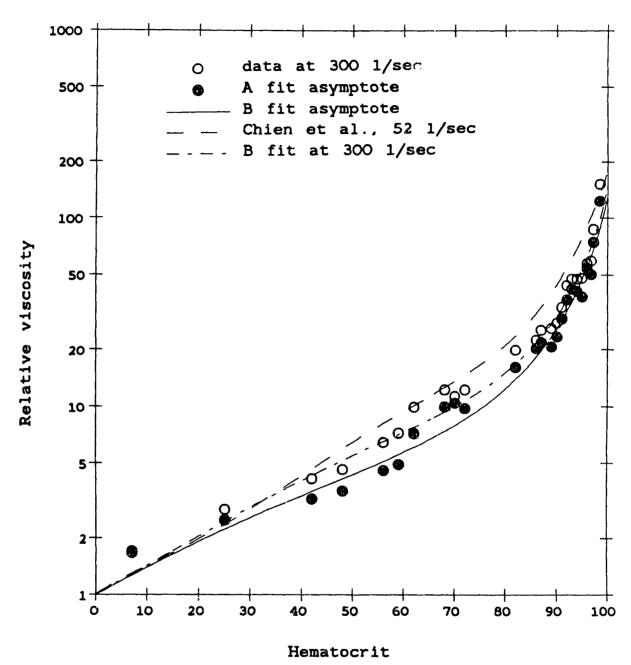


Figure 5-4: High shear rate asymptotes for saline fits.

High shear rate asymptotes for plasma fits

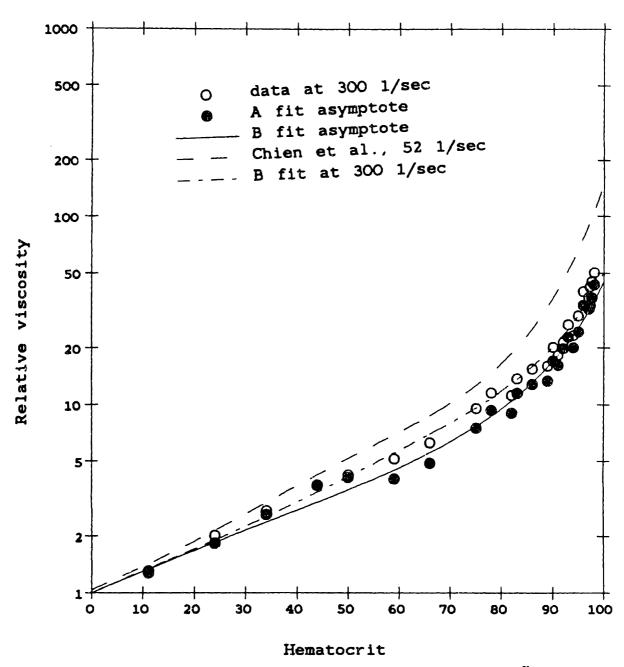


Figure 5-5: High shear rate asymptotes for plasma fits.

5.3 Dependence of ko on hematocrit and plasma proteins

The values for k_0 of 4.48 in plasma at H=44, 2.22 in plasma at H=89, and 3.48 in saline at H=48 were comparable to values previously fit by Quemada (see Table 2-II. The A fit values for k_0 are plotted versus hematocrit in Figure 5-6 for saline and in Figure 5-7 for plasma. Again, included in both plots are values from fits of the Quemada equation to the Chien polynomials. There is very close agreement between the A fit k_0 and the Chien k_0 , particularly at high hematocrits, and this follows from the comparable viscosity values obtained at low shear rate and high hematocrits.

The B fits in Figure 5-6 represents a relatively weighted fit of the open symbol to a third-order polynomial, to which an exponential term has been added for plasma:

$$k_0 = \sum_{i=1}^{4} k_{0i} \cdot c^{(i-1)} + k_{05} \cdot exp(k_{06} \cdot c)$$
 (5.5)

The best-fit values and standard deviations for saline are

 $k_{01} = 3.503 \pm 0.413$

 $k_{02} = 3.467 \pm 2.140$

 $k_{03} = -9.976 \pm 3.470$

 $k_{04} = 5.026 \pm 2.841.$

 $k_{05} = 0$

 $k_{06} = 0.$

At c<20, the data is fit to a constant $k_0=3.838$. The polynomial reaches a maximum at about c=0.2, and there is no physical reason to expect k_0 to do this. It seems physically reasonable to expect k_0 to approach a constant at low hematocrits in saline, as will be explained shortly. Attempts were made to fit to equations which level off to a constant as c approaches zero, such as equations of the form k_{01} tanh $(k_{02}c+k_{03})$, but these did not prove satisfactory.

For the plasma fit, the exponential term is required to model the dependence

kO vs. hematocrit
saline suspensions

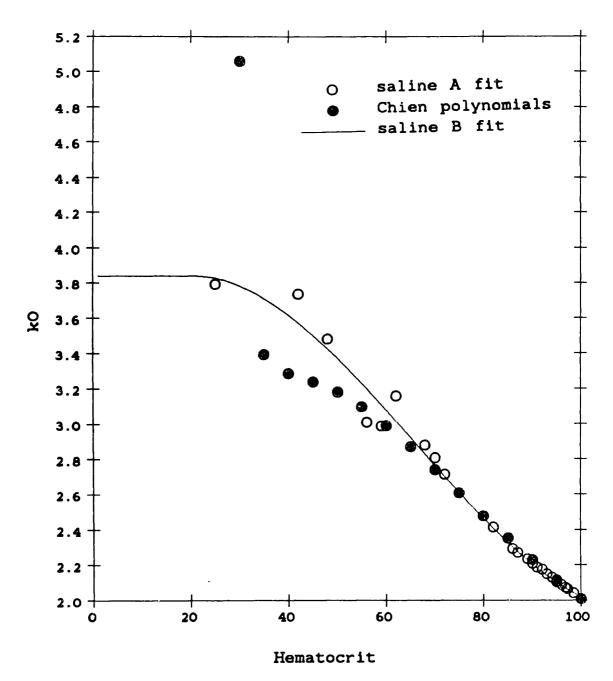


Figure 5-6: Plot of k₀ versus hematocrit for saline suspensions.

kO vs. hematocrit plasma suspensions

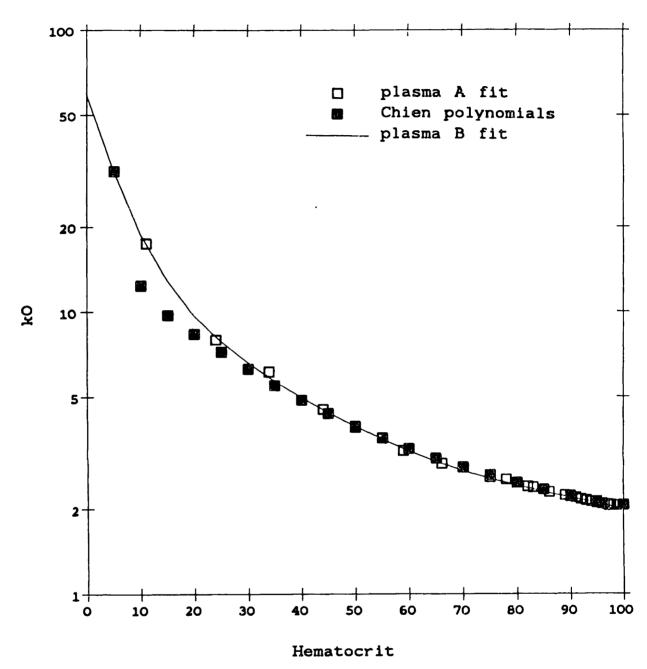


Figure 5-7: Plot of k₀ versus hematocrit for plasma suspensions.

at low hematocrits. The best-fit values for plasma are

 $k_{01} = 13.28 \pm 0.60$

 $k_{02} = -31.93 \pm 2.67$

 $k_{03} = 32.13 \pm 3.74$

 $k_{04} = -11.49 \pm 0.02$

 $k_{05} = 45.46 \pm 1.06$

 $k_{06} = -16.78 \pm 0.65.$

The plasma B fit is a relatively weighted fit to the open squares in Figure 5-7 plus the single filled square at H=5. The Chien polynomial value was included because these values closely followed the data at low hematocrit and because this is a critical region for fitting the exponential term. Values at hematocrits of 90 and above were additionally weighted by a factor of 10 to insure agreement at high H. This additional weighting is needed to avoid the appearance of singular points, where $\frac{c}{2}k_0>1$, in the B fits.

The sensitivity of the asymptotic zero-shear-rate viscosity to the value of k_0 is an expression for $\frac{\partial \eta_r}{\partial k}$ equivalent to that shown for k_∞ in the last section, with k now equal to k_0 . For saline suspensions, this sensitivity is highest at high hematocrits. For plasma suspensions, the sensitivity is highest at low hematocrits because of the large values for k_0 at low hematocrits. For example, for both suspensions, at c=0.95, $k_0\approx 2$ and $\frac{\partial \eta_r}{\partial k}=760$. For saline at c=0.45, $k_0\approx 3.2$ and $\frac{\partial \eta_r}{\partial k}=20.5$. For plasma at c=0.45, $k_0\approx 4.4$ and $\frac{\partial \eta_r}{\partial k}=450,000$. Insurance must also be taken to avoid singular points in the refit Quemada equation where $\frac{c}{2}k_0-1>0$.

Saline and plasma values are plotted together on Figure 5-8. The values are almost identical at high hematocrits, down to about H=65. With further decrease in hematocrit, the saline values appear to level off, while the plasma values show a large increase. At zero shear rate, the emulsive and shear deformation effects are

kO vs. hematocrit saline vs. plasma suspensions

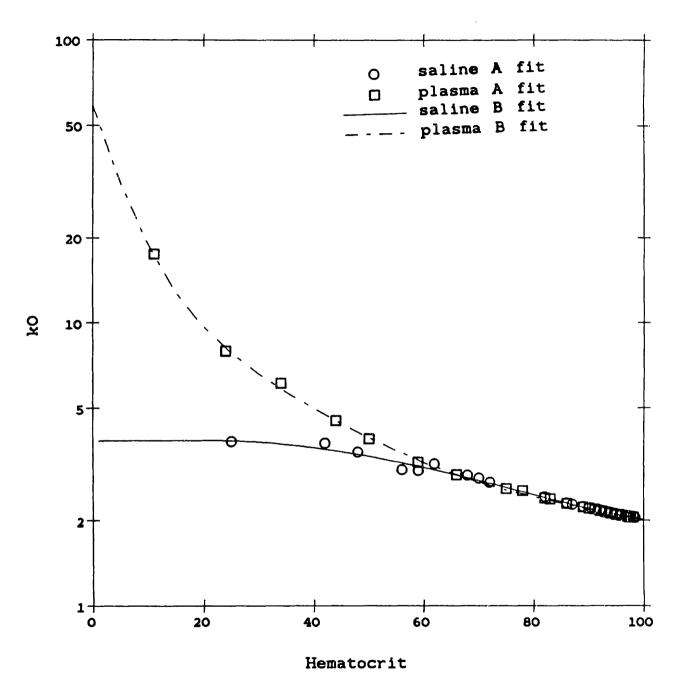


Figure 5-8: Comparison of k_0 values for saline and plasma suspensions.

minimized, and thus k_0 should principally be an indicator of cell-cell interactions, either protein-mediated (aggregation) or steric (crowding). At low hematocrits, crowding is not seen, and the difference between saline and plasma k_0 is caused by rouleaux formation. Where plasma and saline values are equal, at high hematocrits, should be where crowding effects predominate over aggregation. An analysis by Chien et al. [1966] suggested that at a hematocrit of 60, crowding interactions begin to influency viscosity relative to aggregation and that at H=80, they begin to be the dominant influence. This is also probably related to the inversion phenomenon. The merging of the B fit lines in Figure 5-8 around H=65 would seem to lend some credence to this hypothesis.

At low shear rate, and at hematocrits low enough so that crowding is not a factor, normal cells in saline solution should approximate the behavior of hardened cells in saline. The maximum packing concentration c_p for hardened erythrocytes in saline has been determined experimentally to be about 0.6 [Chien et al., 1971]. Using the relationship derived in Appendix C for rigid particles, $k_0=2/c_p=3.33$, which compares reasonably well with the asymptotic value of 3.838 from the B fit.

The A and B fit values for viscosity at zero shear rate are plotted in Figures 5-9 and 5-10 for saline and plasma suspensions, respectively. Unlike for high shear rates, a smooth limiting envelope can not be generated from the k_0 values. The γ =0 curve for saline is not well-behaved at high hematocrits, and the γ =0 curve for plasma is obviously meaningless. The message behind these figures is that, except for low hematocrit saline suspensions, the Quemada equation is extremely sensitive to k_0 in the limit of low shear rate. If one wishes to use the Quemada equation at low shear rates, k_0 values must be derived from fits to data that clearly reach an asymptote at low γ . Values for k_0 which have been extrapolated from data at higher shear rates, such as those in this work, will do a satisfactory job of

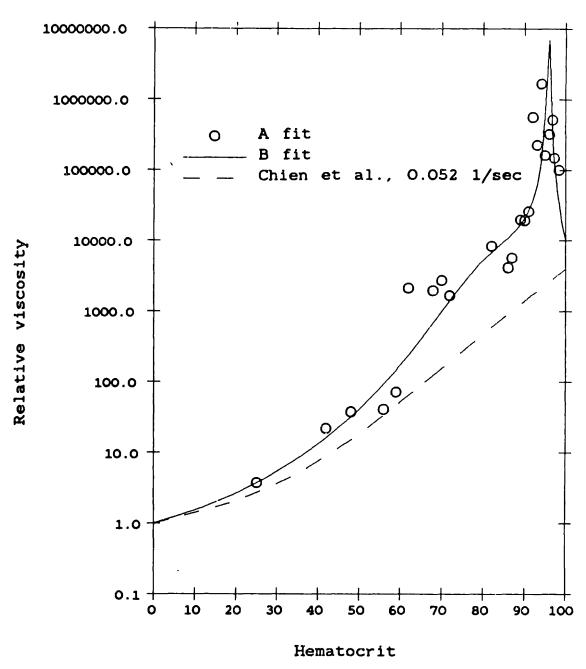


Figure 5-9: Zero shear rate asymptotes for saline fits.

Viscosity at zero shear rate for plasma fits

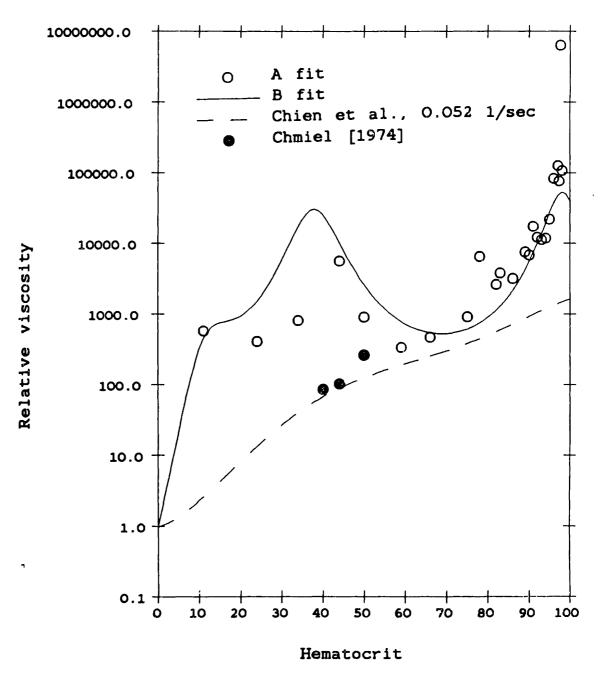


Figure 5-10: Zero shear rate asymptotes for plasma fits.

modeling overall behavior, but they will not be accurate enough for predicting viscosity at low shear rates.

At very high hematocrits, the difference between saline and plasma k_0 can probably also be related by equation (5.4), replacing k_{∞} with k_0 . An attempt was made to use this equation to derive new plasma k_0 values from the Fit A saline values, in hopes that the new values would provide a more realistic $\gamma=0$ curve. The highest hematocrit at which a singular point does not result from the saline A fit is 95. Using the saline value 2.1 at H=95, equation (5.4) gives a plasma k_0 of 2.099, and $\eta_r=10^5$. Similarly, at H=94, the saline value of 2.126 results in a plasma value of 2.126 and $\eta_r=10^6$. This indicates that at high hematocrits, the saline A fit values are inaccurate also, at least on the scale of determining low shear rate viscosity.

As an example of just how accurately k_0 must be determined, Chmiel [1974] collected data for whole blood at shear rates of 0.1 to 0.005 sec⁻¹ in a wide-gap Couette system, in which an asymptotic approach to a constant viscosity at low shear rate was demonstrated. Assuming a η_f , which is not explicitly given in the paper, of 1.2 cP, relative viscosities at H=50, 44, and 40 correspond to k_0 values of 3.75, 4.09 and 4.45, respectively. The parameter values from this study of 3.87 at H=50 and 4.48 at H=44 are both comparable, within 3 and 10 per cent of the Chmiel values, respectively, and yet the calculated viscosities at γ =0 are an order of magnitude or more higher. For comparison, Chmiel's data is shown on Figure 5-10 as filled circles.

From an analytical standpoint, the difficulty stems from the fact that for plasma, $\frac{c}{2}k_0$ is always approximately equal to 0.99. Thus a smooth plot of $(1-\frac{c}{2}\cdot k_0)^{-2}$ depends on accurately representing small deviations from zero.

5.4 Dependence of γ_c on hematocrit and plasma proteins

The values for the A fits of γ_c for saline are plotted versus hematocrit in Figure 5-11. Also plotted are values derived from fits of the Quemada equation to the Chien et al. polynomials. There is a good deal of scatter in the A fit values, but the trend seems to be for γ becoming large as hematocrit decreses. The values from the Chien polynomials decay toward zero as hematocrit decreases. The result of these opposing trends is seen in the different curvatures of the two sets of data along the γ axis (see Figures 4-20 to 4-23). The data from this work and the A fits are convex, while the Chien points indicate a concave curvature.

From a strictly analytical viewpoint, it can be seen how γ_c affects this curvature. It will be recalled from the discussion in Section 2.4 that the Quemada equation results in a sigmoidal curve along the x-axis (γ axis). As γ_c increases, the curve is shifted to the right, and the curvature at a fixed shear rate becomes more convex. As γ_c decreases, the reverse happens.

The question exists whether the high γ_c values are artifacts resulting from secondary flows in the viscometer at higher shear rates and low hematocrits. Jerrard [1950] has developed charts for assessing the onset of instability in rotating-cylinder viscometers in which the outer cylinder rotates, such as the Haake viscometer used in this work. Based on the geometry of the Haake viscometer, the critical shear rate in \sec^{-1} for secondary flow is 3.5 x $10^5\nu$, where ν is the kinematic viscosity of the fluid in stokes. For water, plasma, and red cells in saline at H=42, the calculated values are 2300, 4100, and 10,000 \sec^{-1} , respectively. It would seem that secondary flow is not a consideration, and yet shear-thickening behavior was noted in the measurement of both saline and plasma viscosities, which is normally an indication of some instability.

gamma-critical vs. hematocrit saline suspensions

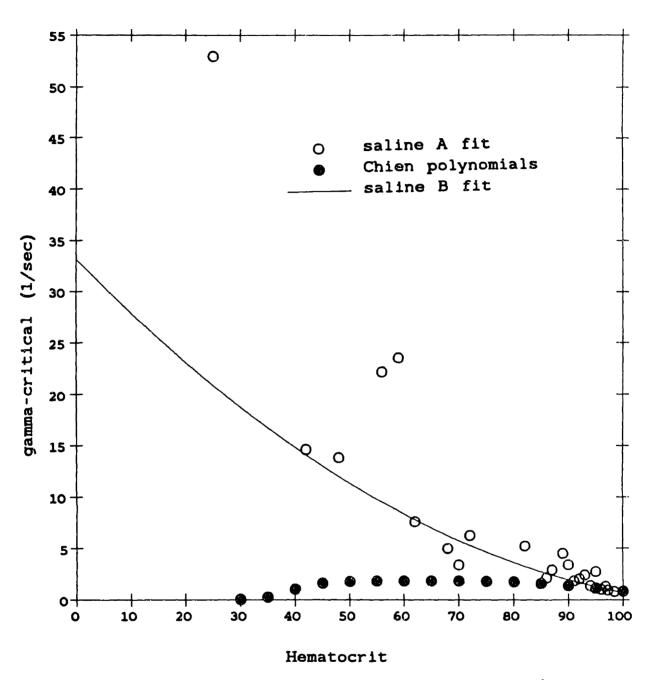


Figure 5-11: Plot of γ versus hematocrit for saline suspensions.

It is possible that the concavity of the Chien et al. values is forced from the nature of the fifth-order polynomials used to calculate them, and that the actual data of Chien [et al.] would correspond to the data of this work. Later data by Chien [1970] shows convex curvature similar to the A fits (see Figures 2-3 and 2-11). Quemada [1978b] fit a γ_c value of 25 sec⁻¹ to this later data of Chien, which agrees with the values shown in Figure 5-11.

Plasma values for γ_c are plotted in Figure 5-12. Both the Chien polynomials and the A fits indicate $\gamma_c \approx 0$ at H=0, then an increase to a maximum at about H=70-75, and subsequent decrease with incresing H. Correspondingly, the A fits are concave at both high and low hematorits, but around H=70 (see Figures 4-42 to 4-44) a more sigmoidal curve is seen.

The B fit in Figure 5-11 represents a relatively weighted fit of the saline A fit values to the form

$$\gamma_c = \sum_{i=1}^{3} \gamma_{ci} c^{(i-1)} \tag{5.6}$$

where the best-fit values are

$$\gamma_{c1} = 33.16 \pm 11.95$$

$$\gamma_{c2} = -54.79 {\pm} 28.57$$

$$\gamma_{c3} = 22.33 \pm 16.93.$$

A second-order polynomial was fit to the Chien values in Figure 5-11. This fit, when substituted for the saline B fit curve from this study, resulted in a shifting of the curve to the left and predicted relative viscosities up to an order of magnitude lower than the data at low shear rates. For plasma, the B fit is of the form

$$\gamma_c = \gamma_{c1} \cdot \exp(-(\gamma_{c2}c + \gamma_{c3})^2) \tag{5.7}$$

where by a relatively weighted fit, the values are

gamma-critical vs. hematocrit plasma suspensions

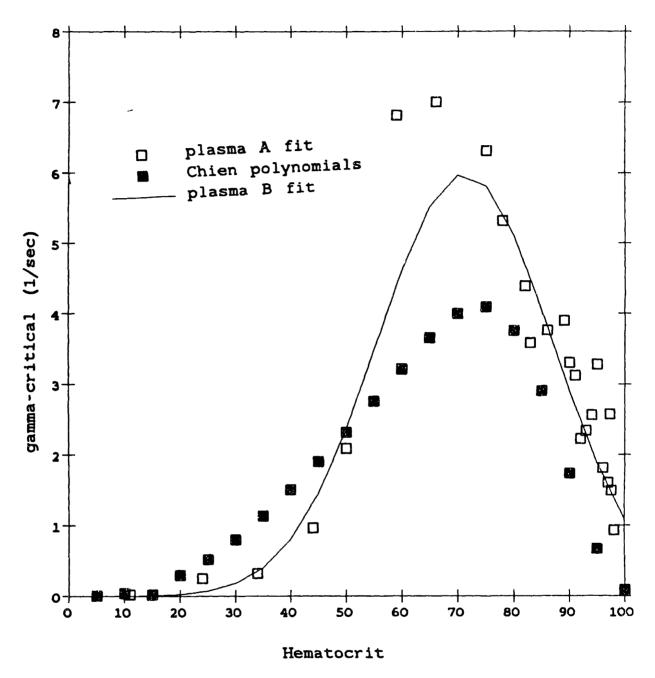


Figure 5-12: Plot of γ_c versus hematocrit for plasma suspensions.

$$\gamma_{c1} = 5.979 \pm 0.580$$

$$\gamma_{c2} = -4.536 \pm 0.162$$

$$\gamma_{c3} = 3.232 \pm 0.098.$$

The saline and plasma values are plotted together on Figure 5-13. The values from the two suspensions converge with increasing hematocrit at about H=70 and are comparable at high concentrations, with the saline values somewhat higher.

From a physical interpretation, γ_c is analogous to a rotational diffusion constant, with a dependence $\gamma_c \sim a^{-3}$, where a is the particle radius (see Appendix C). Thus effects which increase effective particle size will decrease γ_c . The two such mechanisms for increasing effective particle size are aggregation and crowding. In saline, the cells do not aggregate, and so there is a simple trend of γ_c decreasing with hematocrit. In plasma suspensions, one could imagine that initially as concentration increases, crowding acts to diminish rouleau and aggregate size, and γ_c increases. When γ_c reaches a maximum that roughly corresponds to inversion, crowding acts to pack cells together and γ_c decreases.

5.5 Limiting behavior of parameters

A major concern in globally refitting the Quemada expression over all hematocrits is the limiting behavior of the equation, and specifically the intrinsic viscosity $k=k_{\infty}+\frac{k_0-k_{\infty}}{-}$ as the cell volume concentration goes to zero. Since the equation was derived for concentrated dispersions, it may be appropriate to say that it is not valid in the limit $c \to 0$. Nevertheless, the equation can be fit successfully to low concentration data, and the parameters do appear to approach asymptotic values at low hematocrits.

Newtonian behavior should be recovered where k is not a function of shear

gamma-critical vs. hematocrit
saline vs. plasma suspensions

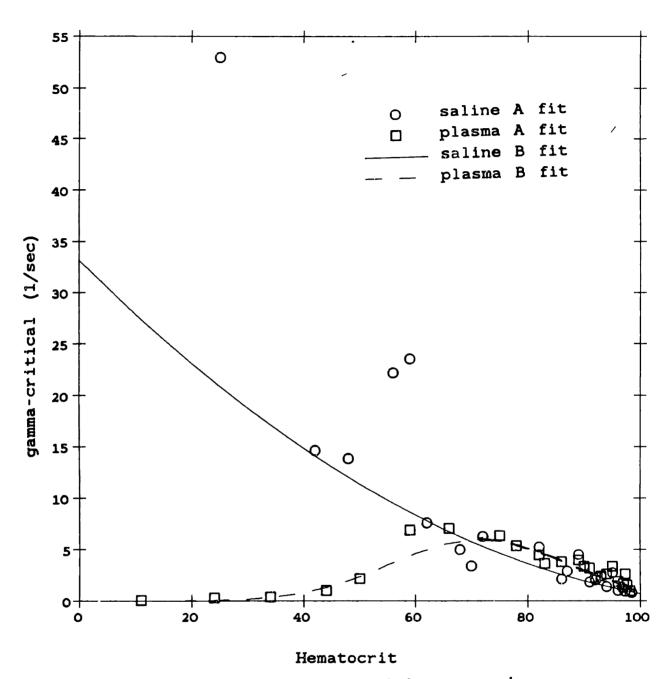


Figure 5-13: Comparison of γ_c for saline and plasma suspensions.

rate. There are three possible mathematical ways by which k can become independent of shear rate, and these will be considered in turn, first from a purely analytical standpoint, and then by how the analysis relates to data and to physical interpretation:

- $k_{\infty} = k_0$. Quemada [1981] proposed that at the Newtonian thresholds H=30 for saline suspensions and H=5 for plasma suspensions, k_{∞} and k_0 become equal at some intermediate value. The data does not support this, as the difference between the two parameters is greatest at low hematocrits for both plasma and saline suspensions. Additionally, from a conceptual standpoint, it would seem that even in the absence of aggregation and cell-cell crowding, orientation and deformation would lead to a finite distinction between intrinsic viscosities at low and high shear rates.
- $\gamma_c \to \infty$, $k \to k_0$. This behavior is demonstrated by the Eagle's solution data of this work and appears to correlate with the analysis of γ_c as inversely proportional to particle radius, although if this were strictly true, some asymptotic finite value would be expected. Also, the limit of $k \to k_0$ is troublesome, because it indicates that as long as γ_c is finite, the viscosity will decrease at large enough γ . A more realistic stating of this limit that would satisfy these concerns is to combine this criterion with the first case, so that γ_c approaches a large, but finite, value and $k_\infty \to k_0$.
- $\gamma_c \to 0$, $k \to k_\infty$. This behavior is demonstrated by both sets of Chien data and by the plasma data of this work after incorportation of the Chien data, and it is also coupled with a large increase in k_0 , which causes the curves to increase sharply at low H. It appears to be

incompatible with the idea of γ_c as a rotational diffusion constant dependent solely on effective particle radius, although it seems logical that as concentration decreases, non-Newtonian behavior will be expressed at increasingly lower shear rates. A possible explanation is that there is an initial increase in the frequency of particle collisions as cell concentration increases, with a resulting enhancement of aggregate formation, followed by a decrease when steric effects limit mobility. It is interesting to note that the maximum in γ_c in all cases occurs around H=70-75, which again corresponds with the analysis of Chien et al. [1966] as the advent of prominent effects from cell crowding.

5.6 Comparison of global fit equations to data

The B fit values for the rheological parameters are shown in Table 5-VI. These values are obtained from the equations discussed in the previous three sections, and are used to plot the dashed curves in Figures 4-2 to 4-49. As shown in Figures 5-14 to 5-17, the B fits provide a reasonable representation of the data, whether plotted as a function of hematocrit or of shear rate. The fits are best at shear rates greater than 0.5 sec⁻¹. The plasma curves provide better fits to data at shear rates down to 0.05 sec⁻¹, despite the crossing over of the plasma curves of Figure 5-17 and the relatively smooth behavior of the saline curves in Figure 5-15. Even in the absence of data, the saline curves probably adequately model viscosity at low hematocrits and low shear rates, since the behavior is Newtonian. At hematocrits greater than 98, both the saline and plasma fits tend to underestimate the data. When plotted against the Chien polynomials (see Figures 5-18 and 5-19) the same comments can be made as for the comparison of the polynomials to the data of this work (see Figures 4-54 and 4-55).

Hematocrit	k-inf. B fit	k-O B fit	gamcrit. B fit
98.4 97.2 96.8 96.0 95.0 93.0 91.0 97.0 87.0 86.0 82.0 70.0 68.0 62.0 59.0 56.0 48.0 77.0	1.815 1.808 1.806 1.803 1.798 1.795 1.791 1.786 1.784 1.782 1.781 1.785 1.826 1.840 1.855 1.912 1.947 1.986 2.110 2.221 2.626 3.838	2.044 2.063 2.070 2.084 2.102 2.122 2.142 2.163 2.184 2.207 2.230 2.278 2.303 2.409 2.766 2.828 3.016 3.108 3.199 3.425 3.572 3.825 3.699	0.868 1.001 1.047 1.141 1.262 1.388 1.519 1.653 1.793 1.936 2.084 2.394 2.556 3.247 5.749 6.228 7.774 8.607 9.480 12.006 14.087 20.858 29.434
Hematocrit	1-1-6	1- 0	
	B fit	k-O B fit	gamcrit. B fit

Table 5-VI: B fit values of Quemada parameters for Eagle's solution and plasma.

Top, values for Eagle's solution. Bottom, values for plasma.

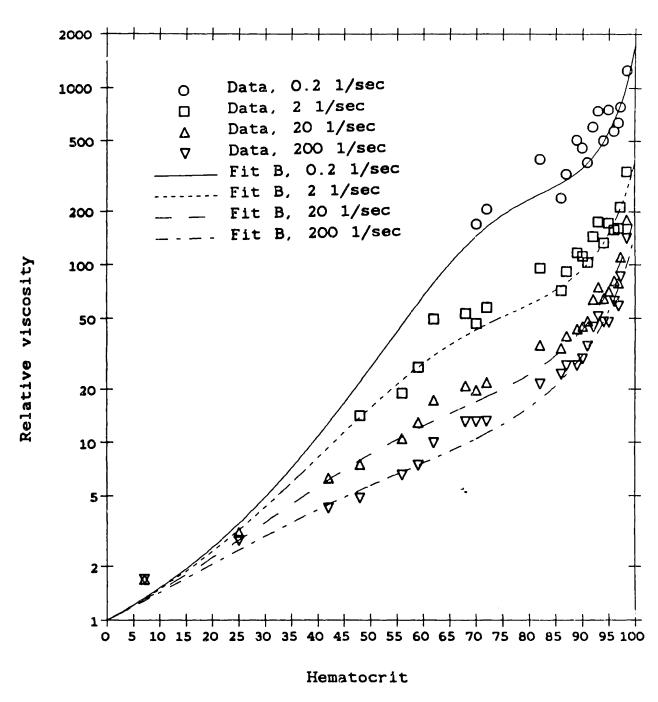


Figure 5-14: Comparison of saline global fit to data as a function of hematocrit.

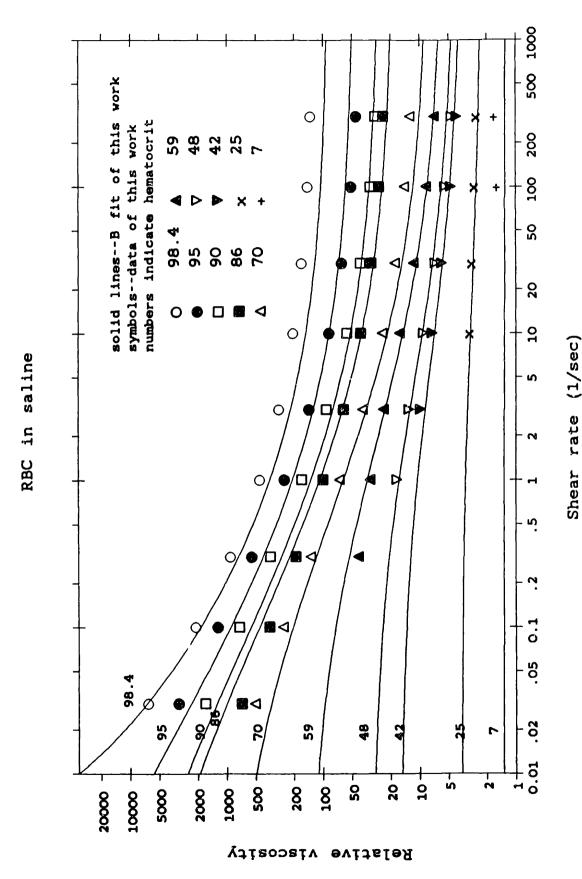


Figure 5-15: Comparison of saline global fit to data as a function of shear rate.

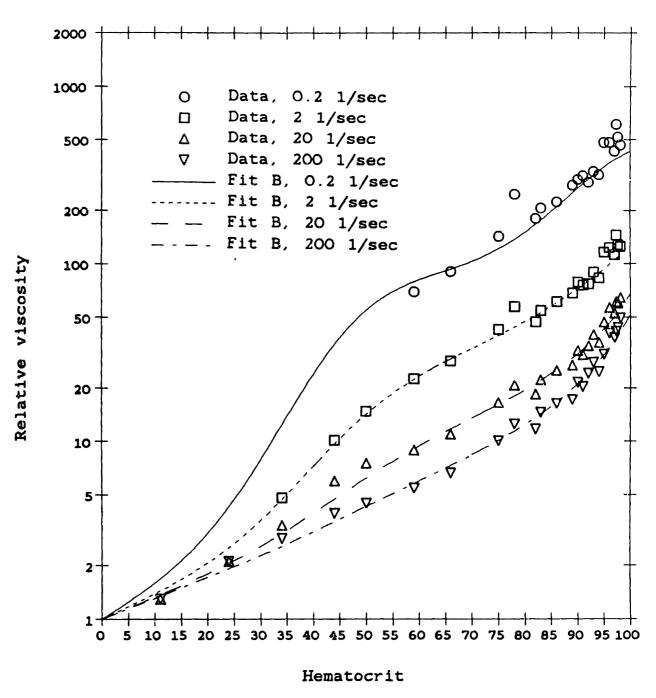


Figure 5-16: Comparison of plasma global fit to data as a function of hematocrit.

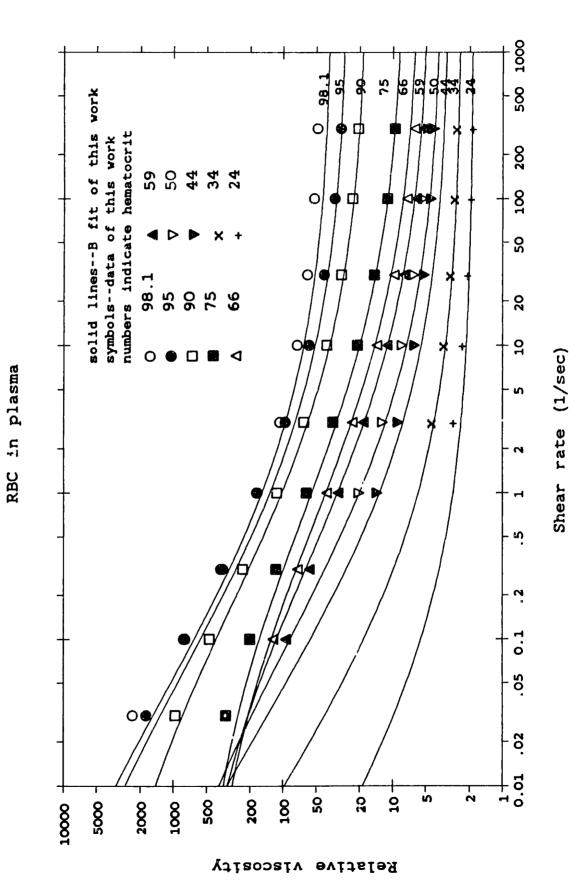


Figure 5-17: Comparison of plasma global fit to data as a function of shear rate.

RBC in saline

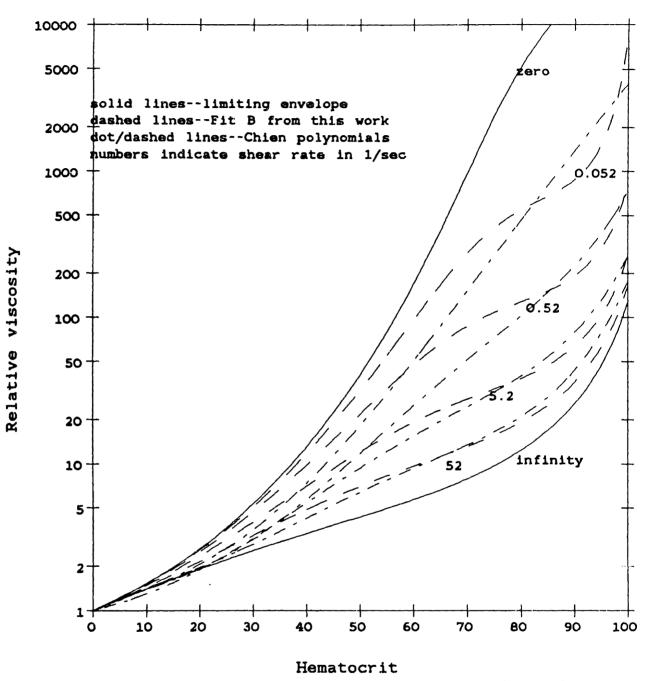


Figure 5-18: Comparison of saline global fit to Chien polynomials.

RBC in plasma

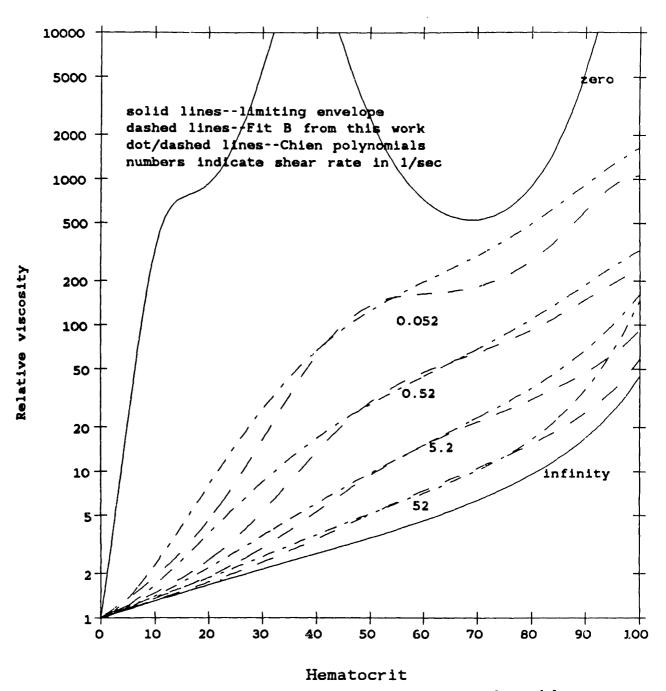


Figure 5-19: Comparison of plasma global fit to Chien polynomials.

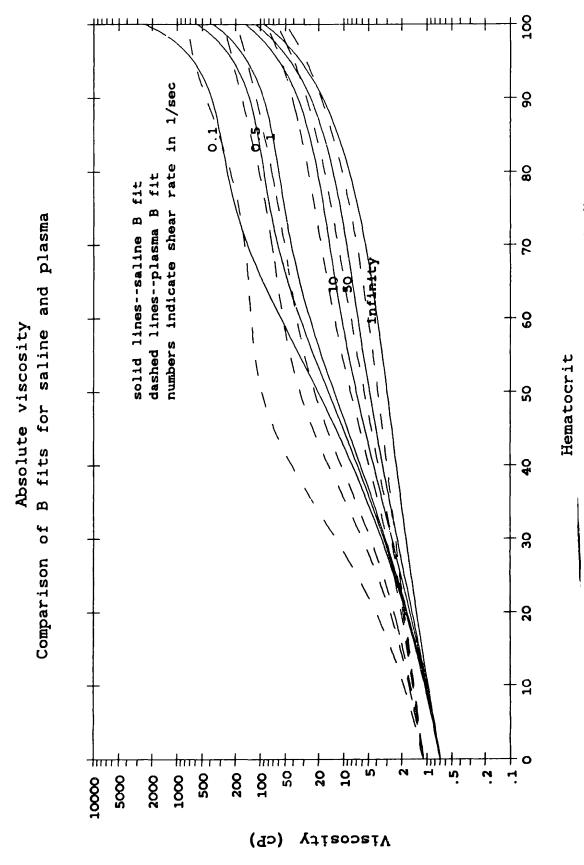


Figure 5-20: Comparison of B fit curves for plasma and saline.

The B fit curves for plasma and saline are compared at various shear rates in Figure 5-20. In the limit of high hematocrit, the B fit curves begin to approach each other in a manner similar to the data (see Figure 5-21). Plasma suspensions maintain slightly higher viscosities until about H=92-95 when the curves cross. This crossing is primarily due to the saline data at H=98.4, where the viscosity was much higher than for any other sample.

The final global fits (B fits) are summarized in Table 5-VII. The equations are plotted alone as functions of hematocrit and shear rate in Figures 5-22 and 5-23 for saline and in Figures 5-24 and 5-25 for plasma.

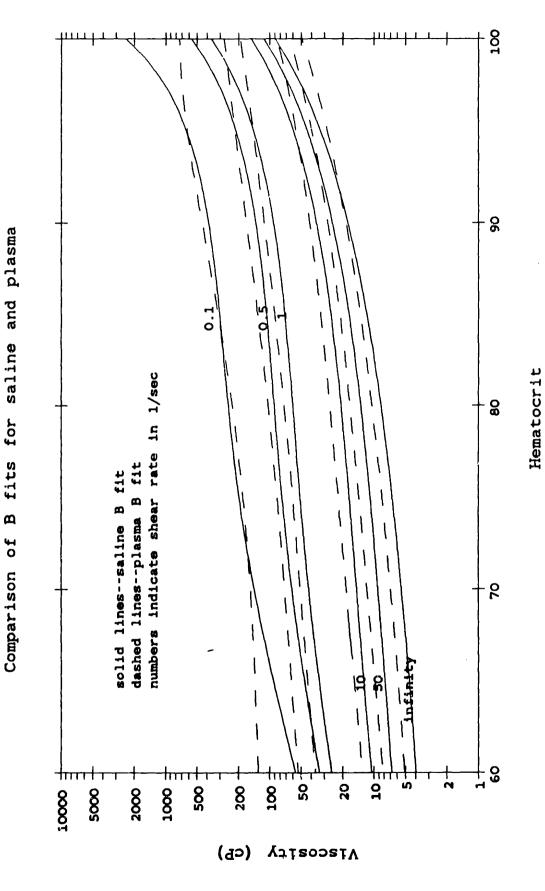
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5.7 Summary, conclusions, and recommendations

Data collected at hematocrits above 90 shows the still-fluid nature of packed cells, emphasizing that blood is more like an emulsion than a suspension of rigid particles. At high hematocrits, the difference in viscosity between cells in plasma and cells in saline solution is small, but it increases at lower hematocrits and lower shear rates, indicating the effects of the plasma proteins on aggregation.

The complex interactions of blood cells and plasma, summarized in Section 2.4, constitute the challenge of developing theoretical expressions for blood rheology. To date, theory can only be taken so far, and then at some point one must incoporate empirical fits into the theory.

The three-parameter Quemada equation has been fit individually to data at each hematocrit and has proven to be an effective model on this basis. The parameters were empirically fitted to functions of hematocrit, and in this way a set of equations has been derived which can be used with the Quemada expression to represent blood viscosity over a wide range of hematocrits and shear rates,



Absolute viscosity at high hematocrits

Figure 5-21: High hematocrit viscosities from the B fit for saline and plasma.

QUEMADA EQUATION
$$\eta_r = \left[1 - \frac{c}{2} \left(k_{\infty} + \frac{k_0 - k_{\infty}}{1 + \sqrt{\gamma/\gamma_c}}\right)\right]^{-2}$$

Parameter Equation

Constants

	saline	plasma
$k_{\infty} = \sum_{i=1}^{3} k_{\infty i} \cdot c^{(i-1)}$	$k_{\infty 1} = 3.458$ $k_{\infty 2} = -3.894$ $k_{\infty 3} = 2.260$	$k_{\infty 1} = 2.688$ $k_{\infty 2} = -2.300$ $k_{\infty 3} = 1.314$
$k_0 = \sum_{i=1}^4 k_{0i} \cdot c^{(i-1)} + k_{05} \exp(k_{06} \cdot c)$	$k_{01} = 3.503$ $k_{02} = 3.467$ $k_{03} = -9.976$	$k_{01} = 13.28$ $k_{02} = -31.93$ $k_{03} = 32.13$
(Note: for saline and c<20, k ₀ =3.838)	$k_{04}^{03} = 5.026$ $k_{05} = 0$ $k_{06} = 0$	$k_{04} = -11.49$ $k_{05} = 45.46$ $k_{06} = -16.78$
saline $\gamma_c = \sum_{i=1}^{3} \gamma_{ci} \cdot c^{(i-1)}$	γ_{c1} =33.16 γ_{c2} =-54.79 γ_{c3} =22.33	
plasma $\gamma_{c} = \gamma_{c1} \exp(-(\gamma_{c2} c + \gamma_{c3}))^{2})$	$\gamma_{c1} = 5.979$ $\gamma_{c2} = -4.536$ $\gamma_{c3} = 3.232$	

Table 5-VII: Summary of global fits for saline and plasma suspensions.

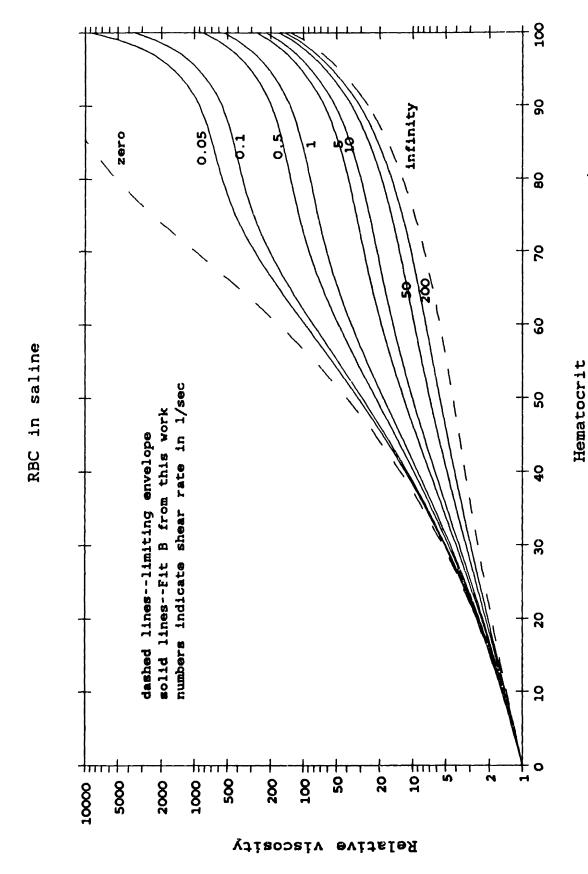


Figure 5-22: Plot of saline global equations versus hematocrit.

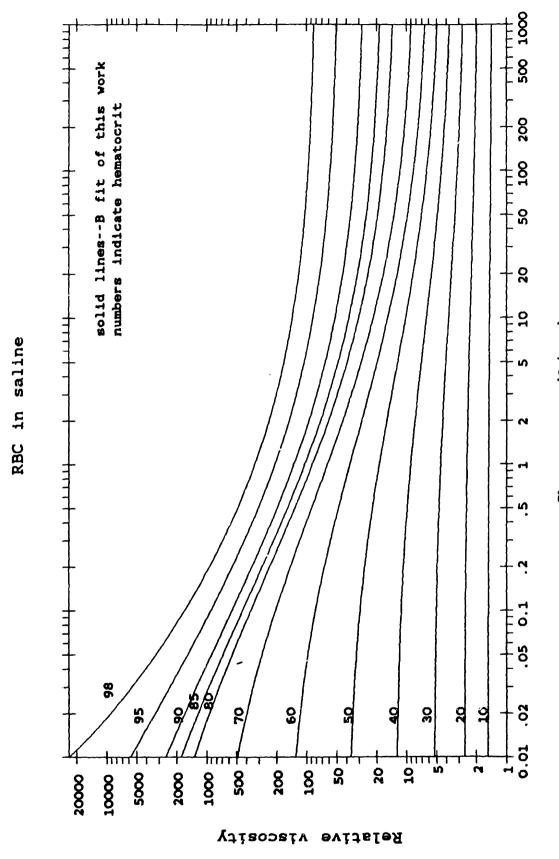


Figure 5-23: Plot of saline global equations versus shear rate.

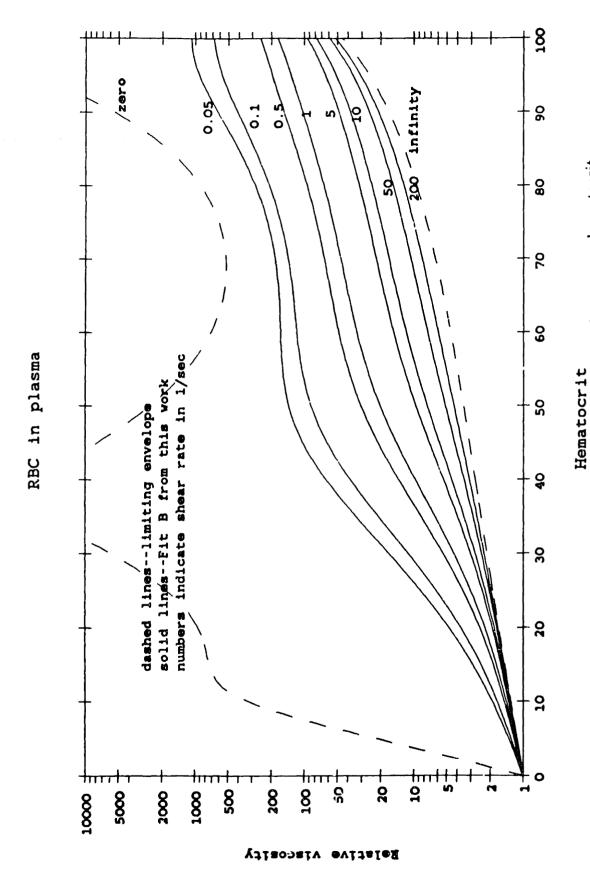


Figure 5-24: Plot of plasma global equations versus hematocrit.

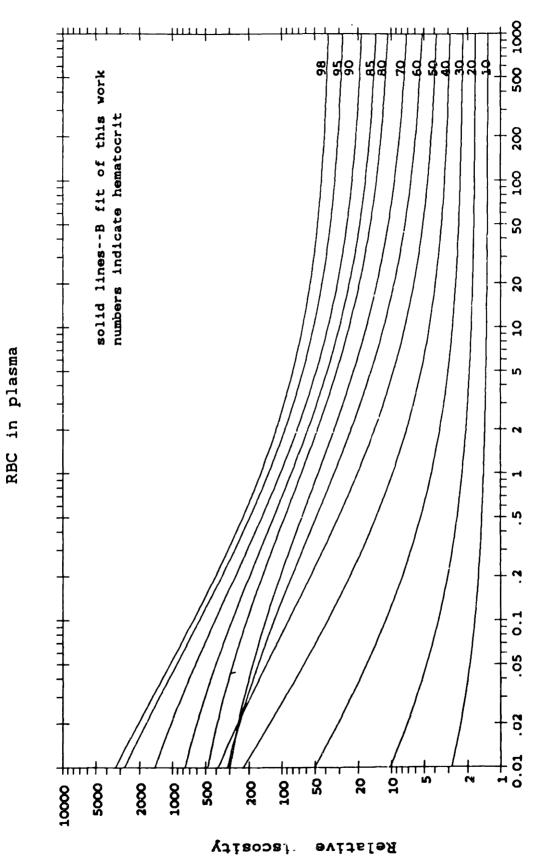


Figure 5-25: Plot of plasma global equations versus shear rate.

particularly those of interest for cross-flow membrane plasmapheresis phenomena. The data of this work did not extend to low enough shear rates for plasma suspensions to reasonably model viscosity dependence at $\gamma < 0.1 \text{ sec}^{-1}$ globally.

The difficulties in extending the Quemada equation to all hematocrit lies in the extreme sensitivity of the equation to the value of k_0 at low shear rates. Idealiy, determination of the parameters requires data at only three shear rates: $\gamma=0,\,\infty,$ and γ_c , which is defined as the point where $k=\frac{k_\infty+k_0}{2}$. It would be interesting to see if a fit to only three shear rates could actually model behavior everywhere. Data from a device such as a wide-gap Couette viscometer should be obtained to extend the low shear rate utility of the equations.

In extending the Quemada equation to all hematocrits and shear rates, the present development uses ten constants for saline solution and twelve constants for plasma suspensions. The complexity of this fits seems reasonable when one considers that Chien et al. required six constants to model viscosity behavior over all hematocrits at a single shear rate. Interpretation of the meaning of the parameter dependence suffers from the fact that they are conceptual properties than physically measureable quantities.

The Quemada expression does an overall satisfactory job of describing blood viscosity and is probably the most promising way to develop a set of global equations for every hematocrit and every shear rate. A major drawback is that it does not flatten to its limiting high shear rate value as quickly as one would like. One adjustment that could be made is in the power dependence of the square root term, which was obtained from an empirical representation $\theta = \gamma_r^p$ where p=0.5 (see Appendix C). Perhaps a larger value could be assigned to p, or p could be allowed to vary with hematocrit.

The hematocrit dependence of the two limiting viscosities shows an added variation due to the suspending fluid viscosity. A possible modification to the equation is to include the emulsive properties of erythrocytes into the idea of the intrinsic viscosity and thus make the rheological parameters independent of η_f . This can be done by incorporating some sort of Taylor coefficient, with a simplifying assumption of constant internal viscosity.

Most formulations for representing viscosity are for $\eta_{\rm r}$, and thus there is an implicit dependence of η on $\eta_{\rm f}$ at all hematocrits. Ideally, η should become independent of $\eta_{\rm f}$ at high hematocrits, and a truly general expression for viscosity should provide for this. With regards to this, the Quemada model seems to indicate that cell crowding effects and inversion becomes important at hematocrits of 65 to 80 and above, as this seems to be the region where all three rheological parameters become similar for saline and plasma suspensions.

Appendix A

1.056

Physical Properties of Human Blood and the Red Blood Cell

Properties of whole blood

Whole blood

Plasma

specific gravity(25/4 °C)

specific gravity(25/4 °C) 1.0239 viscosity (37 °C) 1.2 cP

Plasma proteins

albumin m.w. 69,000

4.5 g/100 ml plasma globulins m.w. 35,000-1,000,000

2.5 g/100ml plasma

fibrinogen m.w. 330,000

0.3 g/100ml plasma

Erythrocytes

concentration

male 5.2x10⁶/mm³ whole blood

42 volume %

female 4.7x10⁶/mm³ whole blood

38 volume %

Leukocytes

concentration 7.0x10³/mm³ whole blood

0.1 to 0.5 volume %

Platelets

concentration 3.0x10⁵/mm³ whole blood

0.1 to 0.6 volume %

Properties of Red Blood Cell

Red blood cell

specific gravity 1.098

mean corpusular volume 85-100 μ m³

 $\begin{array}{ccc} \text{surface area} & 140 \ \mu\text{m}^2 \\ \text{diameter} & 8.4 \ \mu\text{m} \\ \text{center thickness} & 1 \ \mu\text{m} \end{array}$

peripheral thickness 2.4 μm

mean corpuscular

hemoglobin concentration 31-35 g/100 ml packed red cells

Sources: Beck [1981] and Guyton [1981].

Appendix B Modified Eagle's Solution Recipe

In one liter of distilled water, dissolve

NaCl 6.2 gm

KCl 0.36 gm

 $NaH_3PO_4\cdot H_2O$ 0.13 gm

(sodium phosphate monobasic)

NaHCO₃ 2.0 gm

CaCl₂ 0.18 gm

 $MgCl_2 \cdot 6H_2O$ 0.15 gm

dextrose 0.9 gm

Adapted from Eagle [1959].

Appendix C Derivation of Quemada Equation

Quemada [1977, 1978a, 1978b] examined the steady-state viscometric flow of concentrated disperse systems. He noted that in such flows the concentration of the dispersed phase is not uniform but that an approximation to two-phase flow is developed: an axial region of high concentration and a region near the wall of low concentration, which in a sense provides a region of lubricant flow. What follows here describes his application of the principle of minimum energy dissipation, which states that with fixed system properties (concentration, temperature, flow conditions, fluid characteristics), the steady-state solution is that which minimizes the rate of energy dissipation (or, more generally, the rate of entropy production). The development assumes many features which are strictly valid only for suspensions of uniform, non-deformable rigid spheres but, as seen in the text (Section 2.4), with appropriate modifications the final result correlates well with experimental data for blood suspensions.

Consider simple viscometric flow in direction x between two plates separated by a distance 2Y along axis y, where $v_y = v_z = 0$, $v_x = v_x(y)$ and no-slip conditions at the walls. The concentration profile in the channel is c = c(y). The viscous dissipation rate term in the conservation of momentum equation is [Bird et al., 1960]

$$\frac{DU}{Dt}|_{\text{viscous}} = \underline{r} \cdot \nabla \mathbf{v} = \frac{1}{2} \sum_{i} \sum_{j} \left[\left(\frac{\partial v_{i}}{\partial x_{j}} + \frac{\partial v_{j}}{\partial x_{i}} \right) - \frac{2}{3} (\nabla \cdot \mathbf{v}) \delta_{ij} \right]^{2}$$
 (C.1)

where U is the internal energy, $\frac{D}{Dt}$ is the substantial time derivative, \underline{t} is the stress tensor, and δ_{ij} is the Kronecker delta function. For viscometric flow with an incompressible fluid, $(\nabla \cdot \mathbf{v}) = 0$, and this reduces to

$$\underline{r}\nabla\mathbf{v} = \frac{1}{2}\eta \left(\frac{\partial v_x}{\partial y}\right)^2 \tag{C.2}$$

Generalizing this to include dissipation from mass fluxes and integrating over the surface element s_x normal to the x-direction gives

$$\frac{DU}{Dt}|_{\text{viscous}} = \int_{s_x} \left[\frac{1}{2} \eta \left(\frac{\partial v_x}{\partial y}\right)^2 + \frac{1}{2} D \left(\frac{\partial c}{\partial y}\right)^2\right] ds_x$$
 (C.3)

where D is the diffusivity of the dispersed particles.

Equation (C.3) is to be minimized subject to the following constraints:

1. Flow rate contraints

Fluid flow constraints
$$Q_f = \int_{s_x} (1-c) \cdot v \cdot ds_x$$

Particle flow constraints
$$Q_p = \int_{s_x} c \cdot v \cdot ds_x$$

2. Mean particle concentration

$$\bar{c} = \frac{\int_{s_x}^{c \cdot ds_x}}{s_x}$$

3. Upper and lower limits of concentration, $c_w \le c \le c_b$. Using a method of optimum control theory, this constraint can be written as

$$\psi^2 = (c_h - c)(c - c_w)$$

so that ψ has an imaginary solution when c lies outside of the limits.

Equation (C.3) is minimized by the use of Lagrange multipliers [Wylie, 1975].

The auxiliary function to be solved is

$$F = \int_{s_x} \left\{ \frac{1}{2} \eta v_x'^2 + \frac{1}{2} \mathcal{D} c'^2 + \lambda_1 (1 - c) v_x + \lambda_2 c v_x + \lambda_3 c + \Lambda(x) [\psi^2 - (c - c_b)(c - c_w)] \right\} ds_x$$
 (C.4)

where λ_1 , λ_2 , λ_3 , and $\Lambda(x)$ are the multipliers, and the "prime" symbol denotes

partial differentiation with respect to x. Solution of F for extrema satisfies the set of equations:

$$\frac{\partial}{\partial x} \left(\frac{\partial F}{\partial f'} \right) - \frac{\partial F}{\partial f} = 0 \tag{C.5}$$

where $f = v_x$, c, and ψ .

At this point Newtonian behavior in the viscometer is assumed and the equations obtained are

$$(\eta v_{\tau})' = \lambda_1 (1-c) + \lambda_2 c \tag{C.6}$$

$$(\mathcal{D}c')' = \frac{1}{2}v_x'^2\frac{\partial\eta}{\partial c} + (\lambda_2 - \lambda_1)v_x + \lambda_3 + \Lambda(2c - c_b - c_w)$$
 (C.7)

$$0 = A\psi \tag{C.8}$$

Quemada [1977] notes that other works using the principle of minimum energy dissipation have yielded similar sets of equations. Equation (C.6) can be considered as a generalization of the momentum transport equation, since it reduces to the Navier-Stokes equations for the case of a homogeneous (c=0) incompressible fluid, with λ_1 equal to the pressure gradient. Equation (C.7) is a generalized mass transport equation, and equation (C.8) provides the boundaries of the admissible domain.

Further solution is based on the observation that the transition between the concentration in the bulk and the concentration near the wall is relatively sharp. Also, for particles with radius $\geq 1 \mu m$, Brownian diffusion is negligible compared to viscous drag.

Equations (C.6) and (C.7) are now decoupled by setting the left hand side of equation (C.7) to zero and using an empirical "rectangular" concentration profile similar to the one used by Vand [1948] to describe the viscometric flow of a suspended solution of rigid spheres:

$$c = \begin{cases} c_b & \text{for } 0 \le y \le \beta Y \\ c_w & \text{for } \beta Y \le y \le Y \end{cases}$$

where $\beta < 1$.

Satisfaction of extrema at the break point $y_b = \beta Y$ is accounted for by Erdmann-Weierstrass corner conditions [Tolle, 1975]:

$$\begin{split} \frac{\partial F}{\partial f_{i}^{'}}|_{y_{b+}} &= \frac{\partial F}{\partial f_{i}^{'}}|_{y_{b-}} \\ F - \sum_{i} \frac{\partial F}{\partial f_{i}^{'}}|_{y_{b+}} &= F - \sum_{i} \frac{\partial F}{\partial f_{i}^{'}}|_{y_{b-}}. \end{split}$$

Additionally, the velocity must be continuous at y_b . Defining $\Delta f = f|_{y_{b+}} - f|_{y_{b-}}$, these conditions become

$$\Delta v_x = 0 \tag{C.9}$$

$$\Delta(\eta v_x') = 0 \tag{C.10}$$

$$\Delta(\mathcal{D}c') = 0 \tag{C.11}$$

$$\Delta \frac{\partial F}{\partial \psi'} = 0 \tag{C.12}$$

$$\Delta(\frac{1}{2}\eta v_x^{\prime 2} - (\lambda_1(1-c)v_x + \lambda_2 cv_x + \lambda_3 c)) = 0$$
 (C.13)

These equations can now be used to solve for the velocity profile. Assuming two-phase flow with c_b , v_b in the core and c_w , v_w near the wall and applying equations (C.6), (C.9), and (C.10), the result is the same as that derived for any two-phase Newtonian flow:

$$v_w(y) = \frac{Y^2 \Delta p}{4L\eta_w} (1 - \frac{y^2}{Y^2}) \tag{C.14}$$

$$v_b(y) = \frac{Y^2 \Delta p}{4L\eta_w} (1 - \beta^2) + \frac{Y^2 \Delta p}{4L\eta_b} (\beta^2 - \frac{y^2}{Y^2})$$
 (C.15)

Solving equations (C.7) and (C.13) for the concentration relationship gives

$$\left(\frac{d\phi}{dc}\right)_b + \left(\frac{d\phi}{dc}\right)_w = \frac{2}{c_b - c_w}(\phi_b - \phi_w) \tag{C.16}$$

where ϕ is a relative viscosity based on the pure fluid viscosity, $\phi \equiv \eta_{\rm f}/\eta \equiv 1/\eta_{\rm r}$. In the limiting case where $c_{\rm w} \to 0$,

$$\frac{d\phi}{dc} - k(c,\gamma) = \frac{2}{c}(\phi - 1) \tag{C.17}$$

where $k \equiv -(\frac{d\phi}{dc})_{c \to 0} = (\frac{d\eta_r}{dc})_{c \to 0}$ is the intrinsic viscosity.

The intrinsic viscosity is a commonly used empirical parameter in polymer rheology. Deviations from the Einstein value k=2.5 from equation (2.9) are used for determination of dispersion characteristics such as polydispersity, solvation, particle ellipticity, and molecular weight (see, for example, Hiemenz [1977], Chapter 2).

Equation (C.17) is integrated using the condition that in the limit as c approaches its packing concentration c_p , $\eta \to \infty$, $\frac{d\eta}{dc} \to \infty$ and the result is

$$\eta_r = \frac{1}{\phi} = (1 - \frac{1}{2}kc)^{-2} \tag{C.18}$$

This expression is rigorously valid only for Newtonian viscosities, and the boundary condition as $c \to c_p$ is true only for rigid particles. Quemada argues, however, that in highly concentrated systems the two-phase flow model is still valid and that with appropriate modifications this equation is applicable to blood suspensions. The form of equation (C.18) is very similar to that of other equations modified from the Einstein equation, (2.9).

The non-Newtonian aspects of blood are related to changes in the particle morphology (from aggregation, plasma trapping, deformation, crowding, etc.) at changing concentration and shear rate. Equation (C.18) can be empirically modified to incorporate these effects in one of two ways:

First, k is defined as before, but c is now the volume concentration of effective particles, where an effective particle is defined as a statistically-averaged "typical" aggregation of individual units, including any trapped fluid. If cells aggregated without deforming or trapping fluid, then c would be constant no matter

the degree of aggregation. With fluid trapping, aggregation would lead to effective particles with a larger volume than the individual cells, and c would increase by a factor of $(1-\epsilon)^{-1}$, where ϵ is the porosity of the effective particle.

The alternative and more convenient method is to define c as before, equal to the volume percent of solids, but to now empirically incorporate the effective volume changes into k. To visualize this, two samples of suspensions of rigid, attracting particles can be imagined, each at identical concentration c, one at shear rate γ_1 and the other at $\gamma_2 > \gamma_1$.

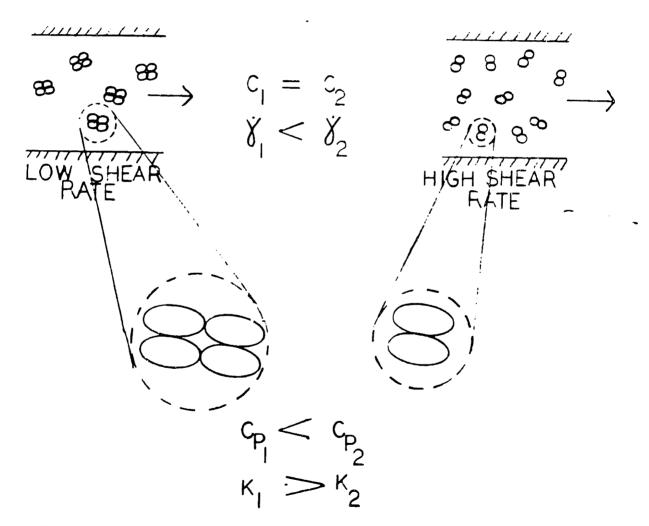


Figure C-1: Hypothetical comparison of two samples with identical solid concentrations at different shear rates.

As shown in Figure C-1, at γ_1 , the average effective particle consists of four

units, and at γ_2 , the average effective particle is two units. Because of the extra fluid trapping, the particles at γ_1 can not be packed as tightly as those at γ_2 . If the packing concentration c_p is defined as the maximum volume concentration of solids achievable by packing the effective particles as closely as possible, then $c_{p1} < c_{p2}$. Also, as $c \to c_p$, $\eta \to \infty$ and from equation (C.18),

$$c_{p2}$$
. Also, as $c \to c_{p}$, $\eta \to \infty$ and from equation (C.18),
$$c_{p} = \frac{2}{k(c,\gamma)} \tag{C.19}$$

Since in the above example $c_1=c_2$, the effect of increasing γ at constant c is to lower k, consistent with shear-thinning behavior. If the individual units could deform elastically and orient themselves along fluid streamlines, these effects would result in a further reduction of k with shear rate.

Thus, for relatively rigid particles, the intrinsic viscosity is proportional to the volume occupied by a single effective particle. For fluid particles such as red blood cells, equation (C.18) and especially equation (C.19) are true only in a qualitative sense, as the boundary condition of infinite viscosity at high concentration is obviously not justifiable. Nevertheless, Quemada [1981] has used this model to estimate the size and structure of red cell aggregates as a function of hematocrit and shear rate.

Continuing with the development for rigid spheres, it is at this point necessary to address the concentration and shear rate dependence of the intrinsic viscosity k. Simplifying to the case of constant concentration, Quemada proposes an expression for k based on a two limit relaxation model. Defining $k_0 = k(\gamma = 0)$ and $k_{\infty} = k(\gamma = 0)$ large, but not high enough to disrupt individual units), the model assumes aggregate formation dependent on collision frequency and aggregate disruption by shear. At a constant concentration,

for aggregation,
$$\left(\frac{dk}{d\ell}\right)_A = \frac{1}{\tau_A}(k_0 - k)$$
 (C.20)

for disaggregation,
$$\left(\frac{dk}{dt}\right)_D = \frac{1}{\tau_D}(k-k_\infty)$$
 (C.21)

$$\frac{dk}{dt} = \frac{1}{\tau_A} (k_0 - k) - \frac{1}{\tau_D} (k - k_\infty). \tag{C.22}$$

where τ_A and τ_D represent the time constants for aggregation and disaggregation. At steady-state,

$$k = \frac{k_0 + \theta k_{\infty}}{1 + \theta} \tag{C.23}$$

where $\theta = \tau_A / \tau_D$.

For dilute suspensions of rigid spheres, the time constant for aggregation, τ_A , is assumed to be the inverse of the Brownian collision frequency as derived by Smoluchowski [1917]:

$$\tau_A = \frac{\pi \eta_f a^3}{2c\kappa T} \tag{C.24}$$

where a is the sphere radius, κ is Boltzmann's constant, and T is absolute temperature. This expression is comparable to both the time constant for translation of the particle over a distance equal to its radius and to the time constant for rotation of a sphere through π radians.

The time constant for disaggregation due to shear, τ_D , is assumed to be the inverse of the shear-induced collision frequency developed by Goldsmith and Mason [1967]:

$$\tau_D = \frac{\pi \gamma}{8c} \tag{C.25}$$

Combining equations (C.24) and (C.25),

$$\theta = \gamma_r \tag{C.26}$$

where the relative shear rate $\gamma_{\rm r}=\gamma/\gamma_{\rm c}$ and the critical shear rate $\gamma_{\rm c}$ is $\frac{\kappa T}{4\eta_f a^3}$. For

dilute suspenions of rigid spheres γ_c is roughly equivalent to the rotational diffusion coefficient. Equivalent ratios to θ appear frequently in the literature of polymer rheology. Batchelor [1976] described this ratio as a Peclet number $\frac{\gamma_a^2}{D}$ which represents the time constant for diffusional rotation divided by the time constant for shear-induced motion.

For non-rigid paticles such as blood, the relaxation model must also incorporate time constants for changes in particle shape. Assuming that a basic functional relationship $\theta(\gamma_r)$ exists as it does for rigid particles, it then becomes necessary to formulate an expression for γ_c for deformable bodies. Using the Maxwell relaxation time, Quemada suggests

$$\gamma_c = \frac{E_i}{\eta_i} \tag{C.27}$$

where E_i is the elastic modulus and η_i is the internal viscosity of the particle. Since $E_i \sim a^{-3}$, the variance with particle size is the same as for spheres.

Using equation (C.26) as a starting point, Quemada derived a semi-empirical relationship for concentrated suspensions:

$$\theta = \gamma_r^p \tag{C.28}$$
for $0 \le p \le 1$

where for blood p \approx 0.5. Substituting equations (C.23) and (C.28) into equation (C.18) and rearranging leads to the final form of the equation:

$$\eta = (1 - \frac{c}{2} \cdot \frac{k_0 + k_\infty \sqrt{\gamma_r}}{1 + \sqrt{\gamma_r}})^{-2}$$
 (C.29)

where k_0 and k_∞ are functions of concentration and γ_r is a function of concentration and directly proportional to the shear rate. In this work, the concentration dependences of the three rheological parameters k_∞ , k_0 , and γ_c are found from empirical fits to data.

To summarize, the Quemada equation is derived from a model of a concentrated suspension of rigid, attracting spheres in which two-phase viscometric flow is observed. Deviation of particle behavior from this model, such as deformability and fluidity, are incorporated empirically into the parameters.

The Quemada expression does not predict a yield shear stress per se, but in the limit of high concentration, $c \to c_p$, equation (C.29) can be shown to yield the Casson relation, equation (2.7) [Quemada, 1981]. In the limit of low shear, $\gamma \ll \gamma_c$, no yield shear stress is obtained and Newtonian behavior is recovered from the equation. Quemada argues that, while it is possible that blood may indeed have a yield shear stress, it is of almost negligible magnitude due to the smallness of the cohesive forces between cells. In the limit of high shear, $\gamma \gg \gamma_c$, a pseudo-yield stress can be extrapolated to zero shear rate.

Appendix D Computer Program for Data Fitting

This is the FORTRAN computer program described in Section 3.4 for regression of data to non-linear functions. It is adapted from Zydney [1985].

٠.:

```
program datafit
        double precision b(5), b1(5), bo(5), f(5), f1(5), a(5,5),
        1 ainv(5,5), y1(200), dy(200,5), y(200), ee, el, ss,
        1 xtx(5,5), c(5,5), gamma(200), eta(200), delz(5),
        1 zval, zvalnew
        character+5 type, hct
c ASSIGN DIFFERENTIAL MUTIPLIERS AND CONVERGENCE REQUIREMENTS
        d1=0.999
        d2 = .99
        c1 = .001
        c2=.001
C READ IN DATA FROM DATAFILE
        print *, 'enter sample type and hematocrit'
        read *, type, hct
                                  ٠.:
        open (unit=4.
       file=type(:len(type))//'dat'//hct(:len(hct))//'.dat',
           status='old')
        do 10 1=1,200
                read (4,501) gamma(i), eta(i)
                format(2(f10.3))
501
                if (gamma(i) .eq. -100. .and. eta(i) .eq. -100.) goto 20
10
        continue
20
        n=1-1
c IMPUT INTIAL GUESSES
        print *, 'cell volume fraction and number of unknowns'
        read . h. ir
        do 30 1=1,1r
                print . 'initial guess for unknown &',1,'?'
                read *, b(1)
30
        continue
C LOOP TO EVALUATE RESIDUALS AND JACOBIAN
         do 130 ii=1, ir+1
36
                do 80 jj=1, ir+1
        CALCULATE SUM OF SQUARED RESIDUALS (SS)
C
            AND SUM OF WEIGHTED SQUARED RESIDUALS (EE)
c
                        ee=0.
                        ss=0.
                        do 40 1=1,B
                                call predictval(gamma(i),y(i),b,h)
                                ee=ee+((y(i)-eta(i))/y(i))**2.
                                 if (ii .eq. 1 .and. jj .eq. 1)
                                         gs=ss+(y(1)-eta(1))**2.
                                endif
                        continue
40
        PRINT VALUE OF SUN OF SQUARES BEFORE DERIVATIVES ARE EVALUATED
C
```

```
if (ii .eq. 1 .and. jj .eq. 1) then
                                 print *, 'sum of weighted sqd residuals=',ee
                         endif
         IF THIS IS THE FIRST PASS, THEN SET LAST VALUES (BL) EQUAL TO
c
        CURREBI GUESSES (B) AND DO NOT EVALUATE DERIVATIVE
                         if (jj .eq. 1) then
                                 el=aa
                                 do 50 i=1.ir
                                         bl(i)=b(i)
50
                                 continue
                                 goto 70
c
        OTHERWISE, DETERMINE THE DERIVATIVE VALUE (F) FOR THIS B
                         else
                                 f(jj-1)=(ee-el)/(b(jj-1)-bl(jj-1))
        RESET B VALUES
c
                                 do 60 1=1.ir
                                         b(i)=bl(i)
60
                                 continue
                         endif
                                  :
        MAKE SMALL CHANGE IN THE BEXT B AND START LOOP TO EVALUATE
C
        BEXT F
70
                         b(jj)=d1+b(jj)
80
                continue
        BEGIN DETERMINATION OF JACOBIAN (A)
C
        ON FIRST PASS, MAKE OLD VALUES EQUAL TO CURRENT VALUES
c
                if (ii .eq. 1) then
                         do 90 i=1.ir
                                 bo(i)=bl(i)
                                 fl(i)=f(i)
90
                        continue
                        goto 110
        OTHERWISE, EVALUATE JACOBIAN FOR THIS F AND B
C
                        else
                                 do 100 i= 1, ir
                                   a(i,ii-1)=f((i)-f1(i))/(b1(ii-1)-bo(ii-1))
100
                                 continue
                        endif
        RESET B VALUES
C
110
                do 120 i=1.ir
                        b(i)=bo(i)
120
                continue
        MAKE DIFFERENTIAL CHANGE IN NEXT B
C
                b(ii)=d2+b(ii)
130
        continue
c END OF LOOP TO CALCULATE RESIDUALS AND JACOBIAN
C INVERT JACOBIAN AND RESET B VALUES
        call invert(ir,a,ainv)
        do 140 i=1,ir
                b(1)=bo(1)
140
        ccatinge
```

```
c MAKE WEXT GUESSES FOR B
        do 160 j=1,ir
                 do 150 i=1, ir
                         b(j)=b(j)-fl(1)+ainv(j,1)
150
                continue
160
        continue
c CHECK FOR CONVERGENCE
        do 170 1=1.1r
                if (abs(1-b(i)/bo(i)) .gt. c1) goto 180
                if (abs(f(i)) .gt. c2) goto 180
170
        continue
c ON CONVERGENCE, GO TO FINAL OUTPUT STAGE
        goto 200
c IF NOT CONVERGED, OUTPUT NEXT GUESS
180
        do 190 i=1,ir
                print *, 'next guess for b(',i,')=',b(i)
190
        continue
        goto35
c FIMAL OUTPUT
        do 260 jj=1, ir+1
200
                do 210 1=1,m
                        call predictval(gamma(1),y(1),b,h)
210
                continue
c EVALUATE STANDARD DEVIATIONS FOR B VALUES
        EVALUATE COMPONENTS OF X MATRIX (DY)
                if (jj .gt. 1) then
                        do 220 i=1.n
                                 dy(i,jj-1)=(y(i)-yl(i))/(b(jj-1)-bl(jj-1))
220
                        continue
                else
                        do 230 1=1.m
                                yl(i)=y(i)
230
                        continue
                        do 240 1=1,1r
                                 b1(1)=b(1)
240
                        continue
                endif
                do 250 i=1,ir
                        b(1)=b1(1)
250
                costinue
                b(jj)=d1+b(jj)
260
        continue
        EVALUATE COVARIANCE MATRIX (C)
        do 290 i=1.ir
                do 280 j=1,ir
                        e≖C.
                        do 270 k=1,a
                                s=s+dy(k,1)+dy(k,j)
```

```
270
                          continue
                          xtx(i,j)=s
 280
                 continue
 290
         continue
         call invert(ir,xtx,c)
         do 300 i=1,ir
                 print *, 'standard deviation of b(',i,)=',sqrt(c(i,i)*ss/(n-ir))
 300
         continue
 c CALCULATION OF CORRELATION COEFFICIENTS
         do 307 i=1,ir
                 do 305 j=1,ir
                         corcoef=c(i,j)/sqrt(c(i,i)*c(j,j))
                         print *,'coeff.',i,'-',j,'=',corcoef
 305
                 continue
 307
         continue
c CALCULATION OF 95% CONFIDENCE LIMITS EVALUATED AT GAMMA=.02,.2,2,20,200
         GET STUDENT I VALUE AND ESTABLISH VALUES AT WHICH TO CALCULATE
 C
         print *, 'input student t value'
         read*, tval
         do 360 ij=-2.2
                 gam=2. #10. #cii
C
        CALCULATE DERIVATIVES
                 call predictval(gam,zval,b,h)
                 do 310 i=1, ir
                         bo(1)=b(1)
310
                 continue
                 do 330 ii≃1,ir
                         b(11)=d2*b(11)
                         call predictval(gam,zvalnow,b,h)
                         delz(ii)=(zval-zvalnew)/(bo(ii)-b(ii))
                         do 320 jj=1,ir
                                 b(jj)=bo(jj)
320
                         continue
330
                continue
        CALCULATE VARIANCE IN EQUATION AT THIS VALUE
C
                V=0.
                do 350 1=1,1r
                         do 340 j=1,ir
                                 v=v+delz(1) odelz(j) ose/(n-ir) oc (1.j)
340
                         continue
350
                continue
        OUTPUT CONFIDENCE LIMITS
                print *, '95% conf. int. at shear rate', gam, '=', tval*sqrt(v)
360
        continge
        end
```

```
subroutine predictval(xx,yy,b,h)
        double precision b(5), xx, yy
        yy=1./(1.-(b(1)+(b(2)-b(1))/(1+sqrt(xx/b(3))))+b/2.)++2.
        return
        end
c SUBROUTINE TO INVERT MATRIX
        subroutine invert(ir, rorigmatx, rinvmatx)
        double precision rorignatx(5,5), rinvmatx(5,5)
        do 3 1=1,1r
                do 2 j=1,ir
                         rinvmatx(i,j)=0.
                         if (i \cdot eq. j) rinvmatx(i,j)=1.
2
                continue
3
        continue
        do 60 j=1,1r
                1=1-1
                i=i+1
10
                if (i .gt. ir) then
                        print *, 'singular matrix'
                         stop 100
                endif
                if (rorigmatx(1,j) .eq. 2) goto 10
                do 20 k=1.ir
                         q=rorigmatx(j,k)
                         qq=rorigmatx(i,k)
                        rorigmatx(j,k)=qq
                        rorigmatx(i,k)=q
                         q=rinvmatx(j,k)
                         qq=rinvmatx(i,k)
                        rinvmatx(j,k)=qq
                        rinvmatx(i,k)=q
20
                continue
                t=1/rorigmatx(j,j)
                do 30 k=1,ir
                      rorigmatx(j,k)=t*rorigmatx(j,k)
                        rinvmatx(j,k)=t+rinvmatx(j,k)
30
                continue
                do 50 l=1,ir
                        if (1 .eq. j) goto 50
                        t=-rorigmatx(1,j)
                        do 40 k=1, 1r
                            rorigmatx(1,k)=rorigmatx(1,k)+tororigmatx(j,k)
                            rinvmatx(1,k)=rinvmatx(1,k)+t+rinvmatx(j,k)
40
                        continue
50
                continue
60
        continue
        return
        end
```

Appendix E Notation

The dimensions given are in terms of mass (M), length (L), time (t), and temperature (T). When no dimensions are listed, the units are dimensionless, or they may vary.

a radius of particle or rouleau, L.

 A_c contact area between cells in rouleau, L^2 .

 A_{ij} component of jacobian matrix $=\frac{\partial F_i}{\partial b_i}$.

a constants for Chien polynomials.

b_i parameter of function Y to be fit to data.

c cell volume fraction=H/100.

c_b volume fraction of particles in bulk region.

c_p packing concentration=2/k. c_{protein} protein concentration, ML⁻³.

cw volume fraction of particles in wall layer.

D dissipated energy of rouleau formation, ML²t⁻².

D translational diffusivity, L²t⁻¹.

E elastic stored energy in rouleau, ML²t⁻².

sum of squared residuals.

E_i elestic modulus, ML⁻¹t⁻².

F auxiliary equation from method of Lagrange multipliers.

 $\mathbf{F_i}$ component of the matrix which represents the gradient of $\mathbf{E} = \frac{\partial E}{\partial b_i}$.

f independent variables of F.

H hematocrit=100·c.

h length of capillary, L.

K kinetic energy of rouleau, ML^2t^{-2} .

fitted parameter for centrifugation equation (3.2), M⁻¹Lt².

k intrinsic viscosity.

_	
$\mathbf{k_0}$	intrinsic viscosity at zero shear rate.
k _{0i}	parameter to fit k_0 as a function of c.
k _∞	intrinsic viscosity at high shear rate.
$\mathbf{k}_{\infty i}$	parameter to fit k_{∞} as a function of c.
L	length of capillary or channel, L.
M	torque exerted on inner cylinder of viscometer, ML.
N	number of data points to fit to equation Y.
P	number of parameters for equation Y.
P	pressure, $ML^{-1}t^{-2}$.
Q	volumetric flow rate, L^3t^{-1} .
Q_{f}	volumetric flow rate of fluid, L^3t^{-1} .
$\mathbf{Q_p}$	volumetric flow rate of particles, L ³ t ⁻¹ .
R	radius of capillary, L.
R_{i}	radius of inner cylinder of viscometer, L.
R_{o}	radius of outer cylinder of viscometer, L.
S	total entropy of fluid volume, $ML^2t^{-2}T^{-1}$.
s _x	integrated surface area normal to x-direction, L^2 .
T	absolute temperature, T.
t	time, t.
T_0	reference temperature, T.
U	total internal energy of fluid volume, ML^2t^{-2} .
v	total volume of fluid element, L^3 .
v	velocity, Lt ⁻¹ .
W	work done by external surface and body forces on rouleau, ML^2t^{-2} .
x	rectangular coordinate, L.
$\mathbf{x_i}$	rectangular coordinate, L.
X _{ij}	component of matrix with elements $\frac{\partial Y_i}{\partial b_i}$.
Y	function to be fit to data.
у	rectangular coordinate, L.
y _i	calculated values from function Y corresponding to experimental

value y_{i,exp}. experimental value corresponding to calculated value y. $y_{i,exp}$ Greek symbols shape factor for Einstein equation (2.9). surface energy of cell membrane, Mt⁻². γ shear rate, t⁻¹. ን critical shear rate for Quemada equation (2.11), t⁻¹. $\gamma_{\mathbf{c}}$ parameter to fit γ_c as a function of c. γ_{ci} relative shear rate $=\gamma/\gamma_c$. $\gamma_{\mathbf{r}}$ Kronecker delta function. δ_{ii} local porosity=1-c. Ē average porosity in a cell column. local porosity at zero compressive pressure. ξO non-Newtonian viscosity, ML⁻¹t⁻¹. η viscosity of suspension in bulk region, ML-1t-1. $\eta_{\mathbf{b}}$ viscosity of suspending fluid phase, ML-1t-1. $\eta_{\mathbf{f}}$ relative viscosity = $\eta/\eta_{\rm f}$. $\eta_{\mathbf{r}}$ viscosity of suspension in wall layer, ML⁻¹t⁻¹. $\eta_{\mathbf{w}}$ ratio τ_A/τ_D . Boltzmann's constant, ML²t⁻²T⁻¹. Lagrange multiplier. Λ Lagrange multiplier. λ_{i} Newtonian viscosity, ML⁻¹t⁻¹. Casson Newtonian viscosity, ML⁻¹t⁻¹. μN plasma viscosity, ML-1t-1. $\mu_{\mathbf{D}}$ water viscosity, ML-1t-1. $\mu_{\mathbf{w}}$ kinematic viscosity= η/ρ , L²t⁻¹. 3.14159 compressive pressure, ML⁻¹t⁻². density of erythrocyte, ML-3. $\rho_{\rm c}$

density of suspending fluid, ML⁻³.

Pf

$\sigma_{\mathbf{y}}$	standard deviation of function Y.
T	Taylor coefficient for equation (2.5).
τ	shear stress, $ML^{-1}t^{-2}$.
<u> </u>	stress tensor.
$^{ au}$ A	time constant for rouleau aggregation, t.
$^{ au}$ D	time constant for rouleau disaggregation, t.
$^{ au_{\mathbf{y}}}$	yield shear stress, ML ⁻¹ t ⁻² .
φ	relative viscosity= $1/\eta_r$.
ψ	control theory constraint, $\psi^2 = (c_b - c)(c - c_w)$.
ω.	angular velocity, radians/t.

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Appendix F Data From Viscosity Measurements

Listed in this appendix are the tables of data used in Chapter 4. Data is listed by hematocrit, and the beginning of different samples within a hematocrit is noted in the left-hand column. The beginning of data for a new hematocrit is delineated by a new set of column headings. A description of the units of blood and the various batches and samples obtained from the units is given in Table F-I. The Eagle's solution data begins on page 225, the plasma data begins on page 237.

Unit expiration date	enti- coagulant	Betch	suspending fluid	Batch suspending suspending fluid days since fluid viscosity (cP) drawing	days since drawing	days
27-AUG-84	&	16	Eagle's	0.69	11	10
11-SEP-84	8	18	Eagle's	0.69	25	7
27-SEP-84	CPD-A1	19	Eagle's Eagle's	0.69	22 25	13
21-DEC-84	CPD-A1	24	Eagle's	69.0	35	•
O6-JUN-85	AS-1	30 31	plasma plasma plasma	1.05	01 11	333 313
06-AUG-85	AS-1	8 B	plasma Eagle's	1.06	12	32

Table F-I: Catalog of units and batches used in this work.

Table F-II: Data tables for Eagle's solution suspensions.

? wample and I	theer rate i	2 viscositu	3 relative	32	20 44	72 518	105 649 104 658
hematecrit		100)	VISCOBITY .	33 34	23 37 23 79	71 800 70 623	102 442
1 20-5 2 H=98 4	0 03 0 10	40aa 671 1a09 939	5892 837 2333 243	35	25 78 25 75	70 045 70 737	101 514
3	0 16	1126 194 986 269	1040 658 1287 491	37	28 44 29 96	49 100 49 100	100 293 100 243
5	0 29	731 250	1059 783	30 37	35 72 75 80	64 771 66 129	101 117 45 8 39
6 7	9 35 0 42	654 672 564 ca8	927 104 818 359	40 41	84 22	PO 051	06 987 92 529
•	Ŭ 48 0 61	515 038 437 014	746 432 633 369	42 43	87 14 106 48	63 849 62 711	40 6 0 6
Ď	0 80	369 657	\$15 735 \$02 552	44	129 85 138 42	99 666 62 007	86 472 89 865
2	0 197 0 199	346 76 8 322 404	457 252	45 46	163 75	61 537 59 514	UP 184 86 232
) . I	1 13 1 18	294 679 293 125	427 0m2 424 819	47 40	165 54 175 78	61 140	88 609
5	1 40	263 096 262 084	391 29 0 379 832	49	205 20	59 415 60 869	01 109 ' 83 214
,	1 66	240 520	348 590	50 51	23 8 20	59 395	86 000 87 846
B 7	1 69 1 93	242 420 224 486	35: 333 325 342	52 53	232 96 257 97	50 614 59 367	86 039
•	1 94 2 19	226 007 210 956	327 146 301 733	54	277 RO 299 79	59 406 59 812	84 074 84 484
l 2	2 20	212 410	307 941	35 O sample and			
3 1	2 39 2 45	202 8 11 202 481	293 929 293 451	Nematocrit			
5	2 59 2 79	196 779 190 366	295 187 275 893	1 20-4	0 09	1357 417	140/ 5/4
b 7	3 00	120 040	269 623	2 M-40 .	0 11 0 17	668 170 485 913	968 29 0 704 222
a •	3 43 5 98	182 386 149 946	254 329 215 864	3	0 24	390 164	505 455 477 799
0	8 01	133 720	193 797	9	0 30 0 47	329 4 8 1 239 4 38	347 012
1 2	8 53 10 66	134 729 125 099	195 055 181 301	7	O 60	225 B74	327 354 284 126
3 4	13 32 13 64	119 265	173 717 176 687	į	0 80 0 80	18a 612	270 452
5	15 98	115 576	158 951	10	0 44	161 323	278 404 233 804
2	16 17 18 73	119 452 114 117	171 670 168 286	11	1 19	146 117	21: 764 201 479
9	19 29	113 637	1091	13 14	1 26 1 39	139 020 133 793	1-ე თე
0	22 40 22 40	114 402 111 9*3	165 9(-0 162 164	15	1 51	124 540 124 745	183 391 180 790
1 2	25 11 25 27	112 558 110 668	153 128	17	1 59 1 77	117 233	159 903
3	29 59	109 798	159 128	16	1 92	113 719	164 6 10 160 072
4 5	36 39 61 74	115 829	167 868 160 250	20 20	2 21	105 905	153 184 152 438
6	44 03 93 57	101 227	146 736 156 870	21 22	2 25 2 45	105 182	140 820
é	78 00	108 240 101 760	147 478	23 24	2 47 2 91	101 034 93 670	146 426 135 754
49 • 6	117 10 138 15 143 45	107 154 103 754 106 324	155 270 154 710 154 093	25 26	4 0e 5 32	84 ú72 75 540	t 943 1 913
51 52	145.09	102 471	148 509	27	6 61 7 98	75 31 8 65 103	1c: 910
53 54	198 18 201 73	102.664 105 578	143, 780 173, 59 1	29 29	9 14	63 ÷C4	91 890 87 401
35	231 09	102 534	199. 180	31 33	11 06 11 18	60 369 19 224	85 802
36 57	23 7 86 250 9 2	103 653	1€3 120 14€ 433	32	12 97 14 58	57 885 55 669	83 871 80 480
58	265 44 277 38	105 515 103 374	183, 920	33 34	14 99	76 119 73 676	01 232 77 791
5 ? 60	299. 76	104 353	151. 236	35 36	17 24 17 44	54 331	76 741
) sample and hematecrit	1 shear rate (1/sec)	2 viscosity	~ iscosity	37 28 39	19 22 19 34 21 27 22 34	52 449 53 101 52 067 51 007	76 013 76 958 75 459 73 923
1 20-3	0. 04	1920 301	2783 045	40 41	23. 17	51 275	74 312
2 H=97. 2	0 10 0 17	908 883 651 079	1317 222 943 593	42 43	25 09 25 20	50 569 47 931	73 316 72 364
3	0 23	505. BJ7	732.097	44	24 67	48 404 50 444	70 441 73 426
• .	0.29 0.42	434, 286 339, 943	629, 400 492, 671	46	35 67 48 45	47 689	69 404
7	0 41	246 492	389 409	47 49	46 18 67 59	43 028 45 699	66 230
•	0 8 7 0 9 3	218.062 211.625	304 993 304 993	49	99 12	42 058 43 882	80 954 83 597
10 L1	1 0s 1 38	194 783 169 747	282, 294 246, 010	50 51	99 39 124 89	43 137	62 517
12	1.40	169 679	244 462	52	139 81 136 78	41 470 42 527	60 101 61 646
13 14	1 63 1 73	156, 552 152, 379	224. 887 220 839	53 54	165 24	41 253	59 797
15	1 87	140 224	211 119 203 330	55	168 64 198 33	42 11 8 41 050	51 041 59, 493
16 17	2.06 2.14	140 29 3 137 544	199 337	54 57	226 77	41 815	r0.601
10 17	2 40 2 45	131 414 127 911	190 455 188 277	58 54	291 30 291 33	40 934 40 778	₹9 325 90 094
20	2 92	120 592	174 771	60	296 76	41 103	₽ ¶ 570
22	3. 45 u 20	118 914 97 244	172 239 146 933	O sample and hematocrit	l shear rate (1/sec)	2 V11COSITY (cP)	3 reletive Vilcositi
23 24	9 40 8 75	87 749 87 497	127 172 127 097				
25	11. 29	82. 094	118 977	5 H=40 1 16-0	0 03	1007 669 673 443	2614 721 97a 004
26 27	11 91 13 64	80 730 78 579	117 000 110 891	3	0 28	307 006	318 08°
26 29	15 21 17 04	76 612 75 436	111.032	4 9	0.47 9.66	219 480 178 824	259 140
30	17. 84	74 227	109 328 107 575	6 7	0 B7 1 05	157 898 140 092	203 03:
31	30 21	73. 352	104 307	é	1 14	134 747	175 284
				9 10	1 37 1 40	122 744 121, 600	177 890 176 23
				11	1 62	112 a73 109, 394	
				12	l 73	107. 378	

13 14 15 14 17 18 19 20 21 22 24 25 24 27 28 29 29 29 20 30 31 32 33 34 40 41 42 43 44 45 46 47 46 47 46 47 48 49 50 51 52 53 40 61 61 62 60 61	1 200 2 100	104 454 102 387 98 759 98 759 98 759 99 759 94 254 97 397 98 897 97 397 86 937 86 937 87 789 81 115 57 778 58 778 58 778 58 778 59 778 50 778 50 778 50 778	111 3d3 117 952 1-3 125 123 314 123 923 123 358 125 368 125 368 125 368 125 377 100 977 12 461 12 651 17 1303 17 2 651 17 303 17 2 651 17 303 17 303 17 303 18 303 19 304 19 305 10 306 10 306	112 19-9 113 19-9 114 115 116 117 118 119 120 122 122 122 123 124 125 125 126 127 128 129 129 131 130 131 134 144 149 144 149 144 150 151 154 157 169 160 161	0 03 0 07 0 15 0 28 0 28 0 27 0 47 0 46 0 75 1 17 1 40 1 17 1 40 1 17 1 40 2 20 2 26 2 30 2 30 2 30 8 50 11 30 11	171: 111	2479 E71 900 Box 607 379 521 142 1329 525 842 2003 759 246 400 237 494 143 327 160 759 154 170 152 657 154 170 152 657 153 657 154 668 157 770 81 969 117 368 17 77 828 17 77 828 17 77 828 17 78 426 17 77 828 17 77 828 17 77 828 17 77 828 17 78 426 17 72 868 17 77 888 18 613 18 68 613 18 68 613 18 68 613 18 68 614 19 66 614 19 66 621 19 60 621 19 60 621 19 60 621 19 60 621 19 60 60 80 10 60 80 10 60 80 10
64 65 66 67 77 77 77 78 79 80 81 82 82 83 84 85 87 79 79 79 79 79 79 70 71 71 72 73 74 75 76 77 78 79 79 70 71 71 72 73 74 75 76 77 78 79 79 79 79 79 79 79 79 79 79	0 86 1 05 1 130 1 40 1 156 1 73 1 40 1 73 1 62 2 07 2 2 64 2 39 2 2 64 2 3 92 2 64 2 3 92 2 64 2 3 92 2 64 2 7 92 1 60 1 7 93 1 60 2 1 7 93 2 1 60 2 1 7 93 2 1 60 2 1 7 93 2 1 60 2 1 7 93 2 1 60 2 1 7 93 2 1 60 2 1 7 93 2 1 60 2 1 7 93 2 2 1 7 93	184 008 163 133 153 009 169 159 009 149 356 142 053 136 077 127 510 126 099 118 222 116 995 113 457 111 471 108 238 106 900 102 287 86 005 73 079 73 079 74 088 75 977 61 185 62 286 60 771 61 185 62 286 60 771 61 185 62 286 60 771 61 185 62 286 60 771 61 185 62 286 60 771 61 185 62 286 60 771 61 185 62 286 60 771 61 185 62 286 60 771 61 185 62 286 60 771 61 185 62 286 60 771 61 185 62 286 60 771 61 185 62 286 60 771 61 185 60 771 60	206 A78 206 A78 206 A78 206 A78 207 A78 208 A78 209 A7	162 1-3 1-4 1-2 162 163 169 170	167 of 142 75 143 26 218 79 219 63 240 12 250 71 172 83 172 83 174 of 174 of 174 of 174 of 174 of 174 of 174 of 174 of 175 of 175 of 176 of 177 of	40.302 -0.188 -0.4762 -0.4762 -0.4762 -0.4863 -0.48	38 409 -5 355 -7 759 -7 7655 -7 7655 -7 765 -7 742 -5 7446 -5 520 -5 765 -7 14138111 -255 843 -1124 519 -7 15 502 -7 12 502 -7 12 502 -7 12 502 -7 12 502 -7 12 502 -7 12 502 -7 12 502 -7 12 503 -7 1443 -7 12 503 -7 1443 -7 12 503 -7 1443 -7 12 503 -7 1443 -7 12 503 -7 1443 -7 1

28 29 40 41 42 44 45 46 47 46 47 46 47 46 47 48 49 49 50 51 51 52 53 54 55 51 51 52 53 64 65 67 77 77 77 77 77 77 77 77 77 77 77 77	19 86 21 41 22 37 23 20 24 99 27 98 28 99 27 98 28 91 29 97 29 98 29 98 29 98 20 98	47 781 47 162 40 349 45 280 45 482 45 482 45 483 46 683 47 683 48 683 48 688 49 100 281	1	0 87 0 87 0 87 1 18 1 27 1 06 1 20 2 32 2 46 2 32 2 46 2 32 2 46 2 32 2 46 2 32 2 46 2 32 2 46 2 32 3 30 4 7 14 9 09 10 65 11 90 12 90 12 90 12 90 24 61 19 90 22 19 94 19 90 22 19 94 19 90 24 61 10 57 10 73 10 74 10	147 649 141 476 141 476 141 476 141 476 140 442 116 447 1103 480 103 231 54 640 93 627 65 220 66 913 55 640 50 831 69 899 47 516 46 431 45 150 66 431 47 522 42 200 42 187 43 699 43 222 44 246 45 187 47 676 48 246 48 246 48 246 48 247 48 257 48 267 48 486 48 277 27 123 26 762 23 769 34 124 36 377 37 123 35 546 37 103 31 546 32 777 33 554 34 124 35 266 37 103 33 554 36 762 33 576 33 576 33 576 34 124 35 266 37 103 33 576 33 576 33 576 33 576 34 124 35 266 37 103	0-94 0-94 0-1-2 0-6-6 1-2 0-6-6 1-3-7 0-6-6 1-3-7 0-6-6 1-3-7 0-6-6 1-3-7
91 92 97 64 99 64 99 160 101 102 103 104 109 106 107 108 109 110 111 112 113 114 119 119 120 121 122 123 124 125 126 127 128 129 2 sample and hematorit 1 19-4 2 He94 3	5 33 5 51 7 42 7 76 9 97 13 60 12 52 13 91 15 08 16 30 17 68 17 68 19 24 66 22 11 22 49 24 65 25 14 27 19 28 67 48 69 60 30 74 10 79 98 106 56 137 59 109 50 109 57 201 57	73 746 70 811 62 839 62 268 56 758 56 027 52 708 51 240 50 030 51 240 50 030 61 247 46 412 43 436 44 999 40 234 43 266 43 436 43 239 40 234 25 970 37 247 34 771 34 721 33 746 32 046 32 047 34 771 34 771 34 771 34 771 35 716 33 765 31 65 31 64 32 647 31 744 32 474 32 474 32 474 32 474 32 474 32 474 32 474 32 474 32 474 32 474 32 474 32 474 32 474 32 474 32 474 32 474 32 474 32 4751 403 085 312 162 371 553 312 163	105 078 62 102 525 63 102 525 64 103 107 65 12 109 67 12 129 67 13 129 68 14 261 70 17 510 71 17 510 72 13 076 73 14 76 77 15 264 76 15 264 76 15 264 77 15 264 76 15 264 77 16 264 76 17 37 480 18 310 84 18 310 84 18 310 84 18 310 84 18 310 85 18 310 86 18 310 87 18	0 57 0 94 1 31 1 97 1 80 1 97 1 80 2 20 2 39 2 59 2 71 2 90 2 39 2 59 2 71 2 90 3 11 2 97 7 45 9 99 111 7 61 11 7 61 11 7 62 12 76 20 2	135 724 133 429 108 943 107 575 95 447 108 575 97 478 669 419 80 730 80	13 3/5 11 678 11 678 11 678 11 678 11 678 11 678 12

O sample and hematocrit	1 snear rate	2 viscosity (cP)	3 relative				44 503
1 10-3	0 04	2052. 857	2975 195 101		42 81 60 09	37 431 33 125	54 578 48 007
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10	1 26 1 32	192, 593 180 570	279 120 109 261 646 110		152 55 182 65	29 377	-2 979
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25 26	7: 32 7: 74	62 297	119 271 125 107 229 126		0 75 0 79	171 203 176 511	248 265 255 613
27 27	7. /2	73 989 73 778	107 229 126 106 925 127		0 94	140 579	219 332
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30	15 46	64 B62	94 032 130		1 32	125 714	182 194
31 32	15 52 16 44	45 401 71 3 5 0	94 784 131 103 406 132		1 51	113 175 110 a2 7	164 022 160 329
23	18 02	42 449	90 796 133		1 75	105 394	152 745 150 530
34 35	19 25 20 59	61 643 60 945	89 334 134 89 32, 135		1 77	103 872 101 5 9 3	147 239
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O sample and 1 hematocrit	(1/sec)	(cP)	O relative viscosity	100 101 102	29 98 42 15 46 48	27 719 26 540 22 676	40 172 38 475 32 8 64
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8	1. 50	74 198 72 067	104 474	109	155 0P 104 95	20 348 14 437	29 490 29 170
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11 12	1.02 1.93	63. 7 62 58. 937	92.438 85.416	112	233 10	19 588	19 396
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12 13	1 47	96 4BE	139 808	51	207 54	18 794	27 23A
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50 51 52 53 53 55 56 57 0 sample and 1 hematocrit 116-9 2 He67	176 29 164 83 201 e6 211 29 227 22 237 69 259 05 277 29 1 shear rate (1/sec)	19 C78 18 325 18 772 19 1:0 19 494 17 629 18 211 17 749 2 VICCOSTEU 1071 935 000 381 653	27 One 27 Cm	90 91 92 93 94 95 96 97 99 100 101	12 56 15 11 15 22 16 21 17 86 18 86 19 86 21 42 22 49 23 96 24 48 25 50 22 45 27 58	29 463 29 279 27 330 27 517 26 464 26 467 25 907 25 51 25 101 24 944 24 581 24 581	42 700 12 43 43 323 49 890 38 643 28 897 27 546 27 175 29 378 76 151 35 367 34 44 39 84*
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1 1 1 2 0 70 19 520 12 312 14 24 24 7 3 1750 4 4 3 3 1750 4 4 3 3 3 3 3 3 3 3	DODALCELE	(1/500)			1 *1	208 35		4 445
1 1 1 2 0 70 19 520 12 312 14 24 24 7 3 1750 4 4 3 3 1750 4 4 3 3 3 3 3 3 3 3				717205124	1 75			4 416
1 13	1 10-12	6.70	19 922			244 96		4 674
1 13	2 M456	D 89	15 247					4 572
1 13		0 44	15 047		44			4 597
1	4	1 13	14 794					-
1	5) sample and	I shear rate 2	416606174 I	relative
1					Rematocrit	1/100/	(cP)	444444
8 1 57 13 395 15 4/13 133-1 3 76 5 221 8 8 10 17 11 12 941 18 772 2 94 3 6 72 3 6 8 1								
1					: 33-1	3 76	• 502	9 133
1				18 23	2 M#42	6 94	5 521	8 Oct
11	10			19 510		9 24		
12				13 Aug		10 11		7 2.5
14						12 54		
14	: 7				•	tā 93		3 3.41
15	14			12 417		15 85		> 441
19	17							
17	:5					19 15		= 212
2 6	17		12 089			20 94		a 5,10
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								C 011
	1.5		11 641	lo 871		i= 51		A 146
1	. 1		9 807		1.4	i5 75		2 871
10	_				15	25 65		4 247
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12 12 12 13 13 14 15 17 17 17 17 17 17 17		3 70						- 591
1	• ?							4 6/35
1	: 2							4 500
17 18 7 492 10 808 23 164 4 2 945						135 60		4 369
10						158 31		4 354
1	17		7 492					4 208 4 274
1 20	3.		7 177		24			204
23	7.5				25			4 213
24 45	55	27 77						7 170
1	Ξ.							4 158
27	-5			: 0.3			2 B10	4.072
29				2 242				4 090
29				7 354	30	274 /8		
40 72 48 5 070 7 348 7 1951 8 8 4 5 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1					O sample and	1 shear rate	2 v1820614	3 F01461V0
40 72 48 5 070 7 348 7 309 1 33-2 5 53 2 451 41 94 47 5 091 7 378 1 33-2 5 53 2 451 425 9 7 1 935 42 105 42 4 744 6 875 2 H=25 9 7 1 935 42 116 88 4 895 7 094 3 13 82 2 825 44 136 42 4 569 6 622 4 13 82 2 132 45 45 138 10 4 712 6 829 5 13 82 2 132 45 46 164 85 4 495 6 514 6 164 85 4 495 6 514 6 164 85 4 495 6 514 6 164 85 4 495 6 514 6 164 86 199 99 4 4 628 6 707 7 17 01 2 134 47 189 99 4 4 628 6 707 7 17 01 2 134 47 189 99 4 4 628 6 707 7 17 01 2 134 48 6 191 40 4 436 6 429 8 19 20 18 2 142 49 19 20 18 2	3.4			7 951	Rematocrii	(1/146)		~
18 10 4 712 6 829 5 13 82 2 132 46	40			7 340			~ 441	
18 10 4 712 6 829 5 13 82 2 132 46			5 091	7 378	1 33-5	3 53	2 431 . mtd	2 833
18 10 4 712 6 829 5 13 82 2 132 46			4 744	a 875	2 H=25	4 97	1 733	3 312
18 10 4 712 6 829 5 13 82 2 132 46	÷3		. 4 895	7 024	a a	9 98	1 975	2 891
45	44			5.622	•		2 192	3 119
## 164 85				a. 829				2 400
47 189 99 4 428 6 707 7 11 21 24 2 602 48 191,40 4 4346 429 8 19 20 18 2 142 49 219 46 4 971 6 629 9 20 18 2 142 50 217 77 4 400 5 377 10 22 53 2 012 51 244 20 4 273 6 388 11 23 36 2 600 52 2 247 23 4 515 5 343 12 25 18 2 C03 53 240 41 4 261 1 320 13 25 18 2 C03 54 299 73 4 412 2 394 14 25 28 8 2 064 54 299 73 4 412 2 394 14 25 28 8 2 064 6 299 73 4 412 2 394 14 27 29 48 2 001 0 sample and 1 snear rate 2 siscosity 3 relative 16 73 89 2 152 6 1 33-3 0 87 11 5050 16 674 19 99 27 2 031 2 Hm49 1 00 12 5410 18 175 20 124 71 1 455 3 1 06 12 5430 16 372 21 125 69 18 43 4 1 32 11 3440 16 441 22 11 150 27 1 962 5 1 46 9 9990 14 346 23 152 57 1 962 5 1 46 9 9990 14 346 23 152 57 1 962 5 1 46 9 9990 14 346 23 152 57 1 962 6 1 64 10 3370 14 901 24 175 89 1 972 7 1 79 9 7760 13 678 26 27 178 98 1 972 7 1 79 9 7960 13 678 26 27 178 98 1 972 9 19 2 18 9 5400 13 626 27 178 98 1 972 10 2 27 6 6340 12 892 29 244 92 1 033 11 2 2 18 9 5400 13 626 27 21 195 1962 11 2 2 51 9 8460 12 892 29 244 92 1 033 11 2 2 84 0 0560 11 679 31 284 70 1 892 12 13 2 2 3 8 4170 12 199 30 13 624 70 1 892 13 2 84 0 0560 11 679 31								3 093
48								2 901
13								3.104
10								2.916
23								3 733
29 29 39 49 42 50 49 50 50 50 50 50 50 50 50 50 50 50 50 50								3 024
1 32-0						29. 10		2 903
O smalle and I shear rate 2 (1900s) It of the shear rate 3 (19						25 28		2 991
O smaple and 1 shear rate 2 siscosity 3 relative 16 72 89 2 152 89 2 152						29 48		2 900
Nematorit (L/sec) (cP)] relative		48 37		3 281
1 33-3	hematocrit	(1/500)		₹180011tu		73 89		2 090
1 33-3						93 00		2 697
2 PANS 1 00 12 5410 18 175 20 124 71 1 455 3 1 00 12 5410 18 175 20 124 71 1 455 3 1 00 12 5410 18 175 21 125 69 18 43 1 132 11 3440 16 441 22 150 27 1 962 3 1 46 9990 14 346 23 155 55 1 865 3 4 1 64 10 3370 14 901 23 175 89 1 972 7 1 79 9 7970 14 197 25 178 98 1 967 9 1 972 9 178 98 1 967 9 1 972 1 18 99 1 972 1 18 99 1 972 1 18 99 1 9740 13 878 26 201 26 1 962 9 1 962 9 1 962 1 1 973 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1						99 27		2 972
1 00 12 6630 16 322 21 125 69 1 843 4 1.32 11 3440 16 441 22 150 27 1 962 2 1 160 27 1 962 2 1 160 2 1								2 891
9 1.32 11 3440 16 441 22 150 27 1912 150 2						125 69		2.671
1 46 9 9900 14 246 20 152 55 1 865 1 667 1		1 12				150 27		2 872
6 1 64 10 2370 14 661 24 175 89 1 572 7 1 79 9 7970 14 197 25 178 98 1 967 0 1 95 9 9760 13 676 26 201 26 1 962 0 1 95 9 9760 13 676 26 201 26 1 962 10 9 5400 13 626 27 211 95 1 1089 10 2 27 8 6340 12 513 28 226 83 1 933 11 2 2 51 9 8660 12 892 29 244 92 1 053 12 2 2 2 3 8 4170 12 199 10 246 03 1 892 13 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2			0.000			152 55		2 703
1 79 9 7970 14 197 25 178 98 1 297 0 1 95 9 5760 13 878 26 201 26 1 962 9 2 18 9 5400 13 626 27 211 95 1 187 10 2 27 8 6340 12 513 28 226 83 1 933 11 2 51 9 8490 12 892 29 244 92 1 193 12 2 51 9 8490 12 892 29 244 92 1 193 13 2 84 9 0500 11 679 31 284 70 1 872		1 46				175 89	1 972	2.839
9 1 95 9 5760 13 878 26 201 20 1 962 9 2 18 9 5400 13 626 27 211 99 1 4899 10 2 27 8 6340 12 513 28 226 83 1 933 12 25 8 3 1 933 12 25 8 3 1 8 10 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	6	1 46	10 3370	14 901	47			
2 18 9 5400 13 626 27 211 95 1 499 1 499 10 22 27 8 6340 12 513 28 22 693 1 933 1 11 2 51 9 8660 12 892 29 244 92 1 453 12 12 2 53 8 6170 12 199 70 246 03 1 692 13 2 64 9 0 0500 11 679 31 2 64 70 1 692 14 14 15 15 15 15 15 15 15 15 15 15 15 15 15	<u> </u>	1 46 1 64 1 79	10 3370 9 7970			178 98	1 207	2 706
10 2. 27 8 6340 12 513 28 226 83 1 930 11 2 51 8 8690 12 892 29 244 92 1 053 12 12 2 53 8 6170 12 199 70 246 03 1 892 13 2 84 9 0 0500 11 679 31 284 70 1 892	6 7 0	1 46 1 64 1 79 1 95	10 3370 9 7970 9 3740	14 197	25	17 8 48 201 30	1 8a7 1 9a2	2 706 2 843
12 2 51 8 8660 12 892 29 244 92 1 033 12 2 53 8 6170 12,199 10 246 03 1 892 13 2 84 0 0500 11 679 11 284 70 1 892	6 7 C	1 46 1 64 1 79 1 95 2 18	10 3370 9 7970 9 3740 9 3400	14 197 13 676 13 626	25 26 27	178 48 201 36 211 95	1 8a7 1 9a2 1 4 87	2 706 2 843 2 738
12 2 84 8 0500 11 479 11 264 70 1 642	6 7 0 9 10	1 46 1 64 1 79 1 95 2 18 2 27	10 3370 9 7970 9 5760 9 5400 6 6340	14 197 13 878 13 626 12 513	25 26 27 28	178 48 201 36 211 99 226 83	1 9a7 1 9a2 1 189 1 933	2 705 2 843 2 738 2 8 01
14 0 0000 11.8/9)1	6 7 0 9 1 Ú	1 46 1 64 1 79 1 95 2 18 2 27 2 51	10 3370 9 7970 9 5740 9 5400 6 6340 9 8480	14 197 13 878 13 626 12 513 12 852	25 26 27 28 29	178 48 201 30 211 95 220 83 244 92	1 957 1 962 1 089 1 933 1 053	2 706 2 843 2 738 2 801 2 666
	6 7 0 9 10 11	1 46 1 64 1 79 1 95 2 19 2 27 2 51 2 50	10 3370 9 7970 9 5740 9 5400 6 8340 8 8400 8 4170	14 197 13 878 13 626 12 513 12 852 12 199	25 26 27 28 29	178 48 201 30 211 95 220 83 244 92 246 03	1 % 7 1 % 62 1 d 87 1 933 1 d 93 1 872	2,705 2,843 2,738 2,801 2,686 2,742
3.00 4.040 13.113 22 244.78 1.414	6 7 9 10 11 12	1 46 1 64 1 75 1 95 2 18 2 27 2 51 2 50 2 84	10 3370 9 7970 9 5740 9 5400 8 6460 8 8460 8 4170 0 0560	14 197 13: 878 13: 624 12: 513 12: 852 12: 100 11: 479	25 26 27 28 29 10	178 48 201 36 211 95 226 83 244 92 246 03 284 70	1 6a7 1 9a2 1 0a9 1 933 1 033 1 892 1 892	2 705 2 843 2 738 2 801 2 666 2 742 2 742
	6 7 0 9 10 11	1 46 1 64 1 79 1 95 2 19 2 27 2 51 2 50	10 3370 9 7970 9 5740 9 5400 6 8340 8 8400 8 4170	14 197 13 878 13 626 12 513 12 852 12 199	25 26 27 28 29 10	178 48 201 30 211 95 220 83 244 92 246 03	1 % 7 1 % 62 1 d 87 1 933 1 d 93 1 872	2 705 2 843 2 738 2 801 2 666 2 742
	6 7 0 9 10 11 12 13	1 46 1 64 1 75 1 95 2 18 2 27 2 51 2 50 2 84	10 3370 9 7970 9 5740 9 5400 8 6460 8 8460 8 4170 0 0560	14 197 13: 878 13: 624 12: 513 12: 852 12: 100 11: 479	25 26 27 28 29 10	178 48 201 36 211 95 226 83 244 92 246 03 284 70	1 6a7 1 9a2 1 0a9 1 933 1 033 1 892 1 892	2,704 2,040 2,738 2,601 2,664 2,742 2,742

O sample ant		te		Lity	3 relat	-
hematocr:t	1/100)		(c P)		V 1 8 C D	erch
1 33-5	24			341		947
2 M=7	69	76	ı	195	1	732
3	100	45	1	177	1	704
1	105	87	1	084	1	574
5	1 38	75	1	171	1	697
•	145	47	1	121	- 1	6-5
7	179	50	1	137	1	64 Ĝ
8	163	27	1	173	1	700
•	204	93	1	118	1	620
10	215	19	:	101	1	712
11	231	21	1	129	1	وره
12	246	90	1	185	1	717
13	277	35	1	151	1	800
14	599	70	1	178	ı	707

Table F-III: Data tables for plasma suspensions.

O sample, hct, plasma visc	1 thear rate	2 viscosity	3 relative	31 32	13.76 14.57	62, 350 61, 992 57, 673 57, 094 57, 714 57, 327 98, 522 95, 098 53, 179 54, 327 92, 501 92, 201 92, 201 92, 201 92, 201 93, 617 90, 000 91, 601 48, 748 50, 131 48, 107 47, 132 48, 518 47, 130 48, 603 46, 603 47, 446 47, 448 46, 584 46, 58	59, 381 59, 002
		2084 400		33	16, 31	59. 673	55.831
1 31-7 2 H=98 1 3 1.21 cP	0.10	924 471	1724 298 745 479	35	18.84	37.714	54, 968
3 1.21 cP	0.17	494 344	342 450	34	19.85	57, 337 84, 532	54.607 53.630
3	0 29	433 674	425 334 238 410	36	21.62	55.078	53. 236;
♠ 7	0. 36	386 667	319 560	34	23, 32	55. 178 53. 791	52. 550 51. 230
•	0.47	277 105	229 079	41	25, 24	94, 327	31. 740
10	0 67 0 67	260 676 226 073	215 435	42 43	27. 14 28. 43	33. 474 32. 301	50: 730 50: 001
11	0. 93	222 923	184 234	44	29.97	52.207	49. 721
12 13	1.12	197. 697 192. 832	163 386	44	42. 93	58. 001	55. 23 7 .
14 15	1. 44	174 078	143 893	47	48. 43	53. 617 50. 000	51.064:
ié	1.57	160. 233 160 638	137.054	49	73.72	51.601	49, 144
17 18	1.86	195 004	120 831	50 51	119.34 125.53	40.748 50.131	46. 446
17	2.12	145. 930	120 403	52	145.00	48.107	45.816
20 21	2. 27 2. 39	142 229	117 545	53 54	157, 30	47. 553	45. 289
22	2 52	135.764	115 518	55	189. 27	48. 518	44. 200
23 24	2. 42	127 621 127.060	103 472 103 008	36 57	178 60 221.07	47. 130 48. 012	44. 8 6 6 45. 726
25 26	3 42	155 050	100.843	36 40	231. 57	44.020	44.590
27	5, 34 5, 97	99.799	82. 479	60	252. 93	47, 646	45 377
28 29	7. 44	93 493	79 079	61 42	271 95 284 50	47.448	45 208
30	9 78	88 311	72 984	43	299 73	46 852	44. 621
35 31	11.24	84 285	69 657	O sample, hct.	1 shear rate	2 viscosity	3 relative
23	13 89	80. 255	44 324	places vice.	(1/600)	(cP)	Viscosity
34 35	15.11 17.20	80 298 74 971	44 342 43 A12	1 29-1	0 03	2501.784	2382. 653
36 37	19.30	77 341	63 918	3 1.05 cP	0.10	1038: 509 712: 406	767, 034 478, 402
38	19 B4 20 21	75.064 75.861	42 034 42 495	4	0.22	355 674	529 213
3 9 40	22.48	73 485	49 731	Š	0. 35	428.460	409.000
41	25, 12	72. 114	61 379 39 400	7	0.48	347. 712	231, 154
42 43	25:31	73.035	40 340	•	0. Bá	249. 748	238.046
44	29.64	75 911	20 533 42 734	10	0.94	236.474	225.213
45 46	29 97 48 72	70 748	58 484	12	1. 27	199 386	189 871
47 40	73.29	42.055	21 502	14	1.31	197 704 173 117	180 290 184 770
••	74. 16	49. 858	34 428	52 53 54 55 56 57 58 59 60 61 62 63 0 sample, hct, plasma visc. 1 29-1 2 H-97, 3 3 1.05 cP 4 7 8 7 10 11 12 13 14 15 16 16 17 18 19 10 11 11 12 13 14 15 16 16 17 18 18 18 18 18 18 18 18 18 18	1 63	177.716	169 253
4 9 50	99. 66 99. 72	64.028 61.312 63.287 60.809 62.555 60.547	52. 716 50. 671	16	1.73	160.006	152 387
51	118.45	43.287	52. 203	17	1. 94	161. 925	154.214
52 53	126. 15 144. 21	60. B07	50 255 51. 648	19	2. 24	147.826	140 787
24 35	143. 72 147. 48	60. 547	50. 039	20	2.46	160,006 161,725 146,750 147,826 141,171 141,486 136,586 131,673 96,446	134.449
56 .			49 851	22	2.72	134.584	130.082
57 50	172, 53 192, 27 193, 09	40. 145 41. 433	49 723 50, 934	23	2. 77 4. 31	76.446	91. 853
59	210.73	60.074	49. 440	25	4. 85	80.061	76 249
60 61	220. 44 238. 47		50. 480 49. 414	27	10.41	71.622	49. 211
62 63	246.00 271.29	41.110	50 504	40	12.50	66.531 65.703	43 343 42 374
64	284. 66	59. 909	50, 274 49, 512	<i>3</i> 0	15.77	63.177	40 193
45	299. 70	60. 3 00	40 875	Ji	17. 22 18. 97	62. 134 60. 446	37, 174 37, 549
O sample, hct. plesma visc.	1 shear rate	2 viscosity	3 relative viscosity	33	20 52	59. 225	56. 405 84. 308
				25	20.00	57. 476	137 742 140 787 124 447 134 749 130 082 125 422 91 853 74 249 49 241 40 188 37 194 57 546 54 405 54 935 54 935 54 935 54 935 54 936 54
1 29-4 2 H=97, 6	0. 04 0. 10	1694, 211 869, 430	1794, 487 846, 314		23. 41 25. 14	97. 701 54. 741	54, 953 54, 058
3 1.05 cP	0. 17 0. 23	417.722 500.130	588. 307 474. 314	30	25. 74	94.725	54 024
5	0. 34	374. 330	354. 524	40	27. 78 29. 98	33.464 35.834	52 175
*	0. 55 0. 74	296. 037 247. 6 70	281. 959 234. 047	41	27, 78 36, 66	54, 764 54, 5 8 3	52, 347 91, 984
•	0. 93	195.210 208.562	185, 914	123	35.83	50 774	46. 361
9 10	1.00 1.19	172, 149	198.630 163.970		91.15 92.17	48.503 46.241	46 193 44 037
11 12	1. 25 1. 39	182.545 158.714	173.871 131.154	46	104.45	47.314	45. 041
13	1.44	168. 526	160.501	44	131.76 138 54	44. 768 46. 405	42. 827 44. 173
14 15	1. 97 1. 70	147, 430 155, 563	140.410 148.155	49	164 76 176 79	44, 53 0 45, 647	42, 417 43, 473
14	1.79	139.117	132, 492	51	191 31	44, 253	42.146
17 18	1. 95 1. 99	141, 274 132, 0 6 5	134, 547 125, 793	52	208. 65 217. 65	45 248 44 025	43 093 41 929
19	2. 18 2. 27	126. 910 129. 171	120.867	54	240.39	44.690	42.752
21	2. 30	121.683	1 23. 020 1 15. 96 9	, 33	244.08		41. 790
22 23	2. 52 2. 78	123, 273 119, 641	117, 403 110, 134	70 57	265. 8 9 270 48		42. 563 41. 714
24	2. 93	107 325	102 214	38	290, 31 299, 74	43 B05	41.719
25 26	3. 00 6. 13	112.493 79.491	107, 327 73, 706		277 /6	44 105	42. 005
27	0. 67	71.003	47. A98) ·			
28 27	9, 27 11, 23	70. 754 68. 643	47. 383 42. 517	•			
30	11.92	49. 325	62 214				

O sample, hct, plasme visc.	1 shear rate	2 viscosity		35 37	22.49	62.647	59 654
	(1/sec)	(cP)	viscos: ty	36	22 73 24,64	62, 944 61, 907	57 947
1 29-5 2 H=77	0. 04 0. 11	1484, 507	1413. 614		25.14	61.073	58 959 58 184
3 1.05 cP	0. 11 0. 17	701.695 485.814	448. 201 442. 402	4.	26. 55 27. 80	61.017	58. 111
4	0. 23	372.031	373. 363	42	29 97	39. 914 39. 249	57. 041 54. 428
•	0. 30 0. 36	337.033	320. 984		30.04	62.674	39 8BO
7	0. 35	298. 671 229. 614	284 449 218.680	49	49. 11 68. 13	56, 384 53, 172	53. 699
8	0. 74	194. 749	197. 399	. 46	86.07	48 310	50. 659 46. 010
10	0. 93 0. 93	175, 531 171, 6 42	167, 172		87 27	51.287	48. 847
11	1.12	154, 109	163.659 146.770	49	106 32 119, 16	49, 887 44, 979	47. 511
12 13	1.20	152, 484	145, 223	91	131.82	48 412	44 742 46 297
14	1. 31 1. 53	144.011 133.425	137. 153 127. 071		145, 47 157, 29	46. 278	44. 074
15	1. 57	131.307	123.034	20	172.05	47, 797 45, 789	45, 521 43, 409
16 17	1. 79 1. 82	123. 597 121, 294	117. 711		182.82	47. 145	44. 700
10	2. 02	115.417	115. 520 110. 111		204. 96 208-29	45.389	43. 228
19 20	2.04	115.842	110 345	57	231.34	46, 693 45, 124	44. 471 42. 975
21	2. 27 2. 32	110, 462 109, 792	105.208 104.564		252, 75	46.065	43. 871
22 23	2. 52	103.481	100 458	40	264, 48 271, 65	44. 87 6 45. 8 64	42 750
23 24	2. 52 2. 78	103.372 101.089	100 354	61 42	277. 31	46 417	43.480 44.207
25	3.00	78. 489	96 275 93 799	5	290.85 299.70	44.796 45.135	42.663
26 27	3.69	93.328	88. 894	64 31-1	0.04	2177, 444	42.986 1799 540
20	5. 60 8. 15	79 336 69 613	75 558	45 H+96 46 1.21 cP	0.10	951.143	784 085
29 30	7. 25	47. 52 L	44. 298 44. 304		0. 17 0. 23	641.230 543 9 37	529 942 449, 535
30	10.04 12.36	45. 453	42.334	4	0 29	438 940	362 760
32	13.87	≜1.≜67 59 939	50 730 57 005	6 ₹ 70	0. 35 0. 42	393.792	325 449
33 34	15.64	57.889	55. 132	71	0 49	344 690 312 801	284 8 58 258 5 13
35	17.06 19.18	36. 997 54, 973	54, 283 52, 357	מ	0. 74	249 716	204 377
36 27	19.61	55.156	52 530	74	0 93 1.12	211.097 199 091	174 460
30	22. 15 22. 47	53. 402	51. 050	75 74	1 31	183 771	164 536 151 8 77
39	24.69	53, 104 52, 205	50. 575 49. 719	7 6 77	1 50 1 68	144 858	136 246
40 41	25. 12	51.702	49. 240	70	1 69	163 929 163 362	135 477 135 175
42	26.60 27.76	51 488 50. 735	47 034	79 80	1 89	152 417	125 764
43	29, 91	53 360	48 319 50 819	0 1	2. 08 2. 27	143 400 139 019	110 470
44 45	29 97 61.71	50. 035	47. 632	62	2.46	134 476	114 892 141 154
44	92 97	45. 843 42. 046	43. 660 40.044	83 84	2.65	128 497	106 196
47 48	93.54	43.008	40.960	65	4 22 7 40	102 914 62 050	85. 052 67. 810
76	125 28	41.475	39. 300	65	9. 27	76. 731	63 414
49	125. 97	40, 533 40, 6 20	36 60J 36 676	67	7. 75		
50 51	150, 61 152, 52	39. 910	36.010		11.91	74 118 70.385	6: 255 56 167
52	178.83	39.389	37. 513	67	12, 50	47. 78B	56 023
93 94	180. 88 205. 23	40. 025 37. 029	38.119 37.170	90 91	14, 55 15, 04	44.007 44.971	54 551 53 695
35	220. 71	39. 568	37. 684	92	16.54	43. 529	52. 503
54	238.08	38.710	36. 967	93 N	17.59 19.18	62. 265	51 457
57 58	252. 48 271. 62	39, 259 39, 110	37, 3 7 0 37, 248	95	20.14	40. 901 59 908	50 331 49. 511
57	284.34	38. 500	34. 667	% 97	21.84	58. 424	48 451
40	299. 73	38. 545	34 824	97/ 98	23. 61 22. 68	58. 341 57. 357	40 216 47 402
O sample, NCt, 1	. Shear rate 2 (1/sec)	lviscosity 3 (cP)	relative	•	24 40	57. 188	47, 263
			Viscosity	100 101	25.80 27 11	34. 138	46 412
1 29- 9 2 H -7 6	0.03	1867. 565	1780 538	102	27.14	59, 521 55, 6 57	45 885 46 194
3 1.03 cP	0. 10 0. 16	746. 951 564. 750	711.3 62 537.857	100 104	29 76	54.310	44 684
4	0. 23	440 491	419.704	105	35 88 42, 24	52. 1 30 52. 131	44 570 43 083
3	0, 27 0, 42	382. 159 300. 793	363.960	106	61.39	48 287	39 908
7	0. 41	240. 947	286 470 229, 492	107 108	85, 74 93, 27	44 482 43.171	36 927 37, 348
# 7	0. 73 0. 80	226. 137	215. 369	109	118 71	42 937	23. 485
10	1.00	204. 243 1 67 . 210		110 111	116.77	43. 698	34. 114
11 12	1.05	178. 164	149 490	112	150. 66 131. 93	42. 573 41. 935	35 184 34 657
13	1, 26 1, 37	167, 476 157, 071		113	176. 13	41. 752	34 671
14	1. 59	150.451	143 477	114	194 69 201 63	41.230 41.467	34 074 34 270
1 5 16	1. 63 1. 86	147, 060 140, 055		116	217 89	40.782	303. 704
17	1. 75	133.415		117 118	220 74 244 33	41. 207 40. 430	34 055
18 17	2. 12	131.231	124 782	117	246. 18	40.721	33 413 33 617
30	2. 20 2. 38	128.673 124.651		120 121	245.29	40.755	33 405
21	2.46	122.458	116.017	122	277 44 277 73	40.140 40.234	33 190 33 253
29 20	2. 91 3. 01	114. 7 06 113.269	109 434		1 shear rate :		
24	5. 54	92. 262	87.849	Plates VISC.	(1/sec)	(eP)	V15604184
25 24	7. 97 B. 09	61.212 61.751	77. 345	1 30-2			
27	10. 64	75. 833	77 85 8 72 241	2 He73	0. 040 0. 100	1705. 263 607. 560	1509.082 714 673
26 27	11.27	73.743	70. 230	3 1. 13 cP	0. 170	613.743	543 135
30	13. 18 13. 73	71.471 69 .517	48 048 44, 207	4 5	0. 230 0. 270	474 8 05 3 87 413	420 181
3 1	15.72	48. 479	45 218	•	0.340	344 677	344 790 303 024
32 30	16. 55	44. 848 44. 837	43 445	7	0.421	304 484	269 455
34	17, 64 19, 87	64, 231	63. 675 61. 172	ţ	0. 610 0. 730	247 lJ4 245 768	218 703 217 494
39	20.17	64. 622	61. 735		0.800	214 275	189 424
				11	0. 990	201 207	178 059

12	1.060	162. 468	161 470	1			
13 14	1. 25 0 1. 260	165.353 173 124	146 330 · 153 207	44	125 16	31.057	25 667
15	1. 500	151.986	134 501	50 51	133 11 150 69	29. 707	24 551
16 17	1. 520 1. 700	156.679 142.276	138.654 125.708	25	166.05	30, 338 27, 075	25 073 24 029
1 6 19	1. 7 70 1. 89 0	142.388 134.182	126 007	53 54	175 98 192, 60	29. 714 28. 487	24 557
20	2. 050	132.048	116 857	55 56	201 48	29, 299	23 703 24 214
22 23	2. 140 2. 320	124.939 123.728	112, 353 1	57	217 09 226, 95		23 455
23	2.390	120. 314	106 474	58 57	238 83	28 234	23 944 23 334
24 25	2. 400 2. 520	121.402 118 321	107 435 104 709	60	246 18 271 44	28.761 28.555	23 786 23 599
26 27	2. 650 2. 850	114 522 111 078	101 347	61 62	278 25 299 64		23 160
28	3.000	108.388	98 , 294 9 5, 919	O samele, het.	1	•	23 250
27 30	4. 94 0 7. 490	86. 278 72. 527	76 352 64 183	plasma visc.	(1/106)	(CP)	VIBCOLLEU
31	T. 280	48.429	60 734 37, 701	1 29-7	0.04		1024 455
32 32	10. 040 12. 58 0	65.202 61.445	37, 701 54 376	2 H=93 3 1.05 cP 4	0. LO 0. 17	513 043	408 612
34 35	12. 590	60. 242	53 329		0. 23	375 090 298 940	357 229 284 724
34	15. 130 15. 230	54. 811 57. 573	50 275 50. 450	5 6	0. 30 0. 34	268, 293 220, 903	255 517
37 38	17. 480 17. 200	54, 326 53, 148	48. 076 47. 034	7 8	0. 42	222.656	210 384 212 053
34	20 210	52. 205	46 199	9	0. 49 0. 93	160, 752 144, 360	153 097 137 505
40 41	22. 490 23. 390	50. 834 50. 224	44 986 44 446	10 11	0. 93 L. 19	135 167	128 730
42 43	24: 480 25: 310	49 540 49 259	47 841	12	1. 19	124 68 0 119 025	118 743 113 357
44	27, 130	48.020	43 592 42 496	13 14 15	L. 39 1. 46	110.207 111.550	104 959
45 46	29, 970 36, 480	47 092 46 234	41. 674 40. 915	15 16	1. 57	103 151	106 238 78 239
47	49 170	42.941	38 001 34 907	17	1. 76 1. 77	98 . 433 101 039	43 746 96 228
48 49	74 610 92 190	39.445 37.761	34 907 33 417	18 19	2 06	73. 491	89 039
50	100 140	37, 479	33. 166 32. 107		2.08 2.32	71.664 88 849	87 299 84 618
51 52	125. 520 131. 6 20	36.281 35 858	32. 107 l 31. 733	21 22	2.40	B6 422	
53 54	151.050	35. 523	31, 434	23	2. 52 2. 53	84.759 84.719	80 485
55	164. 730 170. 160	34 70: 35 025	30.886 30.996	24 25	2. 85 2. 93	80.286 83 245	76 463
5 <u>6</u> 57	197. 730	34 247	30 307	26 27	3.00	79 181	75 410
56	201 960 224 220	34 456 33 902	30 492 30 002	28	4. 85 4. 76	67.079 39.458	63 885
59 60	227, 370 250, 620	34 136 33 391	30 Z09	29 30	0. 45	54 141	
62 61	252.640	33 873	29 727 29 976	31	10 63 11 84	50 635 47 131	48 224 46 810
63	276. 960 277. 700	33 354 33 377	29 517 27 537	32 33	13 93 15 67	46 457 45 165	44 245
							43.014
	1 43 555 5566 3			34	17. 24	43 741	41. 677
O samele, hct.	11/8063	: viscosity :	3	35	17. 24	43 761	41. 677
O sample. hct.	(1/100)	(CP)	3 relative viscosity	39 36	17, 24 18, 85 19, 88		41. 677 40. 837
O sample. hct.	(1/100)	(CP)	3 relative viscosity	35 36 37 38	17. 24 19. 85 19. 66 22. 52	43 761 42 879 42.040 40 742	41. 477 40. 837 40. 038 38. 802
O sample. hct. plasma visc 1 31-5 2 H=94 3 1.21 cP	0 04 0, 11 0, 17 0, 23	(CP)	3 relative viscosity	35 36 37 38 39	17, 24 19, 85 19, 98 22, 52 22, 67 25, 16	43 761 42 879 42 040 40 742 40 934 39 533	41. 477 40. 837 40. 038
O sample. hct. plasme visc I 31-5 2 H=94 3 1.21 cP	0 04 0.11 0.17 0.23 0.30	1135.664 571.671 413.121 339.332 281.048	938 345 472 455 341 422 280 440 232 271	35 36 37 38 39 40 41	17. 24 18.85 19.86 22.52 22.67 25.16 24.48 27.80	42 761 42 879 42 040 40 742 40 93 39 533 39 379	41. 477 40. 837 40. 038 38. 902 38. 983 37. 450 37. 450
O sample. hct. plasma visc 1 31-5 2 He94 3 1.21 cP 4 5	0 04 0 11 0 17 0 23 0 30 0 36 0 42	1135, 664 571, 671 413, 121 339, 332 281, 048 252, 702 229, 341	938 545 472 455 341 422 280 440 232 271 208 845 189 538	35 36 37 38 39 40	17. 24 19. 85 19. 88 22. 52 22. 67 25. 16 24. 48 27. 80 29. 97	42 879 42,040 40,742 40,924 39,533 29,379 38,435 39,154	40. 677 40. 637 40. 038 38. 802 38. 903 37. 650 37. 504 36. 337
O sample. hct. plasma visc 1 31-5 2 H=94 3 1.21 cP 4 5 6 7	0 04 0.11 0.17 0.23 0.30 0.36	1135.664 571.671 413.121 339.332 281.048 252.702 229.341 209.231	3 relative viscosity 	35 34 37 38 39 40 41 42 43	17. 24 18. 85 19. 88 22. 52 22. 67 23. 16 24. 48 27. 80 29. 97 36. 42 61. 93	42 761 42 879 42 040 40 742 40 924 39 533 39 279 38 435 39 134 37 462 33 850	41. 677 40. 837 40. 038 38. 902 38. 985 37. 650 37. 504 36. 795
O sample. hct. Plasma visc 1 31-5 2 H=94 3 1.21 cP 4 7 8 7	0 04 0, 11 0, 17 0, 20 0, 20 0, 42 0, 42 0, 68 0, 68	1135.664 571.671 413.121 339.332 281.048 252.702 229.341 209.231 174.536 151.361	3 relative viscosity 	35 34 37 38 39 40 41 42 43 44 43 44	17. 24 18. 85 19. 86 22. 57 25. 16 24. 48 27. 80 29. 97 36. 42 61. 73 80. 74	42 879 42 879 42 040 40 742 40 904 39 533 39 179 38 635 38 154 37 463 33 850 32 257	41. 677 40. 827 40. 038 38. 802 38. 885 37. 650 37. 904 36. 795 36. 237 33. 677 32. 238 30. 816
O sample. hct. plasma visc 1 31-5 2 H=94 3 1.21 cP 4 5 6 7 8 4 10	0 04 0, 11 0 17 0 23 0 30 0 36 0 42 0 49 0 68 0 87 0 93	1135.464 571.671 413.121 339.332 281.048 252.702 229.341 209.231	3 relative viscosity 938 365 472 453 341 422 280 440 232 271 208 843 189 538 172 918 144 245 123 108	35 36 27 28 39 40 41 42 42 43 44	17. 24 18. 85 19. 88 22. 52 22. 67 25. 16 26. 48 27. 80 29. 97 36. 42 61. 93 80. 74 92. 67 106. 50	42 761 42 879 42 040 40 742 40 924 39 533 39 279 38 635 39 154 37 462 33 850 32 357 30 185 31 331	41. 677 40. 827 40. 038 38. 802 38. 802 37. 650 37. 650 37. 650 37. 650 37. 650 37. 650 37. 650 37. 650 37. 650 38. 795 38. 795 39. 208 30. 816 28. 748 29. 553
0 sample. hct. plasma visc 1 31-5 2 H=94 3 1.21 cP 4 5 6 7 8 9 10 11 12 12	0 04 0.11 0.17 0.23 0.30 0.36 0.47 0.68 0.87 0.93 1.06	1135.464 571.471 413.121 339.332 281.048 252.702 229.341 209.231 174.534 191.381 194.323 134.840 132.312	3 relative viscosity 938 365 472 455 341 422 280 440 232 271 208 845 189 538 172 918 144 245 127 540 111 438	35 36 37 38 39 40 41 42 43 44 44 45 46 47 46 47	17. 24 18. 85 19. 98 22. 52 23. 67 25. 16 24. 80 27. 80 27. 97 36. 47 50. 47	42 761 42 879 42 040 40 742 40 934 39 533 39 134 37 463 33 850 32 357 30 185 31 031 39 119	41. 677 40. 827 40. 038 38. 802 39. 853 37. 650 37. 904 36. 795 36. 337 37. 795 36. 337 37. 795 38. 748 39. 748 29. 748 29. 748 29. 748 29. 752 27. 732
O sample. hct. Plasma visc 1 31-5 2 H=94 3 1.21 cP 4 10 11 12 13 14	0 04 0, 11 0, 17 0, 23 0, 30 0, 46 0, 42 0, 49 0, 68 0, 87 0, 93 1, 04 1, 19 1, 21	(cp) 1135.464 571.471 413.121 239.332 281.048 252.702 229.341 209.231 174.534 151.381 134.840 132.312 120.448 115.744	3 relative viscosity 	35 36 27 38 39 40 41 42 43 44 45 46 47	17. 24 18. 85 19. 86 22. 52 23. 46 24. 48 27. 80 29. 97 36. 42 61. 95 60. 94 92. 67 104. 50 125. 67 151. 27	42 761 42 879 42 040 40 742 40 924 37 523 39 179 38 625 32 257 30 185 31 031 29 119 30 408 29 627	41. 677 40. 827 40. 038 38. 802 38. 802 37. 650 37. 650 37. 904 36. 795 36. 337 33. 679 32. 238 30. 816 28. 748 27. 732 28. 760 29. 407
O sample. hct. plasma visc 1 31-5 2 He94 3 1.21 cP 4 5 6 7 8 4 10 11 12 13 14 15 16 17	0 04 0, 11 0, 17 0 23 0, 30 0, 42 0, 47 0, 68 0 87 0, 87 1, 06 1, 19	1135.464 571.471 413.121 339.332 281.048 252.702 229.341 174.934 151.381 134.223 134.840 132.312 120.448 111.744	3 relative viscosity 938 365 472 453 341 422 280 440 232 271 208 845 189 538 172 918 144 245 123 108 127 540 111 438 109 99 709 93 658 91 835	35 36 37 38 39 40 41 42 43 44 45 46 47 46 47 48 49 50 51 52	17. 24 18. 85 19. 86 22. 67 25. 46 27. 80 27. 97 26. 17 27 27 28 27 29 27 29 21 21 22 27 27	42 761 42 879 42,040 40 742 40,934 37,533 39,379 38,435 39,154 37,463 33,857 30,185 31,031 27,119 30,408 22,828	41. 677 40. 837 40. 038 38. 802 38. 985 37. 650 37. 504 36. 795 36. 337 35. 679 32. 238 30. 816 28. 748 29. 550 27. 732 28. 940
O sample. hct. plasma visc 1 31-3 2 H=94 3 1 21 cP 4 5 6 7 10 11 12 13 14 15 16 17	0 04 0 17 0 17 0 23 0 30 0 36 0 49 0 68 0 87 0 93 1 06 1 19 1 31 1 57 1 86	1135.464 571.471 413.121 339.332 281.048 252.702 229.341 209.221 174.534 191.381 194.323 134.840 132.312 120.448 111.120 103.205 104.862	3 relative viscosity 938 365 472 453 341 422 280 440 232 271 208 843 189 338 172 918 144 245 123 108 127 540 111 438 109 349 99 709 95 636 91 833 85 293 86 479	35 34 37 38 39 40 41 42 43 44 45 45 46 47 48 49 50 51 52 53 53	17. 24 18. 85 19. 98 22. 52 22. 67 25. 16 24. 48 27. 80 29. 97 26. 42 61. 95 60. 74 92. 67 106. 57 125. 67 125. 67 125. 22 170. 178 62	42 761 42 879 42 040 40 742 40 934 39 533 39 134 37 463 33 850 32 357 30 185 31 031 29 119 30 408 29 827 28 652 27 382 28 317	41. 677 40. 827 40. 038 38. 802 38. 802 37. 650 37. 650 37. 904 36. 795 36. 337 35. 679 32. 238 30. 816 28. 748 29. 533 27. 732 28. 740 28. 407 27. 288 27. 783 28. 740 28. 407 27. 288 27. 783 28. 740 28. 407 27. 288 27. 783 28. 740 28. 407 27. 483 28. 740
O sample. hct. Plasma visc 1 31-5 2 H=94 3 1.21 cP 4 10 11 12 13 14 15 16 17 18 19 19 20	0 04 0, 11 0, 17 0 23 0, 20 0, 26 0, 49 0, 69 0, 87 0, 93 1, 06 1, 19 1, 31 1, 52 1, 52 1, 86 2, 08	1139.464 571.471 413.121 239.332 281.048 292.702 229.341 209.231 174.934 191.381 194.223 134.840 132.312 120.448 115.744 111.120 103.205 104.882 100.088 97.173	3 relative viscosity 938 365 472 453 341 422 280 440 232 271 208 843 189 538 172 918 144 245 127 540 111 438 109 349 99 709 99 658 91 835 86 679 82 77 80 106	35 36 37 38 39 40 41 42 43 44 45 46 47 48 47 48 49 50 51 52 53 54	17. 24 18 85 19 86 22 57 25 16 26 48 27 80 27 97 36 42 61. 75 60 74 92. 67 104 50 125. 67 151. 29 152. 22 170. 37 178 62 187 43	42 761 42 879 42 040 40 742 40 904 37 503 39 177 38 605 30 185 31 001 32 187 30 189 31 001 32 189 32 4827 28 652 27 382 28 317 29 090	41. 677 40 837 40 038 38 802 38 985 37. 650 37. 504 36. 795 36. 337 35. 679 32. 238 30. 816 28. 748 29. 353 27. 732 28. 960 29. 407 27. 289 26. 963 26. 963 27. 698
0 sample. hct. plasma visc 1 31-5 2 H=94 3 1.21 cP 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18	0 04 0 17 0 27 0 27 0 30 0 36 0 47 0 68 0 87 0 93 1 06 1 17 1 31 1 57 1 86 2 06 2 25	1135.464 571.471 413.121 339.332 281.048 252.702 229.341 174.934 151.323 134.840 132.312 120.448 113.746 113.7	3 relative viscosity 938 365 472 455 341 422 280 440 232 271 208 845 189 538 172 918 144 245 123 108 127 1540 111 438 109 99 709 99 636 91 825 86 679 82 717 80 366 78 767	35 36 37 38 39 40 41 42 43 44 45 46 47 46 47 48 49 50 51 52 53 53 55 57	17. 24 19. 85 19. 98 22. 52 23. 16 24. 80 29. 97 36. 1. 95 60. 94 92. 67 106. 50 125. 67 125. 67 121. 22 170. 37 178 189, 45	42 761 42 879 42 040 40 742 40 934 39 533 39 134 37 462 33 850 32 357 30 185 31 031 29 119 30 408 27 827 28 652 27 382 28 317 29 083 28 075	41. 677 40. 827 40. 038 38. 802 38. 802 37. 650 37. 650 37. 904 36. 795 36. 337 35. 679 32. 238 30. 816 28. 748 29. 533 27. 732 28. 740 28. 407 27. 288 27. 783 28. 749 27. 478 28. 759 27. 773
0 sample. hct. plasme visc 1 31-3 2 He96 3 1 21 cP 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21	0 04 0 11 0 17 0 23 0 30 0 36 0 49 0 68 0 87 0 93 1 06 1 19 1 31 1 57 1 86 2 06 2 29 2 33 2 45	1135.464 571.471 413.121 339.332 281.048 252.702 229.341 209.221 174.534 151.381 154.323 134.840 132.312 120.448 111.120 103.205 104.862 100.088 97.173 75.550 92.754 11.574 11.574 11.574 11.574 11.574 11.574 11.575 104.862 100.088 97.173 97.550 97.753	9 relative viscosity 938 365 472 453 341 422 280 440 232 271 208 843 189 528 172 918 144 245 123 108 127 540 111 438 109 97 709 99 709 95 636 91 835 86 479 82 717 80 366 78 967 74 821 75 664	35 34 37 38 39 40 41 42 43 44 45 46 47 50 51 52 53 54 55	17. 24 19. 85 19. 98 22. 52 22. 67 25. 16 24. 48 27. 80 29. 47 104. 57 105. 67 125. 67 125. 67 125. 67 127 178. 62 187. 43 204. 59 224. 93 223. 94	42 761 42 879 42 040 40 742 40 934 39 533 39 177 38 635 39 136 30 189 31 031 29 119 30 408 29 827 28 652 27 382 28 317 29 093 28 765 27 755 28 765 27 755 28 765 27 755 28 765	41. 677 40. 827 40. 038 38. 802 38. 985 37. 650 37. 904 36. 795 36. 797 32. 238 30. 816 28. 748 27. 732 28. 760 28. 407 27. 288 27. 732 28. 760 28. 767 27. 288 27. 789 26. 769 27. 478
0 sample. hct. plasme visc 1 31-3 2 He94 3 1 21 cP 4 5 6 7 10 11 12 13 14 15 16 17 18 19 19 20 21 22 23 24	0 04 0, 11 0, 17 0 23 0, 30 0, 42 0, 49 0, 67 0, 87 0, 87 1, 93 1, 194 1, 191 1, 31 1, 32 1, 33 1, 33 2, 06 2, 08 2, 23	(cp) 1135.464 571.471 413.121 339.339.339.339.339.329.229.341 209.231 174.534 151.361 154.323 124.460 132.312 120.446 111.120 103.205 104.862 100.068 97.173 93.550	3 relative viscosity 938 365 472 453 341 422 280 440 232 271 208 843 189 538 172 718 144 245 123 108 127 540 111 438 109 349 99 709 95 636 91 833 85 273 86 479 82 717 80 366 78 967 74 821 75 464 73 160 71 093	35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 53 55 56 57 58	17. 24 18 85 19 86 22 52 22 67 25 16 24 48 27 80 29 97 36 42 61. 95 60 74 92. 67 1025. 67 125. 67 125. 67 125. 67 125. 67 127 178 62 189 45 204. 59 214. 95 224. 91 232. 94 234. 91	42 761 42 879 42 040 40 742 40 924 39 523 39 279 38 625 30 185 31 031 39 119 30 408 37 482 38 652 27 382 28 317 29 090 28 765 27 755 27 785 28 697 27 884 27 785	41. 677 40. 827 40. 038 38. 802 38. 985 37. 650 37. 504 26. 795 36. 337 35. 679 32. 238 30. 818 27. 732 28. 960 28. 760 28. 77 27. 288 27. 783 26. 969 27. 678 24. 752 27. 395 24. 624 27. 395 26. 624 27. 395 26. 512
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30 31 32	9.32 9.87 12.62 13.05 15.28	47, 989 45, 913 42, 906 41, 665 40, 143	42.466 40 631 37 970 36 872 35 525	64 63 31-6 66 Meg9 67 1 21 cP 68 69	299.70 0.04 0.10 0.16 0.23 0.29	17 613 877 600 425 000 304 762 240 682 210 072	16 774 725 209 351 240
30 31 32 33 34 25 36	9.32 9.87 12.42 13.05 15.28 16.89 17.73	47.989 43.913 42.906 41.463 40.143 38.625 38.050	42, 468 40, 631 37, 970 36, 872 35, 525 34, 181 33, 673	64 65 31-6 66 Meg9 67 1 21 cP	299.70 0.04 0.10 0.16 0.23 0.29 0.35	17.613 877.400 425.000 304.762 240.682 210.072 182.149	16 774 725 289 351 240 251 869 198 911 173 613 150 536
30 31 32 33 34 25 36 37	9.32 9.87 12 42 13.05 15.28 16.89 17.93 20.73	47. 989 49. 913 42. 906 41. 465 40. 143 38. 625 36. 050 36. 460	42. 468 40. 631 37. 970 36. 872 35. 525 34. 181 33. 673 32. 265	64 63 31-6 66 Meg9 67 1 21 cP 48 67 70 70	299.70 0.04 0.10 0.16 0.23 0.29	17 613 877 600 425 000 304 762 240 682 210 072 182 149 167 001	16 774 725 289 251 240 251 869 198 911 172 613 150 526 128 017
30 31 32 33 34 35 24 37 39	9.32 9.87 12.62 13.05 15.28 16.89 17.93 20.73 21.88 23.87	47, 989 49, 913 42, 906 41, 663 40, 143 38, 623 36, 030 26, 460 29, 947 24, 984	42. 468 40. 631 37. 970 36. 872 35. 525 34. 181 33. 673 32. 265 31. 812 30. 959	64 63 31-6 66 He89 67 1 21 CP 68 69 70 71 72 73	299.70 0.04 0.10 0.16 0.23 0.29 0.35 0.42 0.48 0.55	17 613 877 600 425 000 304 762 240 682 210 072 182 149 167 001 152 961 145 340	16 774 725 289 251 240 251 869 198 911 173 613 150 536 138 017 128 331 120 132
30 31 32 33 34 35 36 37 39 39	9 32 9 87 12 42 13 05 15 28 16 89 17 93 20 73 21 86 23 87 23 97	47, 989 49, 913 42, 906 41, 465 40, 143 38, 625 36, 050 36, 440 39, 947 34, 984 35, 053	42, 468 40, 407 37, 970 36, 872 35, 929 34, 181 30, 233 31, 812 30, 959 31, 020	64 65 31-6 65 Heg9 67 1 21 cP 69 70 71 72 73 74 75	299.70 0.04 0.10 0.16 0.23 0.29 0.35 0.42 0.48 0.53	17 613 877 400 425 000 304 762 240 482 210 072 182 149 167 001 152 961 143 360 122 353	16 774 725 289 251 240 251 849 198 911 173 613 150 536 138 017 126 331 120 132 151 118
30 31 32 33 34 35 24 37 39	9.32 9.87 12.42 13.05 15.28 16.89 17.73 20.73 21.88 23.87 23.90 27.17	47, 989 49, 913 42, 906 41, 663 40, 143 38, 623 36, 030 26, 460 29, 947 24, 984	42. 468 40. 631 37. 970 36. 872 35. 525 34. 181 33. 673 32. 265 31. 812 30. 959 31. 020 27. 824	64 65 31-6 65 Meg9 67 1 21 CP 68 69 70 71 72 73 74 73 74	299.70 0.04 0.10 0.16 0.23 0.29 0.35 0.42 0.48 0.74 0.73	17 613 877 600 429 600 304 762 240 682 210 072 162 149 167 002 152 961 145 340 122 353 113 742 168 573	16 774 725 289 251 240 251 869 198 911 173 613 150 536 138 017 128 331 120 132
30 31 32 33 34 35 36 37 38 39 40 41 42	9.32 9.87 12.62 13.05 15.28 16.89 17.73 20.87 23.87 23.87 23.87 27.17 29.16	47, 989 49, 912 42, 906 41, 463 40, 142 38, 625 38, 030 26, 440 29, 947 24, 984 25, 052 22, 701 23, 114 24, 364	42, 468 40 631 37 970 36 872 35 525 34 181 32 673 32, 265 31, 812 30, 939 31, 020 27, 824 29, 304	64 65 31-5 65 Meg9 67 1 21 CP 68 69 70 71 72 73 74 75 76 77	299.70 0.04 0.10 0.16 0.23 0.29 0.35 0.42 0.48 0.55 0.74 0.73 0.72 0.73	17 613 877 600 425 000 304 762 240 682 210 072 162 149 167 001 152 961 143 360 122 353 113 942 108 573 94 367	16 774 725 289 251 240 251 849 198 911 173 613 150 536 128 017 126 331 120 132 101 118 94 167 89 730 77 989
30 31 32 33 34 35 36 37 39 40 41 41 42 42	9.32 9 87 12.62 13.05 15.28 16.89 17.93 20.73 21.88 23.87 23.90 27.17 29.16 29.94	47 989 45.712 42.906 41.663 40.142 38.625 36.050 36.460 35.974 24.974 25.052 27.114 24.264	42, 468 40, 631 37, 970 36, 872 35, 525 34, 1811 32, 673 31, 812 30, 939 31, 020 27, 824 29, 304 30, 415 29, 153	64 65 31-6 66 Meg9 67 1 21 CP 689 70 70 71 72 72 73 74 75 75 77 78 77 78 77 78	299.70 0.04 0.10 0.16 0.23 0.29 0.35 0.42 0.48 0.74 0.73	17 613 877 600 429 600 304 762 240 682 210 072 162 149 167 002 152 961 145 340 122 353 113 742 168 573	16 774 725 269 251 240 251 869 198 941 173 613 150 536 138 017 126 331 120 132 101, 118 94 167 89 730 77 989 80 928
30 31 32 33 34 25 34 37 38 39 40 41 42 42 43 44 45	9.32 9.87 12.62 13.05 15.28 16.89 17.93 20.73 21.88 23.87 23.97 29.16 29.97 48.94	47 989 49. 712 42. 906 41. 643 38. 623 26. 630 26. 460 29. 947 24. 984 25. 052 22. 701 20. 114 24. 284 20. 200 27. 670	42, 468, 40 631, 37 970, 36 872, 35 525, 34 1811, 32 673, 32, 265, 31, 812, 30, 939, 31, 020, 27, 824, 29, 3041, 30, 415, 24, 487, 133, 26, 814, 24, 487, 304, 417, 30	64 65 31-6 66 Meg9 67 1 21 cP 66 67 70 71 72 73 74 73 74 75 77 78 80 81	299.70 0.04 0.10 0.16 0.23 0.29 0.35 0.42 0.48 0.53 0.73 0.73 0.73 0.73 1.18 1.20 1.37	17 613 877 600 425 000 240 762 240 682 210 072 162 149 167 001 152 861 152 350 113 742 108 573 74 767 77 723 67 413	14 774 725 209 391 240 291 849 198 911 170 413 150 536 138 017 126 331 120 132 101 118 94 147 89 730 77 989 80 928 72 242 71 202
30 31 32 33 34 25 37 39 40 41 42 42 42 43 44 45 46	9.32 9.87 12.62 13.05 15.28 16.89 17.73 20.73 21.86 23.87 23.90 27.17 29.94 48.94 74.43	47 989 45 912 42 906 41 645 40 143 38 625 38 636 29 947 24 784 25 052 22 701 22 114 24 369 22 742 20 300 27 477 23 528	42, 468 40, 631 37, 970 36, 872 35, 872 34, 1811 33, 673 31, 812 30, 939 31, 020 27, 824 30, 415 20, 415 24, 487 24, 487 24, 391	64 65 31-5 66 M=89 67 1 21 CP 68 49 70 71 72 73 74 75 76 80 81	299.70 0.04 0.10 0.16 0.23 0.27 0.35 0.42 0.48 0.55 0.74 0.93 0.92 1.18 1.20 1.37	17 613 877 600 425 000 304 762 240 682 210 072 167 001 152 961 143 360 122 353 113 742 108 573 74 367 77 723 67 413	16 774 725 289 391 240 251 849 198 911 173 413 150 536 128 017 120 132 101, 118 94 167 77 989 90 928 72 242 71 202 46 545
30 31 32 33 34 35 36 37 39 40 41 42 42 42 43 44 45 46 47 48	9.32 9.87 12.62 13.03 15.28 16.89 17.73 20.73 21.88 23.87 23.90 27.17 29.16 29.97 48.96 74.43 92.31 93.41	47 989 45 912 42 906 41. 663 40. 143 38. 623 38. 623 38. 784 23. 974 24. 364 25. 914 24. 369 32. 144 26. 369 32. 553 26. 553 26. 553 27. 570 28. 553	42, 468 40 631 37 970 36 872 35 929 34 181 32 673 32 265 31 812 30, 939 31, 020 27 824 29, 304 30, 419 21, 193 24, 487 22, 591 22, 592	64 65 31-6 66 Meg9 67 1 21 cP 66 67 70 71 72 73 74 73 74 75 77 78 80 81	299.70 0.04 0.10 0.16 0.23 0.29 0.35 0.42 0.48 0.55 0.74 0.72 0.72 1.18 1.20 1.37 1.51 1.43	17 613 877 600 425 600 304 762 240 682 210 072 162 149 167 001 152 961 145 260 122 353 113 742 108 577 94 367 97 723 67 413 86 154 80 520 79 587	16 774 725 289 391 240 251 849 198 911 170 413 150 506 128 017 120 132 101, 118 94 147 89 730 77 989 80 928 72 242 46 543 46 543 46 54 54 54 54 54 54 54 54 54 54 54 54 54
30 31 32 33 34 35 36 37 30 29 40 41 42 42 42 43 44 45 46 47 48 49	9.32 9.87 12.62 13.05 15.28 16.89 17.93 20.97 21.88 23.87 23.90 27.17 29.16 29.97 48.96 74.43 92.118 93.42 118 93.42	47, 789 43, 713 42, 704 41, 463 40, 142 38, 625 38, 030 26, 440 23, 477 24, 984 23, 701 23, 114 24, 269 22, 702 27, 670 29, 125, 528 26, 557 25, 508 24, 384	42, 468 40 631 37 970 36 872 35 929 34 1811 30 673 32, 263 31, 812 30, 939 31, 020 24 824 29, 304 30, 419 20, 419 21, 591 22, 591 22, 591 21, 571 21, 571	64 63 31-5 66 M-89 67 1 21 CP 68 48 69 70 71 72 73 74 75 76 77 78 78 80 81 80 81 80 82 80 83 80 84 80 85 80 86	299.70 0.04 0.10 0.16 0.23 0.29 0.35 0.42 0.48 0.55 0.74 0.93 1.18 1.20 1.37 1.53 1.79 1.88 2.12	17 613 877 600 427 600 304 762 240 682 210 072 167 001 152 961 145 360 122 353 113 742 168 573 74 367 77 723 67 413 86. 1540 77 549 75 287 73 020	16 774 725 289 351 240 251 849 1173 413 150 356 178 257 178 257 178 257 257 257 257 257 257 257 257 257 257
30 31 32 33 34 35 36 37 39 39 40 41 42 43 44 43 44 45 46 47 48 49 30	9.32 9.87 12.62 13.03 15.28 16.89 17.73 20.73 21.88 23.87 23.90 27.17 29.16 29.97 48.96 74.43 92.31 93.41	47 989 49, 912 42, 904 41, 463 40, 143 38, 425 36, 650 36, 460 35, 974 24, 984 25, 552 22, 701 23, 114 24, 284 20, 300 27, 400 28, 450 28, 557 28, 558 24, 384 24, 707	42 468 40 631 37 970 36 872 35 525 34 1811 32 673 32 265 31 826 30 999 31 020 27 824 29 3041 30 419 22 591 24 817 22 591 23 591 24 817 22 591 21 877 21 877 21 877	649 31-6 649 14-69 67 1 21 CP 640 640 640 647 77 77 77 77 78 60 60 644 666 666 666 666 666 666 666 6	299.70 0.04 0.10 0.16 0.23 0.29 0.35 0.42 0.48 0.55 0.74 0.73 0.73 1.18 1.20 1.37 1.53 1.43 1.79 1.88 2.12 2.14	17 613 877 600 425 600 304 762 240 682 210 072 162 149 167 001 152 961 145 260 122 353 113 742 108 577 94 367 97 723 67 413 86 154 80 520 79 587	14 774 725 289 291 240 251 849 111 173 413 150 536 138 017 120 132 101 118 97 730 77 989 80 928 72 242 46 945 45 740 62 221 60 347 78 58 588
30 31 32 33 34 25 34 37 38 39 40 41 42 42 42 44 45 46 47 48 49 50 51 53	9.32 9 87 12.62 13.03 15.28 16.89 17.93 20.73 21.88 23.87 23.97 29.16 29.97 48.96 49.97 48.96 118.92 125.49 130.61 130.61	47 789 49. 712 42. 906 41. 645 36. 625 36. 626 22. 761 22. 762	42 46B 40 631 37 970 36 872 35 525 34 1811 32 673 32 265 31 812 30 999 31 020 27 824 29 304 30 419 20 419 22 591 21 845 22 871 21 845 20 779 21 845 20 779 21 845 20 779 21 845 20 779 21 845	64 63 31-5 66 M-89 67 1 21 CP 68 48 69 70 71 72 73 74 75 76 77 78 78 80 81 80 81 80 82 80 83 80 84 80 85 80 86	299.70 0.04 0.10 0.16 0.23 0.29 0.35 0.42 0.48 0.53 0.73 0.73 0.73 1.37 1.37 1.37 1.43 1.79 1.88 2.14 2.29	17 613 877 600 425 000 240 452 240 482 210 072 162 149 167 001 152 961 143 360 122 353 113 942 108 373 94 367 97 923 67 413 84 154 80 520 79 549 77 529 70 872 68 674 68 674 67 775	16 774 725 209 331 240 231 849 198 911 173 413 150 536 138 017 126 331 120 132 101 118 94 147 89 730 77 989 80 928 72 242 246 543 55 760 62 221 40 247 58 588 54 757 55 998
30 31 32 33 34 25 37 39 40 41 42 42 42 43 44 45 46 47 48 49 50 51 52 53	9.32 9.87 12.62 13.03 15.28 16.89 17.73 20.73 21.88 23.87 22.90 27.17 29.16 29.97 48.96 74.43 92.21 93.21 93.21 93.21 93.21 93.21	47 989 45. 912 42. 906 41. 663 40. 143 38. 623 38. 623 38. 6460 23. 944 24. 964 22. 701 24. 249 26. 357 25. 528 26. 357 29. 26. 357 29. 270 22. 700 24. 249 22. 700 24. 249 23. 249 23. 249 24. 357 25. 368	42, 46B 40, 631 37, 970 36, 872 31, 812 30, 673 31, 812 30, 939 31, 020 37, 824 30, 413 32, 133 34, 487 32, 133 34, 487 32, 571 31, 579 31, 579 32, 571 31, 579 31,	64 65 31-5 66 Me99 67 1 21 CP 68 49 70 71 77 77 77 78 78 60 61 667 689	299.70 0.04 0.10 0.16 0.23 0.29 0.35 0.42 0.48 0.55 0.74 0.73 0.73 1.18 1.20 1.37 1.53 1.43 1.79 1.88 2.12 2.14	17 613 877 600 425 600 304 762 240 682 210 072 162 149 162 149 163 260 122 253 113 942 108 573 94 367 97 723 67. 413 86. 154 80. 520 70. 887 73. 287 73. 287 73. 287 73. 287 73. 287 74. 473 86. 474 47. 757 45. 728	16 774 725 289 391 240 251 849 198 911 170 413 150 536 128 017 120 132 101, 118 94 167 89 730 77 989 80 928 72 242 46 737 47 202 46 221 46 347 47 58 988 56 757 53 998 56 757 53 998
30 31 32 33 34 35 36 37 39 40 41 42 42 42 44 45 46 47 48 49 50 51 52 53 53 54 55	9.32 9.87 12.62 13.03 15.28 16.89 17.93 20.73 21.88 23.87 23.97 24.16 29.97 48.96 74.94 19.31 19.34 19.36 19	47 789 49. 712 42. 906 41. 645 36. 625 36. 626 22. 761 22. 762	42, 468 40, 631 37, 970 36, 872 35, 525 34, 1811 33, 673 32, 263 31, 812 30, 939 31, 020 27, 824 29, 304 30, 415 24, 487 22, 391 24, 487 22, 591 23, 592 22, 571 21, 579 21, 865 20, 773 21, 479 20, 555 21, 061	64 65 31-5 66 M-87 67 1 21 CP 68 48 69 70 71 72 73 74 75 76 77 78 80 81 80 861 862 864 867 888	299. 70 0. 04 0. 10 0. 15 0. 29 0. 29 0. 42 0. 48 0. 55 0. 74 0. 72 1. 18 1. 20 1. 37 1. 42 1. 79 1. 88 2. 12 2. 14 2. 29 2. 29 2. 29 2. 29 2. 59 2. 65 2. 78	17 613 877 600 425 000 240 762 240 682 210 072 162 149 167 001 152 861 145 260 122 253 113 942 108 573 94 267 97 723 67. 413 66. 520 77. 827 73 020 70. 892 67. 757 68. 474 67. 757 68. 475 67. 757 68. 476 67. 757 68. 476 67. 757 68. 476 67. 757 68. 476 67. 757 67. 158	16 774 725 289 391 240 251 849 198 911 179 512 130 017 120 132 101 118 94 147 89 730 77 989 80 928 72 242 46 545 63 750 64 545 65 757 85 88 56 757 57 998 58 486 53 721 52 197
30 31 32 33 34 25 36 37 39 40 41 42 42 42 43 44 45 46 47 48 49 50 51 52 52 53 53 54	9.32 9.87 12.62 13.03 15.28 16.89 17.73 20.73 21.88 23.90 27.17 29.97 48.96 74.43 92.21 93.21 93.21 138.47 139.61 139.67 149.98	47, 789 45, 712 42, 706 41, 463 38, 033 38, 040 39, 947 34, 784 35, 052 32, 701 32, 114 34, 349 32, 24, 357 25, 505 24, 384 24, 707 23, 270 24, 284 24, 707 23, 770 23, 779 22, 722 23, 779 22, 722 23, 779 22, 722 23, 779	42, 468 40, 631 37, 970 36, 872 35, 525 34, 1811 33, 673 32, 263 31, 812 30, 959 31, 020 27, 824 29, 304 30, 415 24, 487 24, 487 24, 591 21, 577 21, 577 21, 577 21, 577 21, 577 21, 577 21, 479 20, 555 20, 791	64 65 31-5 66 M-89 67 1 21 CP 68 48 69 770 71 773 74 773 77 78 77 78 80 81 80 89 80 80 80 89 80 80 80 80	299.70 0.04 0.10 0.16 0.23 0.29 0.35 0.42 0.48 0.73 0.73 0.73 1.18 1.20 1.37 1.53 1.43 1.79 1.88 2.12 2.14 2.29 2.29 2.39 2.59	17 613 877 600 427 600 304 762 240 682 210 072 162 149 167 001 152 961 145 340 122 353 113 942 113 942 113 942 167 413 86. 154 86. 520 79. 549 75. 287 73 020 70. 872 67. 413 86. 752 67. 413 86. 520 77. 549 75. 287 73. 287 73. 287 74. 45. 65. 65. 65. 65. 65. 65. 65. 65. 65. 6	16 774 725 289 291 240 251 849 911 172 413 150 536 178 291 172 413 150 536 178 291 179 189 28 72 242 71 202 26 545 740 62 221 40 247 58 588 588 598 54 486 53 727 55 998 54 486 53 727 50 782
30 31 32 33 34 35 36 37 39 40 41 42 42 42 44 45 46 47 48 49 50 51 52 53 53 54 55	9.32 9 87 12.62 13.03 15.28 16.89 17.93 20.73 21.87 23.90 27.17 29.16 29.97 48.94 72.31 92.31 93.47 130.67 149.97 130.67 149.43	47, 789 43, 712 42, 706 41, 463 38, 423 36, 630 36, 440 33, 741 24, 764 25, 030 22, 701 20, 114 24, 24, 24, 26, 27, 27, 22, 720 23, 779	42 468 40 631 37 970 36 872 35 525 34 1811 32 673 32 265 31 812 30 999 31 020 27 824 29 304 29 153 24 887 22 591 21 845 20 973 21 845 20 973 21 849 20 785 21 641 20 786 20 784	64 65 31-5 66 14-67 67 1 21 CP 68 48 68 770 770 771 773 74 775 78 80 81 86 87 88 88 89 99 90 91	299.70 0.04 0.10 0.16 0.23 0.29 0.35 0.42 0.48 0.55 0.74 0.93 1.18 1.37 1.52 1.43 1.79 1.88 2.12 2.14 2.29 2.29 2.29 2.45 2.78 2.00 2.56 7.39	17 613 877 600 427 600 304 762 240 682 210 072 162 149 167 001 152 961 143 260 122 353 113 742 108 577 94 367 97 723 67 413 86 154 80 520 79 567 77 567 73 67 728 68 67 75 69 69 69 69 69 69 69 69 69 69 69 69 69 6	16 774 725 209 201 240 201 849 198 911 170 413 150 536 138 017 120 132 101 118 94 147 89 730 77 989 80 928 72 242 46 949 65 740 66 221 60 347 67 789 58 988 94 757 58 988 94 757 98 988
30 31 32 33 34 35 34 37 38 39 40 41 42 42 44 43 44 45 46 47 50 51 52 53 53 54 55 56 57 58 59 60 60 60 60 60 60 60 60 60 60 60 60 60	9.32 9.87 12.62 13.03 15.28 16.89 17.97 20.73 21.88 23.87 23.97 29.16 29.97 48.96 49.21 118.92 118.92 125.49 150.61 158.67 221.40 221.4	47, 789 43, 712 41, 463 40, 143 38, 423 36, 030 34, 440 35, 947 32, 114 32, 243 36, 300 27, 470 23, 328 24, 707 23, 709 24, 707 23, 709 24, 707 22, 702 23, 272 23, 272 23, 272 23, 274 22, 751 22, 751 22, 464	42, 468 40, 631 37, 970 36, 872 35, 525 34, 1811 33, 673 32, 263 31, 812 30, 939 31, 020 27, 824 29, 304 30, 415 29, 132 24, 814 24, 487 21, 579 21, 5	64 65 31-5 66 M-87 67 1 21 CP 67 1 21 CP 70 71 77 77 77 77 78 80 81 80 87 80 87 80 87	299.70 0.04 0.10 0.16 0.23 0.29 0.35 0.42 0.48 0.53 0.73 0.73 0.73 1.30 1.30 1.37 1.53 1.43 1.79 1.88 2.14 2.29 2.14 2.29 2.59 2.59 2.59 2.78 3.00 3.36	17 613 877 600 425 000 240 482 210 072 162 149 167 001 152 363 113 942 108 573 94 367 97 923 67 413 86 154 86 67 79 549 79 529 70 872 68 674 68 674 69 673 69 673 69 674 69 674 6	16 774 725 209 231 240 231 849 198 911 170 413 150 536 138 017 126 331 120 132 101 118 94 147 89 730 77 989 80 928 72 242 77 202 66 543 65 757 66 548 56 757 57 989 56 486 56 757 57 989 56 486 56 757 57 989 56 486 56 757 57 989 56 486 56 757 57 989 56 486 56 757 57 989 57 989 58 486 58 757 59 988 58 757 59 988 59 759 59 988
30 31 32 32 33 35 36 37 39 40 41 42 42 42 42 43 44 44 45 46 47 48 49 30 31 32 33 34 35 36 37 80 80 80 80 80 80 80 80 80 80 80 80 80	9.32 9.87 12.62 13.03 15.28 16.89 17.93 20.73 21.88 23.87 23.97 24.16 29.97 48.94 74.94 19.31 19.34 19.36 19	47 989 49, 712 41, 904 41, 645 40, 143 38, 625 38, 625 38, 626 33, 974 24, 984 24, 984 24, 984 26, 300 27, 23, 114 24, 384 24, 384 24, 384 24, 384 24, 384 24, 384 24, 384 24, 384 24, 384 24, 384 24, 384 24, 751 23, 494 22, 464 22, 464 22, 570	42 468 40 631 37 970 36 872 35 523 34 1811 32 673 32 265 31 812 30 939 31 020 27 824 29 3041 30 413 24 847 22 591 22 591 22 591 22 571 21 579 21 879 21 879	649 31-6 649 11-6 649 11-6 649 11-21 CP 649 64	299.70 0.04 0.10 0.16 0.23 0.29 0.35 0.42 0.48 0.55 0.74 0.93 1.18 1.37 1.52 1.43 1.79 1.88 2.12 2.14 2.29 2.29 2.29 2.45 2.78 2.00 2.56 7.39	17 613 877 600 427 600 304 762 240 682 210 072 162 149 167 001 152 961 143 260 122 353 113 742 108 577 94 367 97 723 67 413 86 154 80 520 79 567 77 567 73 67 728 68 67 75 69 69 69 69 69 69 69 69 69 69 69 69 69 6	16 774 725 289 725 289 721 849 198 911 170 412 150 504 128 017 120 132 101 118 94 147 89 730 77 989 80 928 72 242 46 945 43 740 44 147 88 588 94 757 98 988 94 757 98 988 94 757 98 988 94 757 98 988 94 757 98 988 94 757 98 988 94 757 98 988 94 757 98 988 94 757 98 988 94 757 95 988 94 757 95 988
30 31 32 33 34 35 36 37 39 40 41 42 42 42 43 44 45 46 47 48 50 51 52 53 53 53 53 54 55 57 58 61 61 64 64 64 64 64 64 64 64 64 64 64 64 64	9. 32 9 87 12 62 13. 05 15. 28 16. 89 17 93 20. 73 21 88 23. 87 23. 97 24. 16 29. 97 48. 96 74. 43 92. 31 93. 49 130. 81 159. 67 149. 98 171. 67 221. 63 221. 63 222. 64 277. 16 221. 63 222. 64 277. 16	47 989 45. 712 42. 906 41. 663 40. 143 38. 623 36. 630 35. 944 23. 974 24. 984 24. 394 26. 300 27. 300 27. 320 24. 384 24. 384 24. 394 22. 702 23. 779 22. 379	42, 468 40, 631 37, 970 36, 872 35, 525 34, 1811 32, 673 32, 265 31, 812 30, 939 31, 020 27, 824 29, 304 30, 413 24, 814 24, 867 22, 591 21, 579 21, 8	64 65 31-5 66 121 CP 67 121 CP 67 77 77 77 77 77 77 77 77 77 77	299.70 0.04 0.10 0.16 0.23 0.29 0.35 0.42 0.48 0.55 0.72 0.72 1.37 1.37 1.37 1.37 1.39 2.14 2.29 2.14 2.29 2.39 2.59 2.45 2.78 2.65 2.78	17 613 877 600 425 000 240 762 240 682 210 072 162 149 167 001 152 861 152 350 113 742 108 373 74 367 77 723 84 154 80 520 77 549 75 287 73 020 76 41 162 63 198 65 173 65 198 65 198 66 198 67 198 67 198 67 198 68 198 69	16 774 725 289 291 240 251 849 198 911 170 413 150 536 138 017 120 132 101 118 94 147 89 730 77 989 80 928 72 242 46 945 46 740 62 221 60 347 58 988 94 757 98 988 94 757 98 988 94 757 98 988 94 757 98 988 94 757 98 988 94 757 98 988 94 757 98 988 94 757 98 988 94 757 98 988 94 757 98 988 94 757 98 988 94 757 98 988 94 757 98 988 94 757 95 988
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113	126. 33	19.405	16.103				
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115	159 33		15 693	17	1 89	58.639	55 847
116	176 13				2 07	55 876	53 215
117	185 82 207 99	18.676	15 451 15 705		2.13	57. 347	54 616
110		19 003			2 32	53 764	51, 204
119 120	212. 22 238. 62	19.490 18.293	15 281		2 39	53.900	51 333
121	239. 76		15 450	23	2.51	51 915	49 443
122	264 93		15 007	24	2 70	50 216	47 825
120	271.59		15 259	25	2 72	49 972	47 592
124	299.70		14 994		2 92	47. 995	45 710
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O sample, hct.	i shear rate	2 viscosity	3 relative	20	3.56	43 047	41 014
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2 H=85	0.11	332 065	317 525	32	10 56	28 457	27 102
3 1.05 cP	0 17	236 379	225 123	23	12.48	26.870	25 590
4	0. 24	197 089	187.704		12.64	27. 051	25. 763
5	0. 30	100 071	180 087		15.03	25. 389	24 180
6	0. 36	149 630	142 505 128 698	36	15 29	25.443	24 231
7	0. 43	135, 133	128 698	37	16 95	24, 504	23 337
•	0. 55	121 038	115. 274 97. 686	(38	17.93	25, 443 24, 504 24, 206 23, 358 23, 319	23 053
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52 53 54 55 56 57 59 60 61 62 62 64 64	29 97 42.03 73.80 112.02 126.24 143.88 159.19 182.07 198.84 225.21 245.70 251.73 270.81 271.53 298.05	22.462 22.091 19.694 18.299 18.278 17.379 17.670 16.769 16.769 16.769 16.208 16.208 16.209 16.195 16.1019	22 954 21 039 18 718 17 370 17 408 16 367 16 800 16 136 16 273 15 763 15 763 15 579 15 379 15 436 15 414 15 368 15 256	11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26	9 74 9 92 1 12 1 17 1 45 1 51 1 78 1 82 2 08 2 11 2 28 2 29 2 50 2 84 3 09 4 85 7 40	89, 774 82 861 74, 576 77, 824 70, 481 45, 644 43, 312 40, 273 54, 458 57, 777 54, 309 30, 584 54, 238 49, 335 48, 038 36, 622 30, 998 27, 884	77 819 73 367 69 223 63 288 64 326 58 249 54 231 52 224 49 829 44 8825 47 750 44 683 41 805 44 841 42 750 40 773 29 701 30 267 23 628
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92 93 94 95 96 97 98 99 60 61 62 63 64 65 9 ample, hct. plama visc.	29 97 42 03 73 80 73 19 112 02 124 24 143 88 159 19 182 07 198 84 213 84 225 21 245 70 251 73 270 61 271 53 298 05 1 shear rate (1/sec)	22.402 22.091 19.694 18.209 18.278 17.395 17.697 16.769 16.769 16.398 16.208 16.208 16.136 16.019 2 viscessky (cP)	22 354 21 037 18 718 17 370 17 408 16 367 16 800 16 136 16 273 15 767 15 767 15 770 15 750 15 436 15 236 15 236 15 236 15 236 15 236 15 236 15 236 15 236 15 236 15 236	11 12 13 14 15 16 17 18 20 21 22 23 24 25 26 27 28 29	0 74 0 92 0 93 1 12 1 19 1 45 1 51 1 78 1 82 2 08 2 11 2 29 2 31 2 32 2 33 2 84 3 00 4 85 7 95 9 97 1 1 94	89. 774 82 861 74. 378 77. 824 70. 481 45. 644 43. 312 40. 293 36. 458 57. 777 54. 209 90. 594 54. 238 49. 335 48. 038 26. 622 30. 998 27. 864 28. 207 24. 498	77 819 73 367 69 223 63 289 64 226 58 249 54 251 52 224 49 825 47 730 44 883 41 805 44 881 42 730 40 773 29 701 20 267 23 308 23 308 21 891
92 93 94 95 96 97 96 60 61 62 62 63 64 65 9 sample, hct. plasse visc. 1 29-10 2 Hegg	29 97 42 03 73 80 73 18 112 02 124 24 143 88 139 18 182 07 198 84 213 84 225 21 245 70 251 73 270 81 271 33 298 05 1 shear rate (1/sec) 0 03	22. 462 22. 091 19. 404 18. 209 19. 278 17. 375 17. 440 16. 765 16. 351 16. 765 16. 238 16. 295 16. 104 208 16. 107 2 viscessty (cP) 731 532 222 981	22 954 21 039 18 718 17 370 17 408 16 367 16 800 16 134 15 763 15 767 15 579 15 750 15 414 15 368 15 256 3 relative viscosity 476 407	11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 20	9 74 0 92 1 12 1 17 1 45 1 92 2 08 2 11 2 27 2 38 2 32 2 84 3 00 4 85 7 40 9 97 11 98	89. 774 82 861 74. 578 77. 824 70. 481 45. 644 43. 312 40. 273 54. 658 57. 777 54. 209 30. 584 94. 238 91. 728 49. 335 48. 038 27. 844 28. 207 24. 488 25. 752	77 819 73 367 69 323 63 288 64 326 58 249 54 251 52 324 49 829 44 8825 47 730 44 841 42 730 40 773 34 701 30 267 23 618 23 308 21 891 21 293
92 93 93 94 95 96 97 98 99 60 61 62 62 63 64 63 9 sample, hct. plasse visc. 1 27-10 2 H-83 3 1.09 cP	29 97 42.03 73.80 73.19 112.02 124.24 143.88 159.18 182.07 198.84 213.84 225.21 245.70 251.73 270.81 271.53 298.05 1 shear rate (1/sec) 0.03 0.10	22. 462 22. 091 19. 624 18. 209 19. 278 17. 395 17. 640 16. 763 16. 259 16. 259 16. 208 16. 208 16. 205 16. 205 16. 205 16. 205 16. 205 16. 205 16. 205 16. 205 201 201 201 201 202 202 202 202 202 202	22 954 21 039 18 718 17 370 17 408 14 367 14 800 24 134 15 762 15 762 15 763 15 763 15 753 15 368 15 368 15 368 15 368 17 368 17 368 18 37 368 18 37 368 18 37 368 18 37 368 18 37 368 18 38 38 38 38 38 38 38 38 38 38 38 38 38	11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 20 31	9 74 9 72 9 72 1 12 1 17 1 45 1 51 1 78 1 82 2 08 2 11 2 27 2 31 2 38 2 53 2 84 3 00 4 85 7 7 80 9 97 11 94 12 50 14 40	99. 774 92 981 74. 578 77. 924 70. 481 45. 644 43. 312 40. 293 54. 439 57. 777 54. 309 90. 384 91. 238 49. 335 48. 038 36. 429 27. 844 28. 207 24. 488 25. 752 24. 441	77 819 73 367 69 323 63 288 64 326 58 249 54 251 52 324 49 829 44 823 47 730 44 881 42 730 40 771 30 267 23 618 23 028 23 308 21 891 21 283 20 364
92 93 94 95 96 97 90 60 61 62 23 64 63 9 sample, hct. plasma visc. 1 29-10 2 H=83 3 1.00 cP	29 97 42 03 73 80 73 19 112 02 126 24 143 88 157 19 182 07 198 84 225 21 245 70 251 73 270 81 271 33 278 05 1 shear rate (1/sec)	22.462 22.091 19.694 18.209 18.278 17.395 17.640 14.765 16.208 16.208 16.208 16.019 2 Viscessty (cp) 731.532 322.981 227.288 175.368	22 554 21 037 18 718 17 370 17 408 16 367 16 800 16 135 16 273 15 763 15 763 15 436 15 368 15 368 16 368 17 368 18	11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 29 20 21 22 23 24 25 26 27 28 29 20 21 20 21 22 23 24 25 26 27 28 29 20 20 20 20 20 20 20 20 20 20 20 20 20	0 74 0 92 0 93 1 12 1 19 1 45 1 51 1 78 1 82 2 08 2 11 2 27 2 31 2 28 2 32 2 84 3 00 4 85 7 40 9 9 97 11 94 12 50 14 40	89, 774 82 861 74, 576 77, 824 70, 481 45, 644 43, 312 40, 293 54, 458 57, 777 54, 309 30, 584 54, 258 49, 335 48, 036 26, 422 30, 998 27, 884 28, 207 24, 448 25, 752 24, 641 24, 329	77 819 73 367 69 223 63 288 64 326 58 249 54 251 52 224 49 829 44 8825 47 750 44 8841 42 750 40 773 29 701 20 267 23 108 23 268 23 108 21 891 21 283 20 364 20 107
92 93 94 95 96 97 98 99 60 61 62 62 63 64 69 90 91 91 91 91 91 91 91 91 91 91	29 97 42 03 73 80 73 19 112 02 124 24 143 88 137 18 182 07 198 84 213 84 225 21 245 70 251 73 270 81 271 53 298 05 1 shear rate (1/sec) 0 03 0 16 0 22 0 29	22. 462 22. 091 19. 404 18. 209 18. 278 17. 375 17. 440 16. 743 17. 087 16. 258 16. 258 16. 238 16. 208 16. 208 16. 208 16. 208 16. 208 20. 208 22. 22. 281 227 288 175 288 175 288 175 288	22 554 21 037 18 718 17 370 17 408 16 367 16 800 26 136 16 273 15 763 15 767 15 579 15 750 15 368 15 368 15 256 3 reletive viscosity 207 601 218 350 167 017	11 12 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 20 21 22 23 24 25 26 27 28 29 20 21 22 23 24 25 26 27 28 29 20 20 21 20 20 20 20 20 20 20 20 20 20 20 20 20	9 74 0 92 0 93 1 12 1 17 1 45 1 178 1 82 2 08 2 11 2 27 2 38 2 53 3 00 4 40 7 95 9 97 11 94 12 50 14 40 15 05 17 24	98. 774 92 981 74. 578 77. 924 70. 481 45. 644 43. 312 40. 293 54. 438 57. 777 54. 209 90. 584 94. 238 91. 728 49. 233 48. 038 27. 844 28. 220 24. 448 25. 732 24. 441 24. 329 23. 309	77 819 73 367 69 223 63 288 64 226 58 249 54 231 52 224 49 829 44 8825 47 730 44 683 41 803 44 841 42 750 40 773 29 701 20 267 23 618 23 028 23 308 21 991 21 283 20 364 20 1364 20 1364
92 93 94 95 96 97 98 99 60 61 62 63 64 65 91 91 91 91 91 91 91 91 91 91	29 97 42.03 73.80 73.19 112.02 124.24 143.88 159.19 182.07 198.84 223.21 245.70 251.73 270.61 271.53 270.60 1 shear rate (1/sec) 0.03 0.10 0.10 0.10 0.22 0.29 0.39	22. 402 22. 091 19. 634 18. 209 18. 278 17. 375 17. 640 18. 765 16. 765 16. 558 16. 538 16. 209 16. 126 22. 181 22. 182 22. 781 22. 781 22. 788 16. 209 16. 175 26. 152 27. 288 175 288 16. 290 144 103	22 554 21. 039 18. 718 17. 370 17. 408 16. 367 16. 800 16. 136 16. 273 15. 763 15. 763 15. 763 15. 763 15. 763 15. 368 15. 268 15. 268 27. 267 28. 267 29. 267	11 12 13 14 15 16 17 18 20 21 22 23 24 25 26 27 28 29 20 21 23 24 25 26 27 28 29 20 21 21 22 23 24 25 26 27 28 29 20 21 20 21 20 21 21 22 23 24 25 26 27 27 28 29 20 20 21 20 20 20 20 20 20 20 20 20 20 20 20 20	0 74 0 92 0 93 1 12 1 19 1 45 1 51 1 78 1 82 2 20 2 11 2 28 2 31 2 32 2 33 2 84 3 00 4 85 7 95 9 97 11 94 12 50 14 40 15 50	89, 774 82 861 74, 376 77, 924 70, 481 45, 644 43, 312 40, 293 54, 458 57, 777 54, 309 30, 394 54, 238 49, 335 48, 038 36, 623 30, 998 27, 864 28, 207 24, 488 25, 752 24, 499 23, 309 23, 252	77 819 73 367 69 223 63 288 64 326 58 249 54 251 52 224 49 829 44 825 47 730 44 881 41 805 44 881 42 730 40 773 29 701 20 267 23 618 23 2028 23 308 21 891 21 289 20 107 19 244 20 107
92 93 94 95 96 97 98 99 60 61 62 63 64 65 9 ample, hct. plame visc. 1 29-10 2 H=83 3 1 09 cP 4	29 97 42 03 73 80 73 18 112 02 124 24 143 88 159 18 162 07 198 84 213 84 225 21 245 70 251 73 270 81 271 33 298 03 1 shear rate (1/sec) 0 03 0 16 0 22 0 29 0 35	22. 462 22. 091 19. 404 18. 209 19. 278 17. 373 17. 640 16. 763 17. 087 16. 763 16. 763 16. 208 16. 208 16. 209 16. 104 20 (cP) 731 532 222 981 227 248 175 368 175 268 175 260 144 100 127 220	22 554 21 037 18 718 17 370 17 408 16 367 16 800 16 135 15 763 15 763 15 770 15 436 15 368 15 368 15 368 15 368 15 368 15 368 15 368 15 368 15 368 15 368 17 368 18	11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 20 21 22 23 24 25 26 27 28 29 20 21 20 21 22 23 24 25 26 27 28 29 20 21 20 21 20 21 20 21 20 21 20 21 20 21 20 21 20 21 20 21 20 21 21 21 21 21 21 21 21 21 21 21 21 21	9 74 0 92 1 12 1 17 1 45 1 92 2 08 2 11 2 27 2 32 2 84 3 00 4 85 7 40 9 97 11 2 50 14 40 15 05 17 24 17 59 19 21	98. 774 92 981 74. 578 77. 924 70. 481 45. 644 43. 312 40. 293 54. 458 57. 777 54. 309 90. 594 94. 238 91. 728 49. 335 48. 038 27. 844 28. 207 24. 448 24. 29 23. 309 23. 252 24. 641 24. 229 23. 309 23. 252 24. 541	77 819 73 367 69 223 63 288 64 326 58 249 54 251 52 224 49 829 44 825 47 750 44 841 42 750 40 773 39 701 30 267 23 618 23 028 21 891 21 893 20 364 20 107 19 244 19 217 18 607
92 93 94 95 96 97 90 60 61 62 63 64 65 0 sample, hct. plasse visc. 1 29-10 2 H=83 3 1.00 cP 4	29 97 42.03 73.80 73.19 112.02 124.24 143.88 159.18 182.07 198.84 213.84 225.21 245.70 251.73 270.81 271.53 298.05 1 shear rate (1/sec) 0.03 0.10 0.02 0.22 0.29 0.35	22. 462 22. 091 19. 624 18. 209 18. 278 17. 395 17. 640 16. 763 17. 087 16. 258 16. 258 16. 238 16. 208 16. 295 16. 134 16. 017 2 viscessty (cp) 731 532 322 781 227 228 175 368 175 368 175 368 175 368 175 368 175 368 175 368 176 290 177 220 101 535	22 554 21.039 18.718 17.370 17.408 14.567 14.800 24.134 15.763 16.763 17.763 17.763 17.763 17.763 17.764	11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 32 33 34 35 36 37 38	0 74 0 92 0 93 1 12 1 19 1 45 1 51 1 78 1 82 2 20 2 11 2 28 2 31 2 32 2 33 2 84 3 00 4 85 7 95 9 97 11 94 12 50 14 40 15 50	99, 774 92 981 74, 578 77, 824 70, 481 45, 644 43, 312 40, 293 54, 458 57, 777 54, 209 51, 728 49, 238 49, 238 49, 238 49, 238 48, 249 27, 844 28, 207 24, 489 23, 724 24, 229 23, 209 23, 252 24, 41 24, 229 23, 209 23, 252 24, 22, 214 22, 201	77 819 73 367 69 323 63 289 64 326 58 249 54 251 52 324 49 829 44 823 47 750 44 783 41 805 44 770 30 267 30 267 31 891 21 293 20 384 20 107 19 244 19 217 18 607
92 93 94 95 96 97 98 99 60 61 62 63 64 65 9 ample, hct. plame visc. 1 29-10 2 H=83 3 1 09 cP 4	29 97 42.03 73.80 73.19 112.02 124.24 143.88 159.19 182.07 198.84 223.21 245.70 251.73 270.83 270.83 271.53 270.80 1 shear rate (1/sec) 0.03 0.10 0.16 0.22 0.29 0.29 0.29 0.42 0.61	22. 402 22. 091 19. 694 18. 209 18. 278 17. 349 17. 449 17. 087 16. 551 16. 765 16. 358 16. 538 16. 208 16. 107 2 viscessky (cP) 731 532 322 981 227 268 156 230 144 103 127 200 101 533 89, 755	22 554 21. 039 18. 718 17. 370 17. 408 16. 567 16. 800 16. 130 16. 273 15. 763 15. 763 15. 763 15. 376 16. 377 17. 376	11 12 13 14 15 16 18 20 21 22 23 24 25 26 27 28 29 29 20 31 32 30 31 32 33 34 35 36 37 38 39 40	9 74 9 72 9 1 12 1 17 1 45 1 51 1 78 1 82 2 08 2 11 2 29 2 31 2 39 2 39 2 39 3 30 4 85 7 7 11 94 12 30 14 40 15 05 17 24 17 59 19 21 2 39	89. 774 82 861 74. 578 77. 824 70. 481 45. 644 43. 312 40. 293 54. 458 57. 777 54. 309 30. 594 54. 238 49. 335 48. 038 26. 422 30. 998 27. 884 28. 207 24. 441 24. 229 23. 309 23. 252 24. 641 24. 229 23. 309 23. 252 24. 641 24. 229 23. 309 23. 252 24. 641 24. 229 23. 309 23. 252 24. 641 24. 229 23. 309 23. 252 24. 641 24. 229 23. 309 23. 252 24. 641 24. 229 23. 309 23. 252 24. 641 24. 2301 24. 879	77 819 73 367 69 223 63 288 64 326 58 249 54 251 52 324 49 829 44 8825 47 730 44 881 41 805 44 841 42 750 40 773 29 701 30 267 23 108 23 208 21 891 21 283 20 364 49 121 18 607 18 607 18 607
92 93 94 95 96 97 90 60 61 62 63 64 63 9 sample, hct. plassa visc. 1 29-10 2 H=83 3 1.09 cP 4	29 97 42 03 73 80 73 19 112 02 124 24 143 88 137 18 182 07 198 84 213 84 225 21 245 70 251 73 270 81 271 53 278 03 1 shear rate (1/sec) 0 03 0 16 0 22 0 29 0 35 0 41 0 80 0 73	22. 462 22. 091 19. 204 18. 207 18. 278 17. 395 17. 440 16. 743 17. 087 16. 753 16. 258 16. 208 16. 208 16. 208 16. 208 16. 208 16. 208 16. 208 16. 208 16. 208 17. 322 222 728 175 208	22 554 21 039 21 039 18 718 17 370 17 408 16 567 16 800 26 136 16 273 15 763 15 767 15 579 15 750 15 368 15 256 3 relative viscosity 48 16 370 216 350 167 017 148 810 137 241 11 162 76 700 85 481 82 912	11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 37 38 39 40 41	0 74 0 92 0 93 1 12 1 19 1 45 1 51 1 78 1 82 2 82 2 11 2 29 2 31 2 32 2 84 3 3 3 2 84 3 6 3 7 40 9 9 7 11 94 12 50 14 40 13 05 17 24 17 24 17 24 17 24 17 24 18 20 22 24 23 22 48 23 23 24 24 25 26 25 26 26 26 26 26 26 26 26 26 26 26 26 26	98. 774 92 981 74. 578 77. 924 70. 481 45. 644 43. 312 40. 293 54. 438 57. 777 54. 209 90. 584 94. 238 51. 728 49. 233 48. 038 27. 844 28. 207 24. 488 25. 732 24. 641 24. 329 23. 309 23. 252 24. 261 24. 27 25. 27 26. 27 27 28. 488 29. 732 24. 641 24. 329 23. 309 23. 252 24. 641 24. 329 23. 309 23. 252 24. 641 24. 329 23. 309 23. 252 24. 641 24. 329 23. 309 23. 352 24. 348 25. 732 26. 352 27. 314 27. 301 27. 301	77 819 73 367 69 223 63 288 64 326 58 249 54 231 49 829 44 8825 47 730 44 881 41 803 44 841 42 730 40 773 39 701 30 267 23 618 23 028 21 891 21 293 20 364 20 107 18 401 18 607 18 401 18 002 17 799
92 93 94 95 96 97 98 99 60 61 62 63 64 65 90 91 64 65 91 66 61 62 63 64 65 91 66 61 62 63 64 65 91 66 67 68 68 68 68 68 68 68 68 68 68	29 97 42,03 73,80 73,18 112,02 124,24 143,88 159,18 182,07 198,84 213,84 225,21 245,70 251,73 270,81 271,53 270,81 270,81 271,53 270,81 271,53 270,81 271,53	22. 462 22. 091 19. 694 18. 209 18. 278 17. 379 17. 640 16. 769 16. 591 16. 769 16. 598 16. 208 16. 209 2 viscessty (cP) 731 532 322 781 227 288 179 268 179 268 179 279 14103 1527 220 101 535 87. 755 87. 755 87. 757	22 554 21. 039 18. 718 17. 370 17. 408 16. 367 16. 900 16. 273 15. 762 15. 763 15. 763 15. 763 15. 763 15. 368 15. 253 3 relative viscosity 696. 697 207. 601 218. 250 167. 168. 910 137. 241 121. 162 96. 700 95. 481 82. 712 77. 111	11 12 13 14 15 16 17 18 20 21 22 23 24 25 26 27 28 29 20 31 32 32 32 33 34 35 36 37 38 39 40 41 42	9 74 0 92 1 12 1 17 1 45 1 92 2 08 2 11 2 27 2 28 2 20 2 84 3 00 4 85 7 40 9 97 11 98 12 20 14 40 15 05 17 24 17 32 18 40 17 52 18 40 19 52 19 68 2 11 2 28 2 29 2 84 3 00 4 12 20 1 2 20 1 2 20 1 2 20 2 2 20 2 2 20 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	89. 774 82 861 74. 578 77. 824 70. 481 45. 644 43. 312 40. 293 54. 458 57. 777 54. 309 30. 594 54. 238 49. 335 48. 038 26. 422 30. 998 27. 884 28. 207 24. 441 24. 229 23. 309 23. 252 24. 641 24. 229 23. 309 23. 252 24. 641 24. 229 23. 309 23. 252 24. 641 24. 229 23. 309 23. 252 24. 641 24. 229 23. 309 23. 252 24. 641 24. 229 23. 309 23. 252 24. 641 24. 229 23. 309 23. 252 24. 641 24. 2301 24. 879	77 819 73 367 69 223 63 289 64 326 58 249 54 257 52 224 49 829 44 825 47 730 44 683 44 863 44 863 44 87 730 40 773 29 703 20 267 23 308 21 991 21 293 20 328 23 308 21 991 21 293 20 107 19 244 19 217 18 607 18 401 18 082 17 799 17 619
92 93 93 94 95 96 97 96 60 61 62 63 63 63 64 65 9 sample, hct. plaine visc. 1 29-10 2 H=83 3 1.00 cP 4 9 10 -2 11 -2	29 97 42 03 73 80 73 18 112 02 124 24 143 88 159 18 162 07 198 84 213 84 225 21 245 70 251 73 270 81 271 33 298 03 1 shear rate (1/sec) 0 03 0 10 0 16 0 22 0 29 0 35 0 41 0 80 0 73 0 97 1 18	22. 462 22. 091 19. 2091 19. 2091 19. 278 17. 379 17. 440 16. 743 17. 081 16. 763 16. 238 16. 238 16. 238 16. 298 16. 375 16. 136 16. 375 16. 137 2 Viscessty (cp) 731 532 222 981 227 248 179 258	22 554 21 037 21 037 18 718 17 370 17 408 16 367 16 800 26 136 16 273 15 763 15 763 15 763 15 757 15 759 15 750 15 3614 15 368 15 368 3 Teletive viscosity 207 401 218 350 147 017 148 810 137 241 121 162 76 700 99 481 82 712 77 111 70 087	11 12 13 14 15 16 17 18 20 21 22 23 24 25 26 27 28 29 20 21 22 28 29 20 21 23 24 25 26 27 28 29 20 21 20 21 22 23 24 25 26 27 28 29 20 21 20 21 20 21 20 21 20 21 20 21 20 21 20 20 20 20 20 20 20 20 20 20 20 20 20	0 74 0 92 1 12 1 19 1 45 1 51 1 78 1 82 2 08 2 11 2 28 2 21 2 30 4 85 7 95 9 97 11 94 12 50 14 40 15 05 17 29 19 21 20 14 21 20 22 68 22 18 22 60 22 18 22 60 22 18	89, 774 82 881 74, 378 77, 384 45, 644 45, 644 46, 293 56, 458 57, 777 54, 309 30, 394 54, 238 49, 335 48, 038 36, 623 30, 984 28, 207 24, 488 25, 752 24, 444 28, 207 24, 488 27, 844 28, 207 24, 488 27, 844 28, 207 24, 488 27, 844 28, 207 24, 488 27, 844 28, 207 24, 488 29, 752 24, 488 29, 752 24, 488 29, 752 24, 287 21, 287 21, 287 21, 287 21, 217	77 819 73 367 69 223 63 288 64 326 58 249 54 251 52 224 49 825 47 750 44 881 41 805 44 841 42 750 40 773 29 701 30 267 23 618 23 028 23 108 21 991 21 293 20 164 19 217 16 407 16 401 18 002 17 799 17 419 17 421
92 93 94 95 96 97 99 60 61 62 63 64 63 9 sample, hct. plasma visc. 1 29-10 2 H=83 3 1.00 cP 4 3 6.7 7 - 7 8 - 7 11 Y 12 2 13 - 7 14 3 14 3	29 97 42.03 73.80 73.19 112.02 124.24 143.88 159.18 182.07 198.84 213.84 225.21 245.70 251.73 270.81 271.53 298.05 1 shear rate (1/kec) 0.03 0.10 0.22 0.29 0.35 0.42 0.61 0.80 0.99 1.18	22. 462 22. 091 19. 694 18. 209 18. 278 17. 395 17. 640 18. 763 17. 087 18. 763 16. 258 16. 258 16. 258 16. 258 16. 278 178 178 178 178 178 178 178 178 178 1	22 554 21.039 18.718 17.370 17.408 14.56 14.56 14.56 15.76 16.76 17.16	11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 32 33 34 35 36 37 38 39 40 41 42 42 43	9 74 9 72 1 12 1 17 1 45 1 51 1 78 1 82 2 08 2 11 2 28 2 31 2 28 2 30 2 84 3 00 4 85 7 40 9 9 7 11 94 12 50 14 60 15 05 17 24 17 21 20 22 48 21 20 22 46 23 46 24 60 25 51	89. 774 82 861 74. 578 77. 824 70. 481 45. 644 43. 312 40. 293 54. 458 57. 777 54. 309 30. 584 54. 238 51. 728 49. 335 48. 038 27. 884 28. 207 26. 489 25. 752 24. 641 24. 229 23. 309 23. 252 24. 641 24. 229 23. 309 23. 252 24. 641 24. 229 23. 309 23. 252 24. 641 24. 229 23. 309 23. 252 24. 641 24. 229 23. 309 23. 252 24. 641 24. 229 23. 309 23. 252 24. 531 24. 337 21. 337 21. 337 21. 337	77 819 73 367 69 223 63 289 64 326 58 249 54 257 52 224 49 829 44 825 47 730 44 683 44 863 44 863 44 87 730 40 773 29 703 20 267 23 308 21 991 21 293 20 328 23 308 21 991 21 293 20 107 19 244 19 217 18 607 18 401 18 082 17 799 17 619
92 93 93 94 95 96 97 96 60 61 62 62 63 64 65 9 sample, hct. plasme visc. 1 29-10 2 H-83 3 1 09 cP 4 9 7 7 7 10 7 11 V 12 2 13 1 14 1 15 1 16 2 17 1 18 2 19 3 10 5 10 5 1	29 97 42.03 73.80 73.19 112.02 124.24 143.88 159.19 182.07 198.64 213.84 225.21 245.70 251.73 270.81 271.53 270.81 271.53 270.81 271.53 270.81 270.81 271.53 270.81	22. 402 22. 091 19. 694 18. 209 18. 278 17. 349 17. 640 18. 769 16. 769 16. 769 16. 358 16. 538 16. 538 16. 309 16. 136 18. 019 2 Viscessity (cP) 731 532 322 991 27 268 179 368 179 368 179 368 179 368 179 368 179 379 144 103 127 220 101 539 87. 739 87. 739 87. 739 87. 739 74. 727 77. 547 77.	22 554 21. 039 18. 718 17. 370 17. 408 16. 567 16. 800 16. 130 16. 273 15. 763 15. 763 15. 763 15. 376 15. 368 15. 256 3 relative viscosity 218. 290 167. 017 148. 810 137. 401 121. 162 96. 700 95. 481 82. 912 77. 111 70. 089 71. 169 44. 030	11 12 13 14 15 16 17 18 20 21 22 23 24 25 26 27 28 29 20 31 32 30 31 32 33 34 35 36 37 38 39 40 41 42 42 43 44 44 44	9 74 9 72 9 1 12 1 17 1 45 1 51 1 78 1 82 2 08 2 11 2 20 2 31 2 32 2 31 2 32 2 34 3 07 7 95 9 97 11 94 12 30 14 40 15 05 17 24 17 29 19 21 20 22 21 22 22 31 23 34 31 31 24 35 25 37 26 37 27 31 28 4 37 4 37 5 37 5 38 4 38 5 38 4 39 5 48 5 79 5 99 7 11 78 8 12 30 14 40 15 05 17 24 21 20 22 46 22 18 22 18 22 18 22 18 23 18 24 18 25 18 26 26 27 27 81 28 4 29 18 5 20 18 5 20 18 5 20 18 5 20 18 5 21 7 8 22 18 5 23 18 5 24 18 5 25 16 26 5 26 5 27 81	89. 774 82 861 74. 378 77. 824 70. 481 45. 644 43. 312 40. 293 56. 458 57. 777 54. 209 90. 584 91. 228 49. 335 48. 038 26. 623 30. 984 28. 203 24. 488 25. 752 24. 441 24. 329 23. 329 24. 248 27. 252 28. 491 28. 317 29. 328	77 819 73 367 69 323 63 289 64 326 58 249 54 251 52 324 49 823 47 750 44 883 41 805 44 883 47 770 30 267 23 618 23 028 23 108 21 293 20 167 19 244 20 107 18 407 18 407 18 407 18 607 18 407 18 607 18 607 18 607 18 607 19 217
92 93 94 95 96 97 99 60 61 62 63 64 63 9 sample, hct. plasma visc. 1 29-10 2 H=83 3 1.00 cP 4 3 6.7 7 - 7 8 - 7 11 Y 12 2 13 - 7 14 3 14 3	29 97 42.03 73.80 73.19 112.02 124.24 143.88 139.18 182.07 198.84 213.84 225.21 245.70 251.73 270.81 271.53 278.03 1 shear rate (1/sec) 0.03 0.16 0.22 0.41 0.80 0.29 0.25 0.41 0.80 0.73 0.93 0.93 0.93 0.93 1.40	22. 462 22. 091 19. 209 19. 209 19. 278 17. 393 17. 440 16. 743 17. 091 16. 763 16. 238 16. 238 16. 238 16. 238 16. 238 16. 238 16. 238 16. 238 16. 238 16. 238 17. 322 222 7238 173 288 173 288 173 288 173 288 173 288 173 287 274 723 274 727 275 292 274 727 275 292 274 727 275 292 274 727 275 292 275 292 276 723 276 772 276 723 265 776	22 554 21. 039 18. 718 17. 718 17. 708 14. 567 14. 800 24. 134 15. 763 15. 763 15. 763 15. 763 15. 763 15. 763 15. 368 16. 368	11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 20 31 32 30 31 32 32 30 31 32 32 32 32 32 32 32 32 32 32 32 32 32	9 74 9 72 9 1 12 1 19 1 45 1 51 1 78 1 82 2 08 2 11 2 29 2 31 2 38 2 53 2 84 3 3 00 4 85 7 40 9 7 95 9 97 11 94 12 50 14 40 13 05 17 24 21 20 22 48 23 18 24 60 25 16 24 51 27 81	89. 774 82 861 74. 578 77. 824 77. 481 45. 644 43. 312 40. 293 54. 458 57. 777 54. 209 30. 594 54. 238 49. 335 48. 038 36. 623 30. 998 27. 884 28. 203 24. 461 24. 229 23. 252 24. 641 24. 229 23. 252 24. 641 24. 229 23. 252 24. 641 24. 219 23. 201 21. 879 21. 337 21. 317 21. 317 21. 079 20. 6462	77 819 73 367 69 223 63 288 64 326 58 249 54 252 23 24 49 829 44 8825 47 750 44 8841 42 750 40 773 29 701 20 267 23 618 23 308 21 891 21 283 20 364 49 19 217 18 607 18 401 18 082 17, 799 17 619 17 421 17 212 17 704
92 93 93 94 95 96 97 96 60 61 62 62 63 64 65 9 sample, hct. plasme visc. 1 29-10 2 H-83 3 1 09 cP 4 9 7 7 7 10 7 11 V 12 2 13 1 14 1 15 1 16 2 17 1 18 2 19 3 10 5 10 5 1	29 97 42.03 73.80 73.19 112.02 124.24 143.88 159.19 182.07 198.64 213.84 225.21 245.70 251.73 270.81 271.53 270.81 271.53 270.81 271.53 270.81 270.81 271.53 270.81	22. 402 22. 091 19. 694 18. 209 18. 278 17. 349 17. 640 18. 769 16. 769 16. 769 16. 358 16. 538 16. 538 16. 309 16. 136 18. 019 2 Viscessity (cP) 731 532 322 991 27 268 179 368 179 368 179 368 179 368 179 368 179 379 144 103 127 220 101 539 87. 739 87. 739 87. 739 87. 739 74. 727 77. 547 77.	22 554 21. 039 18. 718 17. 370 17. 408 16. 567 16. 800 16. 130 16. 273 15. 763 15. 763 15. 763 15. 376 15. 368 15. 256 3 relative viscosity 218. 290 167. 017 148. 810 137. 401 121. 162 96. 700 95. 481 82. 912 77. 111 70. 089 71. 169 44. 030	11 12 13 14 15 16 17 18 20 21 22 23 24 25 26 27 28 29 30 31 32 32 32 33 34 35 36 37 38 39 40 41 42 43 44 44 45 46 47	9 74 0 92 1 12 1 17 1 45 1 91 1 82 2 08 2 11 2 27 2 38 2 39 2 84 3 00 4 7 9 9 9 7 11 90 14 40 15 05 17 24 17 59 19 21 20 14 21 26 22 46 23 46 23 46 24 56 25 16 26 86 27 81 27 81 27 82 28 86 29 86 20 14 21 22 86 22 46 23 66 24 60 25 16 26 86 27 81 27 81 27 82 28 80	89. 774 82 881 74. 578 77. 824 70. 481 45. 644 43. 312 40. 293 54. 458 57. 777 54. 309 80. 394 94. 298 81. 728 49. 335 48. 038 27. 844 28. 207 24. 441 24. 229 23. 309 23. 252 24. 541 24. 229 23. 309 24. 281 24. 291 25. 27 26. 282 26. 314 27. 317 21. 317	77 819 73 367 69 323 63 289 64 326 58 249 54 251 52 324 49 829 44 825 47 730 44 881 42 750 40 773 39 701 30 267 23 618 23 028 23 308 21 891 21 284 20 107 19 264 19 217 18 607 18 607 18 607 18 607 18 607 18 783 18 082 17 799 17 421 17 776 16 783 16 783
92 93 94 95 96 97 90 60 61 62 63 64 65 9 sample, hct. Plasme visc. 1 29-10 2 H=80 3 1 05 cP 4 9 9 10 5 10 5 1	29 97 42.03 73.80 73.19 112.02 124.24 143.88 139.18 182.07 198.84 213.84 225.21 245.70 251.73 270.81 271.53 278.03 1 shear rate (1/sec) 0.03 0.16 0.22 0.41 0.80 0.29 0.25 0.41 0.80 0.73 0.93 0.93 0.93 0.93 1.40	22. 462 22. 091 19. 209 19. 209 19. 278 17. 393 17. 440 16. 743 17. 091 16. 763 16. 238 16. 238 16. 238 16. 238 16. 238 16. 238 16. 238 16. 238 16. 238 16. 238 17. 322 222 7238 173 288 173 288 173 288 173 288 173 288 173 287 274 723 274 727 275 292 274 727 275 292 274 727 275 292 274 727 275 292 275 292 276 723 276 772 276 723 265 776	22 554 21. 039 18. 718 17. 718 17. 708 14. 567 14. 800 24. 134 15. 763 15. 763 15. 763 15. 763 15. 763 15. 763 15. 368 16. 368	11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 20 31 32 30 31 32 32 30 31 32 32 32 32 32 32 32 32 32 32 32 32 32	9 74 9 72 9 1 12 1 19 1 45 1 51 1 78 1 82 2 08 2 11 2 29 2 31 2 38 2 53 2 84 3 3 00 4 85 7 40 9 7 95 9 97 11 94 12 50 14 40 13 05 17 24 21 20 22 48 23 18 24 60 25 16 24 51 27 81	89, 774 82 881 74, 378 77, 384 45, 644 43, 312 40, 293 54, 438 57, 777 54, 304 54, 238 51, 728 49, 335 48, 038 36, 623 30, 984 28, 207 24, 448 28, 207 24, 448 22, 23, 24 24, 22, 23, 24 21, 21, 21, 21, 21, 21, 21, 21, 21, 21,	77 819 73 367 69 223 63 288 64 326 58 249 54 252 24 49 829 44 825 47 730 44 683 41 805 44 683 41 805 25 22 23 26 23 308 21 891 21 283 20 107 19 264 20 107 19 264 19 217 18 607 18 603 17, 799 17 421 17 741 17 742 16 763 16 763

49	54 63	17.490		••	0.04	73, 541	45 081
50	80 04		17 444	11	0.93	69.371	
51 92	99 84 105. 57	14 934 15.416	12 742		1.12	45, 348	57 630
53	124.30		12 740 11 364		1 19	60. 87 8	53 874
54	131.04		17 737	14 15	1. 39 1. 44	59, 139 56, 075	52 335 49 624
55	146.07	14.202	11 737	14	1.39	55. 400	
54	196.36	14. 534 13. 762 14. 236 13. 752 14. 017 13. 649	12 012 11 539 11 765)	17	1.76	50, 762	
5 <i>7</i> 50	165.97	13.762	11 539	16	1.85	51.240	
59	181.84 192.30	14.236	11 765	19	2.05	49.070	
60	207, 39	14.017	11 584	20	2.08 2.27	47. 054 45. 504	
≜1	212 22	13.449	11 280	22	2 31	45. 945	
42	226 33	13.982	11. 473	20	2. 58	43, 451	
43	231.93	13.556	11. 203	24	2. 59	42. 928	
64 65	245. 55 251. 79	13.769 13.481	11. 379	25		41, 448	
66	264.60	13.454	11 141 11 206	26	3. 00 4 93	40, 51 1 31, 632	
67	294.88	13.376	11.071	26	9 . 10	25. 444	22 519
48	299 67	13.396 13.415	11 087		9, 24	25.000	
O sample, Act.	1 shear rate	2 viscosity	3 relative	30	10.65	23, 083	20 427
plasma visc	(1/sec)	(cP)	viscosity	,31	12, 55	22, 151	
				32	12.57 15.76	21, 336 19, 977	
1 31-2 2 H=78	0.03	1123, 276 507, 879 300, 738 233, 201	929 327 419 735	33 34	15.07	20, 352	
3 1. 21 cP	0.14	300.738	248 544	35	18.32	19.060	16.867
4	0. 23	233, 201	192, 728 162, 891	34	19 19	19, 637	
5	0.29	177.098	162 891 150 474	37	20.87	10.218	
6	0.35	182.073	150 474	26	21.92 23.40	19.114 17.705	15 668
7	0. 42 0. 61	162 923 128 416	134 647 106 129	39 40	24. 47	17.484	19 473
Ť	O. BO	105 115	86 872	41	25. 31	17, 307	15 316
10	0. 94	118 269	97. 743	42	27, 75	14.785	14 854
11	1.05	91 02B	75 220	43	29.97	16 437 15 085	
	1. 20	100 100	82.727	45	42.48 61.65	13.752	12, 170
13 14	1.20 1.31 1.47 1.50 1.69	4 4/11 4 477	82 727 70 147 49 981	46	B7 03	12 747	11. 324
15	i 30	78 305	A4 715	•/	92 40	12,422	10 993
16	1 69	72 869		40	112.47	12.195	
17	1.73	75 225	62 169	47	118 89 138 00	11.870 11.817	
16 17	1.93	75 225 74 825 70 487	61 839	51	163 56	11.537	
20	1. 94 2. 13	67 287	58 235 55 40 7	52	165 15	11 353	10 047
21	2.20	64 943		53	165 15 204 75 208 08	11 059	
55	2. 33			54	208 08	11, 205	
20	2. 39		51 293	55	237. 78	10 898	
24	2. 53	62.870	51. 959	56 27	234 76 271 62	11 039 10 9 23	
25 26	2 58 2 79	80.272 88 AZA	49 812	56	297 42	10 490	
27	2 99	30.014 010 45	48 450	59	299 70	10 690 10 761	7 523
	• • • •			A	thear rate		
28	3. 55			A	PROUT TOTAL	2 viscosity	3 relative
29	3. 55 3. 45			O sample: hct. 	·1/sec)	2 Viscosity (cP)	3 relative
29 30	3. 55 5. 45 8. 00			O sample: hct. 	·1/sec)	2 Viscosity (cP)	3 relative
29	3. 55 3. 45			O sample, hct. I plasma visc 1 31-3 2 Mebb 3 1 21 cP	·1/sec)	2 Viscosity (cF) 262 590 144 829 104 798	217 017 119 693 88 243
29 30 31 32 33	2. 55 5. 45 8 00 9 36	52, 444 42, 713 35, 876 34, 875 32, 889 31, 364	43 509 35 300 29 646 28 822 27 181 25 921	O sample hct. I plasma visc 1 31-3 2 Medd 3 1 21 cP	0 04 0 17 0 17 0 23	2 Viscosity (cF) 262 590 144 829 104 798	217 017 119 693 88 243
29 30 31 32 33 34	3. 55 5. 45 8 00 9 36 9. 91 12. 01	52. 444 42. 713 35. 896 34. 875 32. 889 31. 344 29. 942	43 509 35 300 29 646 28 822 27 181 25 921 24 745	O sample hct. I plane visc 1 31-3 2 Nead 3 1 21 cP 4	0 04 0 10 0 17 0 23 0 30	2 Viscosity (cP) 262 390 144 828 106.798 89 406 78 362	2 relative viscosity 217 017 119 693 89 263 73 669 64 762
29 30 31 32 33 34 35	3. 55 3. 45 8. 00 9. 36 9. 91 12. 01 12. 45 14. 36	52. 646 42: 713 35: 676 34: 875 32: 667 31: 364 27: 742 28: 371	43 509 35 300 29 646 28 822 27 181 25 921 24 745 23 447	O sample hct. I plana visc 1 31-3 2 Mmab 3 1 21 cP 4	0 04 0 10 0 17 0 23 0 30 0 36	2 Viscosity (cF) 262 590 144 829 106 798 89 406 78 362 70 701	3 relative viscosity 217 017 119 693 89 263 73 689 64 762 58 431
29 30 31 32 33 34 25 36	3, 55 5, 45 8, 00 9, 36 9, 91 12, 01 12, 45 14, 36 15, 31	52. 444 42. 713 35. 894 34. 875 32. 889 31. 364 29. 942 28. 371 28. 425	43 509 25 300 29 646 28 822 27 181 25 921 24 745 22 447	O sample hct. I plane visc 1 31-3 2 Nead 3 1 21 cP 4	0 04 0 10 0 17 0 23 0 30 0 36	2 viscosity (cF) 262 390 144 829 106.799 89 406 78 362 70 701 67 472	2 relative viscosity 217 017 119 693 89 263 73 889 64 762 58 431 59 742
29 30 31 32 33 34 35	2. 55 5. 45 8 00 9 36 9 71 12. 01 12. 45 14. 36 15. 31	52. 646 42. 713 35. 896 34. 875 32. 889 31. 364 29. 942 28. 371 28. 425 26. 780	43 509 35 300 29 646 28 822 27 181 25 921 24 745 23 447 23 492 22 132	O sample, hct. I plane visc 1 31-3 2 Head 3 1 21 cP 4 5 6 7	0 04 0 10 0 17 0 23 0 30 0 36	2 Viscosity (cF) 262 390 144 829 196 798 89 406 78 362 70 701 67 472 63 194	3 relative viscosity 217 017 119 693 89 243 73 689 64 762 58 431 55 762 52 226 48 683
29 30 31 32 33 34 29 36 37 28	2. 55 5. 45 8. 00 9. 36 9. 91 12. 45 14. 36 15. 31 16. 91 18. 43	52. 446 42. 713 35. 894 34. 875 32. 889 31. 344 28. 371 28. 371 28. 375 26. 780 26. 270 25. 478	43 509 25 300 29 682 28 822 27 181 25 921 24 745 23 447 23 477 21 711 21 056	O sample, hct. I plane visc 1 31-3 2 Nead 3 1 21 cP 4 5 6 7 8 7	0 04 0 10 0 17 0 17 0 23 0 30 0 36 0 42 0 45 0 59	262 590 144 828 106 798 89 406 78 362 70 701 67 472 63 194 39 188 54 674	3 relative viscosity 217 017 117 047 89 263 73 689 64 762 58 431 55 762 52 226 48 683 45 185
29 20 31 32 33 24 25 37 26 37 29	2, 55 5, 45 8, 00 9, 36 9, 91 12, 01 14, 36 15, 31 16, 91 18, 63 19, 46 21, 28	52. 646 42. 713 35. 894 34. 875 32. 889 31. 364 29. 922 28. 371 28. 425 26. 270 25. 478 24. 971	43 509 25 300 29 666 28 822 27, 181 25 921 24, 745 22, 447 22, 132 21, 711 21, 056 20, 637	O sample hct. I plane visc 1 31-3 2 Medd 3 1 21 cP 4 5 6 7 8 9	0 04 0 10 0 17 0 17 0 20 0 30 0 30 0 42 0 42 0 44 0 59 0 69	2 Viscosity (cF) 262 390 144 828 106 798 89 406 78 362 70 701 67 472 62 194 39 148 34 674 46 438	2 relative viscosity 217 017 119 693 89 243 73 689 44 762 58 431 55 742 52 226 48 883 45 185 28 560
29 20 21 22 23 24 25 26 27 28 29 40	2, 55 5, 45 8, 00 9, 36 9, 91 12, 45 14, 36 15, 31 16, 91 18, 45 21, 28 22, 03	52. 446 42. 713 35. 894 34. 875 32. 889 31. 289 28. 373 28. 425 26. 780 26. 270 25. 478 24. 971 24. 471	43 509 35 300 29 646 28 822 27 181 23 921 24 745 23 447 22 132 21 711 21 056 20 437 20 170	O sample. hct. I planes visc 1 31-3 2 Heads 3 1 21 cP 4 5 6 7 8 9 10 11	0 04 0 10 0 17 0 17 0 23 0 30 0 36 0 42 0 42 0 42 0 49 0 93	2 Viscosity (cF) 262 390 144 829 106.798 89 406 78 362 70 701 67 472 63.194 39 148 34.678 46.638 46.972	217 017 119 693 89 243 73 689 44 762 58 431 55 762 52 226 48 683 43 183 38, 540 38 820
29 20 31 32 33 24 25 37 26 37 29	2. 55 5. 45 8. 00 9. 36 9. 91 12. 01 14. 36 15. 31 16. 91 18. 43 19. 46 21. 28 22. 03 23. 72	52. 646 42. 713 35. 889 34. 875 32. 889 31. 364 29. 742 28. 371 28. 425 26. 270 25. 471 24. 497 24. 971 24. 971	43 509 25 300 29 682 28 822 27 181 25 921 24 745 23 447 23 477 23 137 21 711 21 056 20 437 20 170	O sample, hct. I plane visc 1 31-3 2 Need 3 1 21 cP 4 7 8 7 10 11 12	0 04 0 10 0 17 0 17 0 20 0 30 0 30 0 42 0 42 0 44 0 59 0 69	2 Viscosity (cF) 262 590 144 828 106 798 89 406 78 362 70 701 67 472 63 194 59 148 54 678 46 972 43 119	3 relative viscosity 217 017 119 493 89 243 73 889 447 62 58 431 55 742 52 226 48 883 45 185 38 540 39 820 35 636
29 30 31 32 33 34 35 36 37 28 39 40 41 42 43	2. 55 5. 45 8 00 9 36 9. 91 12. 01 14. 36 15. 31 16. 91 18. 43 19. 44 21. 28 22. 03 23. 72 23. 72 23. 72	52. 446 42. 713 35. 894 31. 884 31. 384 28. 375 28. 475 28. 475 28. 470 28. 470 28. 470 28. 470 29. 470 21. 470 23. 877 23. 788 23. 249	43 509 25 300 29 646 28 822 27 181 25 721 26 745 22 447 23 447 22 132 21 711 21 756 20 427 20 170 19 733 19 440	O sample, hct. I plane visc 1 31-3 2 Need 3 1 21 cP 4 5 6 7 8 7 10 11 12 13 14	1/sec) 0 04 0 10 0 17 0 23 0 30 0 36 0 42 0 42 0 45 0 59 0 69 0 73 1 17 1 19 1 46	2 Viscosity (cF) 262 590 144 828 106 798 89 406 78 362 70 701 67 472 63 194 59 148 54 678 46 972 43 119	3 relative viscosity 217 017 119 493 89 243 73 889 447 62 58 431 55 742 52 226 48 883 45 185 38 540 39 820 35 636
29 30 31 32 33 34 25 36 37 26 40 41 42 43 43	2. 55 5. 45 8. 00 9. 36 9. 71 12. 01 14. 36 15. 31 16. 91 18. 43 21. 28 22. 03 23. 72 23. 72 23. 85 27. 86	52. 646 42. 712 35. 876 34. 875 32. 889 31. 364 29. 722 28. 371 28. 425 26. 780 25. 478 24. 406 23. 877 24. 406 23. 877 23. 788 22. 701	43 509 25 300 29 666 28 822 27, 181 29 721 24, 745 22, 132 21, 711 21, 036 20, 170 19, 266 19, 214 18, 761	O sample. hct. I plane visc 1 31-3 2 Medd 3 1 21 cP 4 5 6 7 7 8 7 10 11 12 13 13 14	0 04 0 10 0 10 0 10 0 23 0 30 0 30 0 42 0 42 0 42 0 59 0 69 0 73 0 73 1 19 1 19	2 Viscosity (cF) 262 590 144 828 106 798 89 406 78 362 70 701 67 472 63 194 59 148 54 678 46 972 43 119	3 relative viscosity 217 017 119 493 89 243 73 889 447 62 58 431 55 742 52 226 48 883 45 185 38 540 39 820 35 636
29 30 31 32 32 33 34 35 36 37 28 29 40 41 42 43 44 45	3. 55 5. 45 8. 00 9. 36 9. 91 12. 45 14. 34 15. 31 16. 91 18. 43 21. 28 22. 03 23. 92 23. 92 23. 83 27. 88 29. 97	52. 444 42. 712 35. 894 34. 875 32. 889 31. 289 28. 475 28. 425 24. 780 25. 478 24. 771 24. 701 23. 877 23. 877 23. 249 22. 768 22. 249 22. 763	43 509 35 300 29 646 28 822 27 181 29 721 24 745 23 447 23 447 21 056 20 437 20 170 19 733 19 640 18 761 8 761	O sample, hct. I plane visc 1 31-3 2 Need 3 1 21 cP 4 5 6 7 8 7 10 11 12 13 14	1/sec) 0 04 0 10 0 17 0 23 0 30 0 36 0 42 0 42 0 42 0 49 0 93 1 19 1 46 1 51 1 65	2 Viscosity (cF) 262 590 144 828 106 798 89 406 78 362 70 701 67 472 63 194 59 148 54 678 46 972 43 119	3 relative viscosity 217 017 119 493 89 243 73 889 447 62 58 431 55 742 52 226 48 883 45 185 38 540 39 820 35 636
29 30 31 32 33 34 25 36 37 26 40 41 42 43 43	2. 55 5. 45 8. 00 9. 36 9. 91 12. 01 12. 45 14. 36 15. 31 18. 43 19. 44 21. 28 22. 03 23. 72 23. 72 24. 72 25. 85 27. 73 26. 60 27. 73 28. 60 28. 73 28. 73 29. 73 29. 73 29. 73 29. 73 29. 73 20. 74 20. 74	52. 646 42. 712 33. 876 34. 875 32. 889 31. 389 31. 389 26. 371 28. 425 26. 780 25. 478 24. 406 23. 677 23. 788 23. 270 22. 701 22. 701 22. 263	43 509 25 300 29 666 28 822 27 181 28 721 24 745 23 447 22 132 21 711 21 036 20 437 20 170 19 733 19 660 19 216 18 401 17 500	O sample. hct. I plane visc 1 31-3 2 Heads 3 1 21 cP 4 5 6 7 8 9 10 11 12 13 14 15 16	0 04 0 10 0 10 0 10 0 23 0 30 0 30 0 42 0 42 0 42 0 59 0 69 0 73 0 73 1 19 1 19	2 Viscosity (cF) 262 590 144 828 106 798 89 406 78 362 70 701 67 472 63 194 59 148 54 678 46 972 43 119	3 relative viscosity 217 017 119 493 89 243 73 889 447 62 58 431 55 742 52 226 48 883 45 185 38 540 39 820 35 636
29 30 31 32 33 34 35 36 37 28 39 40 41 42 43 44 45 46 47	2. 55 5. 45 8 00 9 36 9. 91 12. 01 14. 36 15. 31 16. 91 18. 43 19. 44 21. 28 22. 03 23. 72 23. 72 23. 72 23. 72 23. 72 23. 73 27. 65 28. 65 29. 97	52. 444 42. 712 35. 894 34. 875 32. 889 31. 289 28. 475 28. 425 24. 780 25. 478 24. 771 24. 701 23. 877 23. 877 23. 249 22. 768 22. 249 22. 763	43 509 25 300 29 666 28 822 27 181 28 721 24 745 23 447 22 132 21 711 21 036 20 437 20 170 19 733 19 660 19 216 18 401 17 500	O sample. hct. I plane visc 1 31-3 2 Need 3 1 21 cP 4 5 6 7 8 7 10 11 12 13 14 15 16 17 18 19 20	1/sec) 0 04 0 10 0 17 0 23 0 30 0 36 0 42 0 42 0 45 0 93 1 19 1 19 1 46 1 51 1 45 1 76 1 92 2 08	2 VISCOSITY (cP) 262 590 144 828 106.798 89 406 78 262 70 701 47 472 62.194 59 148 54.674 46.638 46.972 43.119 42.799 39.763 37.781 36.543 33.423 34.223	3 relative viscosity 217 017 119 493 88 263 73 889 263 58 431 55 742 52 226 48 883 28 360 23 820 23 636 23 37 636 23 270 22 037 21 224 20 201 29 300 26 283
29 30 31 32 33 34 25 36 37 40 41 42 43 44 45 46 47 18 49	3. 55 5. 45 8. 00 9. 36 9. 91 12. 45 14. 36 15. 31 16. 91 19. 44 21. 28 22. 03 23. 72 23. 82 27. 86 27. 96 28. 97 36. 00 41. 30 84. 83 93. 07	52. 646 42. 712 35. 876 34. 875 32. 889 31. 364 29. 371 28. 425 26. 780 25. 478 24. 406 23. 677 24. 406 23. 249 22. 265 21. 175 18. 220 16. 876	43 509 25 300 29 666 28 822 27 181 29 7921 24 745 23 447 23 492 22 132 21 711 21 056 20 437 20 170 19 733 19 640 18 761 18 401 17 505	O sample. hct. I plane visc 1 31-3 2 Medd 3 1 21 cP 4 5 6 7 8 7 10 11 12 13 14 15 16 17 18 19 20 21	0 04 0 10 0 10 0 17 0 23 0 30 0 36 0 .42 0 .42 0 .42 0 .42 0 .42 0 .42 1 .19 1 .19 1 .19 1 .44 1 .51 1 .51 1 .62 2 .28	2 VISCOSITY (cP) 242 590 144 828 104.798 89 406 78 362 70 701 67 472 63.194 97 148 94.674 46.458 46.972 47.117 47.117 47.799 39.773 39.765 37.781 36.453 3	3 relative viscosity 217 017 119 693 89 243 73 689 44 762 58 431 55 742 52 226 48 683 45 185 28 940 33 636 371 32 870 32 27 31 224 30 201 29 200 26 283 27 957
29 30 31 32 32 34 39 36 37 28 39 40 41 42 43 44 45 46 47 18 48	3. 55 5. 45 8. 00 9. 36 9. 91 12. 45 14. 36 15. 31 16. 91 18. 43 11. 46 21. 28 22. 03 23. 72 23. 72 23. 83 27. 86 29. 97 36. 00 61. 30	52. 446 42. 712 35. 894 34. 875 32. 894 31. 284 28. 371 28. 425 26. 780 25. 478 24. 771 24. 404 23. 877 23. 249 22. 705 21. 175 18. 220 16. 870 16. 379 15. 3797	43 509 35 300 29 646 28 822 27 181 29 721 24 745 23 492 22 132 21 711 21 056 20 437 20 170 19 733 19 640 18 761 18 761 18 761 17 500 15 058 13 942 13 3942 13 3942 13 3221	O sample. hct. I plane visc 1 31-3 2 Mede 3 1 21 cP 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21	1/sec) 0 04 0 10 0 17 0 23 0 30 0 36 0 42 0 42 0 45 0 69 0 73 1 17 1 19 1 46 1 51 1 65 1 76 1 72 2 08	2 VISCOSITY (cP) 242 590 144 828 196, 798 89 406 70 701 47 472 43 194 37 148 34 474 44 458 44 972 43 119 42 799 39 773 38 745 37 781 36 543 37 781 36 543 37 828 33 828 32 449	3 relative viscosity 217 017 119 493 89 243 73 889 245 55 431 55 742 52 226 48 883 43 185 34 54 63 35 71 32 870
29 30 31 32 33 34 25 36 37 26 40 41 42 43 44 45 46 47 18 50 51	2. 55 5. 45 8. 00 9. 36 9. 91 12. 01 14. 36 15. 31 16. 91 18. 43 19. 44 21. 28 22. 03 23. 72 23. 72 23. 72 23. 72 23. 72 23. 85 27. 86 29. 97 36. 00 41. 30 84. 85 93. 09 112. 41 119. 53	52. 646 42. 712 35. 896 34. 875 32. 889 31. 364 29. 722 28. 371 28. 425 26. 780 25. 478 24. 406 23. 788 23. 788 23. 249 22. 265 21. 175 18. 220 16. 876 15. 977 15. 977	43 509 25 300 29 646 28 822 27 181 26 742 24 745 23 447 23 492 22 132 21 711 21 036 20 170 19 723 19 460 19 214 18 761 18 401 17 500 15 058 13 942 13 234 13 234	O sample, hct. I plane visc 1 31-3 2 Need 3 1 21 cP 4 5 6 7 8 7 10 11 12 13 14 15 16 17 18 19 20 21 22 23	1/sec) 0 04 0 10 0 17 0 23 0 30 0 30 0 42 0 42 0 42 0 42 0 42 0 42 1 17 1 19 1 46 1 51 1 45 1 74 1 72 2 08 2 18 2 38	2 VISCOSITY (cF) 242 590 144 828 104 798 89 404 78 342 70 701 47 472 40 194 59 148 54 474 44 458 46 972 43 119 42 799 39 773 38 745 37 781 36 543 39 453 39 453 39 453 39 453 34 223 32 649 32 649 33 649 34 649 34 649 34 649 34 649 34 649 35 649 36 649 37 649 38 649 3	3 relative viscosity 217 017 119 649 73 889 263 73 889 263 73 889 263 25 226 48 883 45 185 28 260 33 636 35 371 32 870 32 037 31 224 30 201 29 300 26 28 283 27 957 26 980 76 807
29 30 31 32 32 34 35 36 37 28 39 40 41 42 43 44 45 46 47 18 48	3. 55 5. 45 8. 00 9. 36 9. 91 12. 45 14. 36 15. 31 16. 91 18. 43 11. 46 21. 28 22. 03 23. 72 23. 72 23. 83 27. 86 29. 97 36. 00 61. 30	52. 646 42. 712 35. 876 34. 875 32. 884 31. 384 29. 772 28. 371 28. 425 26. 780 25. 478 24. 476 23. 877 23. 249 22. 249 22. 245 21. 173 18. 220 16. 870 15. 977 15. 977 15. 977	43 509 25 300 29 466 28 822 27 181 29 7921 24 745 23 447 23 492 22 132 21 711 21 056 20 437 20 170 19 733 19 460 17 360 15 058 13 942 13 221 12 885 12 763	O sample. hct. I plane visc 1 31-3 2 Mede 3 1 21 cP 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21	1/sec) 0 04 0 10 0 17 0 23 0 30 0 36 0 42 0 42 0 45 0 69 0 73 1 17 1 19 1 46 1 51 1 65 1 76 1 72 2 08	2 VISCOSITY (cP) 242 590 144 828 196, 798 89 406 70 701 47 472 43 194 37 148 34 474 44 458 44 972 43 119 42 799 39 773 38 745 37 781 36 543 37 781 36 543 37 828 33 828 32 449	3 relative viscosity 217 017 119 049 89 240 70 889 240 70 889 240 58 401 55 742 52 226 48 880 38 540 39 820 39 606 30 371 32 870 32 007 31 224 30 201 29 200 26 280 27 957 26 807 25 708 26 807 25 708 26 900 27 980 28 907 25 708 26 900 27 980 28 907 29 900 20 900
29 30 31 32 33 34 25 36 37 36 40 41 42 43 44 45 46 47 48 49 50 51 52 52	2. 55 5. 45 8. 00 9. 36 9. 91 12. 45 14. 36 15. 31 16. 91 19. 46 21. 28 22. 03 23. 72 23. 72 23. 72 23. 72 23. 72 24. 85 27. 85 27. 86 29. 97 36. 00 41. 30 86. 85 93. 09 112. 41 119. 95 129. 64 146. 07	52. 646 42. 712 35. 896 34. 875 32. 889 31. 364 29. 722 28. 371 28. 425 26. 780 25. 478 24. 406 23. 788 23. 788 23. 249 22. 265 21. 175 18. 220 16. 876 15. 977 15. 977	43 509 25 300 29 646 28 822 27 181 26 742 24 745 23 447 23 492 22 132 21 711 21 036 20 170 19 723 19 460 19 214 18 761 18 401 17 500 15 058 13 942 13 234 13 234	O sample. hct. I plasma visc 1 31-3 2 Hmade 3 1 21 cP 4 5 6 7 8 7 10 11 12 13 14 15 16 17 18 19 20 21 22 22 24 23 24	1/sec) 0 04 0 10 0 17 0 23 0 30 0 36 0 42 0 42 0 42 0 42 0 42 0 42 1 19 1 14 1 51 1 65 1 72 2 08 2 18 2 28 2 79 3 00	2 VIECOSITY (cP) 242 590 144 828 104 798 89 406 78 342 70 701 47 472 43 194 59 148 54 474 44 658 46 972 43 117 42 799 39 773 36 745 37 781 36 343 33 453 34 223 32 828 32 449 32 1098 30 351 20 723	3 relative viscosity 217 017 117 073 189 243 73 887 44 762 58 431 55 742 52 226 48 683 45 185 38 540 33 636 30 371 32 870 32 037 31 224 30 201 27 920 26 283 27 757 26 760 22 771 25 083 24 760 22 771 25 083 24 762 24 7
29 30 31 32 32 34 35 36 37 40 41 42 43 44 45 46 47 50 51 52 54 55	2. 55 5. 45 8 00 9 736 9. 91 12. 45 14. 36 15. 31 16. 91 18. 43 11. 46 21. 28 22. 03 23. 72 23. 72 23. 83 27. 86 29. 97 36. 00 61. 30 86. 83 93. 09 112. 41 119. 39 138. 04	52. 446 42. 712 35. 894 31. 895 32. 894 31. 28. 425 28. 476 28. 476 29. 476 21. 476 22. 476 22. 476 22. 247 22. 249 22. 705 26. 786 27. 155 16. 376 16. 376 15. 379 15. 379 15. 379 16. 379 16. 379 17. 379 18. 379 19. 379 19	43 509 35 300 29 646 28 822 27 181 29 921 24 745 23 447 23 492 22 132 21 711 21 056 20 437 20 170 19 733 19 640 17 500 15 058 13 942 13 3942 13 3942 13 221 12 885 12 763 12 470 12 231	O sample. hct. I planes visc 1 31-3 2 Heads 3 1 21 cP 4 5 6 7 8 7 10 11 12 13 14 15 14 15 16 17 18 19 20 21 22 23 24 25 24 27 26 27	0 04 0 10 0 17 0 27 0 20 0 30 0 30 0 42 0 42 0 45 0 59 0 79 1 17 1 14 1 15 1 35 1 74 2 2 08 2 38 2 40 2 45 2 79 3 58	2 VIECOSITY (CP) 242 590 144 828 196.798 89 406 78 342 70 701 47 472 43 194 39 148 34.474 44 458 46 972 43.119 42 799 39 773 38.785 37.781 36.543 39.453 33.828 32.449 32.424 31.998 30.351 29.723	3 relative viscosity 217 017 119 493 88 243 73 889 243 55 742 55 742 52 226 48 883 48 183 38 540 39 820 33 636 33 71 32 870 33 870 34 807 35 870 36 870 37 8
29 30 31 32 33 34 25 36 37 36 40 41 42 43 44 45 46 47 48 50 51 52 52 52 53	2. 55 5. 45 8. 00 9. 36 9. 91 12. 45 14. 36 15. 31 16. 91 18. 43 19. 44 21. 28 22. 03 23. 72 23. 72 23. 72 23. 72 23. 72 27. 86 27. 96 27. 96 112. 41 119. 53 128. 04 112. 49 112. 41 119. 53 128. 04 146. 07 146. 07	52. 646 42. 712 35. 876 31. 875 32. 889 31. 364 24. 722 28. 371 28. 425 26. 780 25. 478 24. 406 23. 877 24. 406 23. 249 22. 265 21. 175 18. 220 16. 876 15. 977 15. 977 15. 977 15. 971 16. 442 16. 463	43 509 25 300 29 666 28 822 27 181 25 7921 24 745 22 447 22 132 21 711 21 056 20 627 20 170 19 733 19, 640 18 401 17, 500 15 038 13 942 12 221 12 885 12 763 12 466 12 2211 12 885	O sample. hct. I plane visc 1 31-3 2 Medd 3 1 21 cP 4 5 6 7 7 8 7 10 11 12 13 13 14 15 16 17 20 21 22 22 24 25 26 27 28	1/sec) 0 04 0 10 0 17 0 23 0 30 0 36 0 42 0 42 0 42 0 42 0 42 1 17 1 19 1 44 1 51 1 45 1 74 1 74 2 208 2 18 2 38 2 38 2 340 2 45 2 79 3 00 3 348	2 viscosity (cP) 242 590 144 828 194 799 89 496 78 342 70 701 47 472 43 194 59 148 54 474 44 458 46 972 43 119 39 773 38 745 37 781 36 543 33 423 33 828 32 449 32 436 31 098 30 321 24 711 22 147	3 relative viscosity 217 017 119 049 188 243 73 689 44 762 58 431 55 762 52 226 48 683 45 185 28 940 28 940 23 673 21 224 20 201 22 200 22 200 23 670 24 760 25 701 25 082 27 757 26 760 27 757 28 700 22 075 18 320
29 30 31 32 32 34 35 36 37 40 41 42 43 44 45 46 47 50 51 52 54 55	2. 55 5. 45 8. 00 9. 36 9. 91 12. 45 14. 36 15. 31 16. 91 18. 46 21. 28 22. 03 23. 72 23. 72 23. 72 23. 72 25. 85 27. 86 29. 97 36. 00 41. 30 84. 85 93. 09 112. 41 119. 53 128. 04 144. 07 149. 84 172. 39 201. 46 202. 39	52. 646 42. 712 35. 894 34. 875 32. 889 31. 289 31. 289 28. 371 28. 425 26. 780 25. 476 24. 977 24. 406 23. 877 22. 249 22. 249 22. 249 22. 265 21. 173 18. 220 16. 870 15. 997 15. 591 15. 089 14. 779 14. 429 14. 479	43 509 35 300 29 646 28 822 27 181 29 921 24 745 23 447 23 449 22 132 21 711 21 056 20 637 20 170 19 733 19 640 17 214 18 761 18 761 18 761 17 500 15 038 13 942 13 524 12 221 12 885 12 775 12 266 12 221 12 887	O sample. hct. I plane visc 1 31-3 2 Heads 3 1 21 cP 4 5 6 7 8 7 10 11 12 13 14 15 14 15 14 17 18 20 21 22 23 24 25 24 27 28 29	0 04 0 10 0 17 0 27 0 20 0 30 0 30 0 42 0 42 0 45 0 59 0 79 1 17 1 14 1 15 1 35 1 74 2 2 08 2 38 2 40 2 45 2 79 3 58	2 VIECOSITY (CP) 242 590 144 828 196.798 89 406 78 342 70 701 47 472 43 194 39 148 34.474 44 458 46 972 43.119 42 799 39 773 38.785 37.781 36.543 39.453 33.828 32.449 32.424 31.998 30.351 29.723	3 relative viscosity 217 017 119 493 88 243 73 889 243 55 742 55 742 52 226 48 883 48 183 38 540 39 820 33 636 33 71 32 870 33 870 34 807 35 870 36 870 37 8
29 30 31 32 33 34 25 36 37 26 37 40 41 42 43 44 45 46 47 48 47 48 49 50 51 52 53 54 59 56 59	2. 55 5. 45 8. 00 9. 36 9. 91 12. 45 14. 36 15. 31 16. 91 18. 43 19. 44 21. 28 22. 03 23. 72 23. 72 23. 72 23. 72 23. 72 27. 86 27. 96 27. 96 112. 41 119. 53 128. 04 112. 49 112. 41 119. 53 128. 04 146. 07 146. 07	52. 646 42. 712 35. 876 31. 875 32. 884 31. 324 28. 425 26. 780 25. 478 24. 406 23. 877 24. 406 23. 877 23. 249 22. 265 21. 175 16. 870 16. 870 17. 977 18. 977 19. 977 19. 977 19. 979 19. 442 11. 422 14. 429	43 509 25 300 29 666 28 822 27 181 25 7921 24 745 22 447 22 132 21 711 21 056 20 627 20 170 19 733 19, 640 18 401 17, 500 15 038 13 942 12 221 12 885 12 763 12 466 12 2211 12 885	O sample. hct. I plasma visc 1 31-3 2 Hmab 3 1 21 cP 4 5 6 7 8 7 100 111 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31	1/sec) 0 04 0 10 0 17 0 23 0 30 0 36 0 42 0 42 0 42 0 42 0 42 0 42 0 42 0 42	2 VIECOSITY (cP) 242 590 144 829 104 798 89 406 78 342 70 701 47 472 43 194 39 148 34 474 44 458 46 972 43 119 42 799 39 773 38 745 36 343 32 423 32 828 32 449 32 436 31 098 30 351 20 751 22 117 23 117 24 117 26 711 27 147 27 147 27 147 27 147 21 17 727 21 727 21 147 21 17 727 21 147 21 17 727 21 147 21 17	3 relative viscosity 217 017 117 0473 189 2403 72 889 2403 55 742 52 226 48 683 45 185 38 550 32 620 33 626 30 371 32 870 32 020 22 62 22 077 26 883 27 757 26 883 24 562 22 079 18 320 15 161 14 816 13 485 1
29 30 31 32 32 34 35 36 37 40 41 42 43 44 45 50 51 52 54 55 56 57 66 61	2. 55 5. 45 8 00 9 7 36 9. 91 12. 45 14. 36 15. 31 16. 91 18. 43 11. 28 22. 03 23. 72 23. 72 23. 83 27. 86 29. 97 36. 00 61. 30 84. 83 93. 09 112. 41 119. 53 119. 50 140. 60 140. 71 147. 86 172. 59 201. 44 201. 44 205. 56 227. 04 231. 98 227. 04	52. 646 42. 712 33. 876 32. 889 31. 389 31. 389 31. 389 31. 389 26. 371 28. 475 28. 470 29. 471 24. 406 23. 477 22. 701 22. 261 22. 2701 22. 261 16. 376 15. 970 16. 376 15. 970 16. 376 17. 971 19. 409 14. 429 14. 429 14. 429 14. 429 14. 429 14. 429	43 509 35 300 29 646 28 822 27 181 29 721 24 745 23 447 23 492 22 132 21 711 21 056 20 177 19 733 19 640 17 214 18 761 18 761 17 500 15 038 13 942 13 524 12 221 12 885 12 763 12 470 12 321 12 0871 11 7008 11 7008 11 7008 11 7008 11 7008 11 7008 11 7008 11 7018	O sample. hct. I planea visc 1 31-3 2 Mede 3 1 21 cP 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32	1/sec) 0 04 0 10 0 17 0 27 0 20 0 30 0 30 0 42 0 42 0 45 0 59 0 79 1 17 1 19 1 46 1 51 1 55 1 76 2 38 2 40 2 45 2 79 3 58 8 47 7 9 35 11 84 1 1 79	2 VIECOSITY (CP) 262 590 144 828 196.798 89 406 78 262 70 701 47 472 63 194 39 187 46 458 46 972 43 119 42 799 39 773 38 765 37 781 36 543 39 453 32 423 33 828 32 449 32 109 30 391 20 723 26 711 22 167 18 345 17 927 16 317 727 16 317	3 relative viscosity 217 017 119 493 88 243 73 889 245 58 431 55 742 52 226 48 883 45 185 30 54 60 33 820 33 636 33 71 32 870
29 30 31 32 33 34 25 36 37 36 40 41 42 43 44 45 46 47 18 49 50 51 52 52 52 53 54 60 61 62	2. 55 5. 45 8. 00 9. 36 9. 91 12. 01 12. 45 14. 36 15. 31 16. 91 18. 43 19. 46 21. 28 22. 03 23. 72 23. 72 23. 72 23. 85 27. 86 28. 97 36. 00 41. 30 84. 83 92. 07 112. 41 117 53 138. 06 146. 07 148. 07 149. 04 271. 88	52. 646 42. 712 35. 876 31. 875 32. 889 31. 384 24. 722 28. 371 28. 425 26. 780 25. 478 24. 406 23. 249 22. 265 21. 175 18. 220 16. 876 15. 977 15. 977 15. 977 15. 971 16. 443 16. 409 16. 409 16. 409 16. 428 16. 428 16. 428 16. 428	43 509 25 300 29 666 28 822 27 181 25 7921 24 745 22 447 22 149 22 13 711 21 056 20 627 20 170 19 733 19, 640 18 401 17, 500 13 742 12 763 13 942 12 763 12 763 12 763 12 763 12 763 12 763 12 763 12 763 12 763 12 763 13 7763 13 7763 14 7691 15 7691 11 7691 11 7691 11 7769 11 7769 11 7769 11 7769 11 7769 11 7769 11 7769	O sample. hct. I plane visc 1 31-3 2 Medd 3 1 21 cP 4 5 6 7 8 7 10 11 12 13 13 14 15 16 17 18 19 20 21 22 24 25 26 27 28 29 30 31 32 33	1/sec) 0 04 0 10 0 17 0 23 0 30 0 36 0 42 0 42 0 42 0 42 0 42 0 42 1 17 1 14 1 15 1 15 1 15 1 16 2 18 2 38 2 30 2 45 2 79 3 58 8 47 9 35 11 84 11 84 11 89 13 98	2 VIECOSITY (CP) 242 590 144 828 106 788 89 406 78 342 70 701 47 472 43 194 59 148 54 474 46 658 46 972 43 119 42 799 39 773 30 765 37 781 36 543 33 423 33 828 32 449 32 349 32 35 27 11 22 167 18 345 17 927 16 317 16 413 15 446	3 relative viscosity 217 017 117 0493 189 243 73 687 44 762 58 431 55 742 52 226 48 683 45 185 28 540 23 571 22 870 22 037 21 224 200 26 283 27 757 24 763 26 275 18 220 15 181 14 816 13 264 12 765
29 30 31 32 32 34 35 36 37 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 59 56 57 56	2. 55 5. 45 8. 00 9. 36 9. 91 12. 01 12. 45 14. 36 15. 31 16. 91 18. 46 21. 28 22. 03 23. 72 23. 72 23. 72 23. 72 23. 72 24. 119 36. 00 61. 30 64. 83 93. 09 112. 41 119. 53 138. 04 146. 07 149. 68 172. 39 201. 46 205. 36 227. 04 231. 74 231. 85 238. 87 239. 87 230. 88	52. 646 42. 712 35. 894 36. 875 32. 889 31. 324 28. 371 28. 425 26. 780 23. 476 24. 771 24. 404 23. 877 22. 768 22. 249 22. 701 22. 265 21. 173 18. 220 16. 870 16. 376 15. 997 15. 591 15. 699 14. 799 14. 429 14. 429 14. 429 14. 429 14. 680 14. 223 12. 761	43 509 25 300 29 466 28 822 27 181 29 7921 24 745 23 447 23 447 22 132 21 711 21 056 20 437 20 170 19 733 19 640 17 214 18 761 18 401 17 500 15 038 13 942 12 536 12 221 12 885 12 770 12 2861 12 221 12 0871 11 9081 11 721 11 729 11 626 11 725 11 535	O sample. hct. I plane visc 1 31-3 2 Heads 3 1 21 cP 4 5 6 7 8 7 10 11 12 13 14 15 14 15 14 15 14 17 18 20 21 22 23 24 25 26 27 28 29 30 31 32 33	1/sec) 0 04 0 10 0 17 0 23 0 30 0 36 0 42 0 42 0 45 0 69 0 73 0 73 0 73 0 73 0 73 0 73 0 73 0 73	2 VIECOSITY (CP) 242 590 144 829 106.798 89 406 78 342 70 701 47 472 43 194 59 148 59 4674 44 658 46 972 43 119 42 799 39 773 38 765 37.781 36 543 39 453 39 453 39 453 31 674 51 196 51 197 52 167 77 727 78 1345 17 927 18 345 17 927	3 relative viscosity 217 017 119 493 89 243 73 889 245 58 431 55 742 52 226 48 883 45 185 326 32 870 32 037 31 224 30 201 229 300 28 283 27 957 26 807 25 701 25 083 24 362 22 375 18 320 19 19 10 11 4 816 13 489 12 745 12 542
29 30 31 32 33 34 25 36 37 36 40 41 42 43 44 45 46 47 18 49 50 51 52 52 52 53 54 60 61 62	2. 55 5. 45 8. 00 9. 36 9. 91 12. 01 12. 45 14. 36 15. 31 16. 91 18. 43 19. 46 21. 28 22. 03 23. 72 23. 72 23. 72 23. 85 27. 86 28. 97 36. 00 41. 30 84. 83 92. 07 112. 41 117 53 138. 06 146. 07 148. 07 149. 04 271. 88	52. 646 42. 712 35. 876 31. 875 32. 889 31. 384 24. 722 28. 371 28. 425 26. 780 25. 478 24. 406 23. 249 22. 265 21. 175 18. 220 16. 876 15. 977 15. 977 15. 977 15. 971 16. 443 16. 409 16. 409 16. 409 16. 428 16. 428 16. 428 16. 428	43 509 25 300 29 666 28 822 27 181 25 7921 24 745 22 447 22 149 22 13 711 21 056 20 627 20 170 19 733 19, 640 18 401 17, 500 13 742 12 763 13 942 12 763 12 763 12 763 12 763 12 763 12 763 12 763 12 763 12 763 12 763 13 7763 13 7763 14 7691 15 7691 11 7691 11 7691 11 7769 11 7769 11 7769 11 7769 11 7769 11 7769 11 7769	O sample. hct. I plane visc 1 31-3 2 Medd 3 1 21 cP 4 5 6 7 8 7 10 11 12 13 13 14 15 16 17 18 19 20 21 22 24 25 26 27 28 29 30 31 32 33	1/sec) 0 04 0 10 0 17 0 23 0 30 0 36 0 42 0 42 0 42 0 42 0 42 0 42 1 17 1 14 1 15 1 15 1 15 1 16 2 18 2 38 2 30 2 45 2 79 3 58 8 47 9 35 11 84 11 84 11 89 13 98	2 VIECOSITY (CP) 242 590 144 828 106 788 89 406 78 342 70 701 47 472 43 194 59 148 54 474 46 658 46 972 43 119 42 799 39 773 30 765 37 781 36 543 33 423 33 828 32 449 32 349 32 35 27 11 22 167 18 345 17 927 16 317 16 413 15 446	3 relative viscosity 217 017 117 0493 189 243 73 687 44 762 58 431 55 742 52 226 48 683 45 185 28 540 23 571 22 870 22 037 21 224 200 26 283 27 757 24 763 26 275 18 220 15 181 14 816 13 264 12 765
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13 14	1 59	24.546		. I thear rate	2 viscosite	3 relative
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17 18	2 14	23 706	23 030 1 32-4 22 563 2 H=44 22 364 3 1 06 cP	0 93	12 569	11 876
19 20	2 25	23 249	21 933 3 1.00 67	1 12	11 894	11 223
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23 24	6 10	14 732	13.879	2 01	10 412	9 823
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29 30	14 38 15, 92	10 248	10 152 14 7 951			9 411
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34	19 47 21 88	9. 740 9. 413	9 407 16 9 185 17	6 15	7 739	7 301
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37	23 92 25 83	9. 171 8. 966	9 22 20	16 50	6 464	4 098
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40	29 81 30 12	8.511 8.504	6 233 22 6 029 23 6 025 24 6 341 25	20.47 20.88 24.45 24.70 28.41 29.97 34.15	4 298	5 942
41 42	4B 16	4 721	6 341 25	24 70	4 045	3 719
43	93 27 99 99	6 230	5 877 26	28 41	5 809	3 480
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44	144 A3 152, 58	9. 511 9. 504 4. 721 6. 230 6. 184 5. 877 5. 829 5. 710 5. 684	5.499 29	67 98 93 74	4 949	4 449
47 48	176 34	5. 484	5. 387 30 5. 364 31	106.14	4 607 4 532 4 374	4 346 4 275
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52	231.90 239 94	9, 450 5, 51 9	5. 142 35 5. 207 36	182, 52 196-72	4 18B 4 077	3 9 23 3 8 46
53 54	251.67	9. 41 9	3 112 37	550 95	4 058	3 628
-	291.30	5. 340	5.041	238. 32	3. 980	3 755 3 763
plasma visc.	l shear rate (1/sec)	2 viscosity (cP)		258 84	3. 787 3. 914	3 492
	shear rate (1/sec)	2 viscosity (cP)		258 84	3. 787 3. 914 3. 912	3 492 3 491
1 32-5 2 H=90	1 shear rate (1/sec) 	2 viecesty (cP) 22.222 21.291		258 84	3.787 3.914 3.912 Viscosity 3	3 492 3 491 relative
1 32-5 2 H=50 3 1.06 cP	0.49 0.55 0.68	2 viecesity (cP) 22,222 21,281 20,432		258 84	3.989 3.914 3.912 (cP)	3 472 3 491 relative
1 32-5 2 H=50 3 1 06 cP	1 shear rate (1/sec) 0,49 0,55 0,68 0,87 0,77	2 viacouty (cP) 22, 222 21, 281 20, 432 19, 290 18, 250		258 84	3.789 3.914 3.912 (cP) 3.074 5.125	3 472 3 471 relative viscosity 4.787 4.844
1 32-5 2 H=90 3 1 06 cP	0, 49 0, 55 0, 68 0, 67 0, 97 1, 13	2 viscosity (cP) 22.222 21.281 20.432 19.290 18.250 17.920		258 84	3.789 3.914 3.912 (cP) 3 074 5 125 4.853	3 472 3 671 relative viscosity 4.787 4.844 4.578
1 32-5 2 H=50 3 1.06 cP 4 7	1 shear rate (1/ssc) 0,49 0,55 0,68 0,87 0,99 1,13 1,26	2 viscosity (cP) 22.222 21.201 20.432 19.290 18.250 17.920 17.159 17.058		258 84	3.789 3.914 3.912 2.912 (cP) 3.074 5.125 4.853 5.079 5.074	3 492 3 691 relative viscosity 4.787 4.844 4.578 4.792 4.792
1 32-5 2 H=50 3 1.06 cP 4 9	1 shear rate (1/spc) 0, 49 0, 55 0, 68 0, 97 0, 99 1, 13 1, 26 1, 32 1, 44	2 viaconity (cP) 22.222 21.281 20.432 19.290 17.920 17.1920 17.058 17.016		258 84	3.984 3.912 2.912 2.012 3.912 3.074 5.125 4.853 5.074 4.879 5.074	3 492 3 491 Telative Viscosity 4 787 4 844 4 578 4 767 4 403
1 32-5 2 H=50 3 1 06 cP 4 5 4 7 8 9	1 shear rate (1/sec) 0.49 0.55 0.68 0.97 0.97 1.13 1.26 1.32 1.44 1.46	2 viecesty (cP) 22, 222 21, 281 20, 432 19, 290 17, 920 17, 159 17, 016 16, 581 15, 654		258 84	3.984 3.912 2.912 2. viscosity 3 (cP) 3.074 5.125 4.853 5.079 5.074 4.879 4.700 4.624	3 492 3 491 Tellative Viscosity 4 787 4 844 4 578 4 792 4 792 4 403 4 404 4 342
1 32-5 2 H=50 3 1 06 cP 4 7 8 9	1 shear rate (1/spc) 0.49 0.55 0.68 0.97 0.97 1.13 1.26 1.32 1.44 1.46 1.72	2 viacosity (cP) 22.222 21.281 20.432 19.290 18.250 17.920 17.159 17.016 16.581 15.654		258 84	3.914 3.912 3.912 (cP) 3.074 5.125 4.853 5.079 5.079 5.079 4.700 4.700 4.24 3.720	3 492 3 491 1 relative viscosity 4.787 4.844 4.578 4.792 4.787 4.403 4.424 4.342 2.309
1 32-5 2 M=50 3 1 06 cP 4 7 10 11 12 13	1 shear rate (1/sec) 0.49 0.55 0.68 0.67 0.77 1.13 1.26 1.32 1.44 1.46 1.72 1.76 1.92	2 viacesity (cP) 22. 222 21. 281 20. 432 19 290 18. 250 17. 920 17. 920 17. 058 17. 016 16 581 15 685 16 293 15 478		258 84	3.914 3.914 3.912 (cP) 3 074 5 105 4 853 5 079 5 074 4 879 4 700 4 624 3 720 3 729 3 638	3 492 3 491 Teletive viscosisty 4.787 4.844 4.578 4.762 4.767 4.403 4.434 4.362 3.509 3.499 3.499
1 32-5 2 H=50 3 1 06 cP 4 9 4 7 10 11 12 12 13	1 shear rate (1/spc) 0, 49 0, 55 0, 68 0, 67 0, 67 1, 12 1, 26 1, 32 1, 44 1, 46 3, 72 1, 76 1, 92 2, 14 2, 18	2 viacesity (cP) 22: 22: 22: 22: 22: 22: 27: 290 17: 920 17: 920 17: 920 17: 920 17: 93: 17: 016 16: 591 15: 635 428 15: 579 15: 428 15: 579 14: 674		258 84	3.914 3.914 3.912 (cP) 3 074 5 125 4 853 5 077 5 074 4 879 4 700 4 424 3 720 3 720 3 702	3 492 3 491 Telative viscessty 4 787 4 844 4 578 4 792 4 787 4 403 4 434 4 342 3 509 3 499 3 492
1 32-5 2 H=50 3 1.06 cP 4 7 7 10 11 12 13 14 15	1 shear rate (1/spc) 0.49 0.55 0.68 0.97 0.97 1.13 1.26 1.32 1.44 1.46 3.72 1.76 1.72 1.76 1.92 2.14 2.18 2.45 2.53	2 viacesity (cP) 22: 222 21: 281 20: 432 17 290 17: 759 17: 056 17: 016 16: 381 15: 629 15: 379 14: 474 474 14: 708		258 84	3.984 3.914 3.912 (cP) 3 074 3 175 4 853 5 079 5 079 4 700 4 424 3 720 3 720 3 720 3 720 3 720 3 720 3 720 3 720 3 720 3 720	3 492 3 491 1 relative viscessity 4 787 4 844 4 378 4 792 4 787 4 403 4 434 4 342 3 509 3 499 3 432 3 572 2 424
1 32-5 2 M=50 3 1 06 cP 4 5 6 7 10 11 12 13 14 15 16	1 shear rate (1/spc) 0.49 0.55 0.68 0.87 0.99 1.13 1.26 1.32 1.44 1.46 1.72 1.76 1.72 1.76 1.92 2.14 2.18 2.45 2.25 2.84	2 viacesity (cP) 22: 222 21: 281 20: 432 19: 290 17: 759 17: 058 18: 058 18: 0		258 84	3.984 3.914 3.912 (cP) 3 074 5 175 4.853 5 079 5 074 4 879 4 700 4 424 3 700 2 438 3 702 3 702	3 492 3 491 7 relative viscessity 4 787 4 848 4 7787 4 4 787 4 4 003 4 404 4 342 3 509 0 499 0 492 3 492 3 576
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1 32-5 2 M=50 3 1 06 cP 4 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	1 shear rate (1/spc) 0.49 0.55 0.68 0.87 0.99 1.13 1.26 1.32 1.44 1.46 1.72 1.76 1.92 2.14 2.18 2.45 2.53 2.84 3.00 3.62 6.17	2 viacesity (cP) 22: 222 21: 281 20: 432 19: 290 17: 920 17: 159 17: 016 16: 581 15: 855 16: 629 15: 438 15: 379 14: 874 14: 594 14: 109 14: 309 14: 309 14: 309 14: 309 14: 309 14: 309 14: 309 14: 309 14: 309 14: 309 14: 309 14: 309 14: 309		258 84	3.984 3.914 3.912 (cP) 3.074 5.175 4.853 5.074 4.700 4.424 3.700 3.709 3	3 492 3 491 9 491 1 relative viscosity 4 787 4 844 4 578 4 792 4 403 4 404 3 309 0 499 0 492 0 492 0 492 0 492 0 572 0 440 0 3 367 0 3 367 0 3 367
1 32-5 2 H=50 3 i . 06 cP 4 7 9 10 11 12 12 13 14 15 16 17 18	1 shear rate (1/spc) 0.49 0.59 0.59 0.68 0.87 0.99 1.13 1.26 1.32 1.44 1.46 1.72 1.76 1.92 2.14 2.18 2.45 2.53 2.84 3.00 3.62 4.17 8.07	2 viacesity (cP) 22. 222 21. 281 20. 432 17 290 17. 920 17. 159 17. 016 16. 581 15. 854 16. 293 15. 438 15. 379 14. 874 14. 794 14. 794 14. 109 14. 309 12. 292 11. 156 10. 301 9. 750		258 84	3.984 3.914 3.912 (cP) 3.074 5.074 5.074 4.853 5.074 4.700 4.424 3.700 3.709 3	3 492 3 491 1 relative viscosity 4 787 4 844 4 578 4 792 4 403 4 404 4 309 2 403 3 509 2 402 3 402 3 402 3 402 3 402 3 402 3 503 3 404 3 504 3 604 3 6

22 23 24 25 26 27 27 28 29 29 29 30 31 32 32 33 34 35 36 37 38 39 40 0 sample, hct. plasma visc.	28 43 29 97 30 02 55 41 77 18 87 18 106 05 119 06 139 20 165 48 192 06 195 39 218 43 227 28 239 26 259 11 277 80 299 76	3. 426 3. 487 3. 801 3. 423 3. 131 3. 212 3. 041 3. 097 2. 988 3. 024 2. 955 2. 924 2. 974 2. 903 2. 944 2. 892 2. 917 2. 847 2. 874	2. 713
1 32-2 2 H=24 3 1 06 cP 4 3 6 9 10 11 12 13 14 15 16 17 18 19 20 20 21 22 23 24 25 26 27	3.00 5.36 10.01 11.91 14.46 14.53 18.28 18.31 21.47 22.47 24.02 24.50 29.07 36.88 48.64 92.61 106.83 125.67 144.96 158.91 191.94 193.84 224.91 240.27 251.37 260.83 297.75	2 513 2 218 2 245 2 254 2 068 2 235 2 159 2 159 2 173 2 173 2 175 2 103 2 169 2 175 2 175 2 189 2 189	2 314 2 092 2 119 2 040 2 108 1 991 2 108 2 037 2 101 2 013 2 071 2 022 2 022 2 102 1 944 2 052 1 984
O sample, hct. plasma visc. 1 32-3 2 H=11 3 1 06 cP 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 27	1 shear rate (1/sec) 8.72 11.27 12.61 14.45 15.71 17.63 119.20 20.82 22.50 23.36 25.90 27.76 68.67 72.70 106.69 125.61 145.02 158.67 149.97 271.82 227.67 251.25 229.36 229.36	2 viscosity (cF) 1.170 1.289 1.339 1.287 1.308 1.329 1.308 1.340 1.362 1.397 1.362 1.397 1.363 1.411 1.416 1.327 1.411 1.416 1.327 1.421 1.371 1.421 1.421	1 333 1 350 1 348 1 237 1 136

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