

CHEMICAL AND PHYSICAL STUDY OF FUELS GELLED WITH CARBOHYDRATE RESINS

**James Teng and James M. Lucas
Anheuser-Busch, Inc.
St. Louis, Missouri 63118**



SEPTEMBER 1971

FINAL REPORT

Availability is unlimited. Document may be released to the National Technical Information Service, Springfield, Virginia 22151, for sale to the public.

Prepared for

**DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION**

Systems Research & Development Service

Washington D. C., 20590

1. Report No. FAA-RD-71-43	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle CHEMICAL AND PHYSICAL STUDY OF FUELS GELLED WITH CARBOHYDRATE RESINS		5. Report Date September 1971	
		6. Performing Organization Code	
7. Author(s) James Teng, James M. Lucas		8. Performing Organization Report No. FAA-NA-71-18	
9. Performing Organization Name and Address Anheuser-Busch, Inc. St. Louis, Missouri 63118		10. Work Unit No.	
		11. Contract or Grant No. DOT-FA70NA-497	
12. Sponsoring Agency Name and Address Federal Aviation Administration Systems Research & Development Service Washington, D. C. 20590		13. Type of Report and Period Covered Final Report 6-22-70 to 2-2-71	
		14. Sponsoring Agency Code	
15. Supplementary Notes			
16. Abstract A carbohydrate derivative was designed as a gelling agent for turbine fuel. The gelling agent is effective in reducing the fire hazard of the fuel. The free flowing gelled fuel could be adapted readily to existing fuel systems. The rheological profile of this gelled fuel was established over a range of conditions, by means of a rotating viscometer, Rotovisco Viscometer, equipped with special measuring heads. Among the rheological parameters which were measured, the viscoelasticity of the gelled fuel appears likely to be a major factor in contributing to the crash-safe character of the fuel. Pertinent physical properties and microbiological data were also compiled to demonstrate that the fuel gelled with the carbohydrate based gelling agent is compatible with present aircraft fuel systems.			
17. Key Words Gelled Fuels Fuel Thickeners Aircraft Fires Fire Safety		18. Distribution Statement Availability is unlimited. Document may be released to the National Technical Information Service, Springfield, Virginia, 22151, for sale to the public.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 95	22. Price

PREFACE

This report was prepared by Anheuser-Busch, Inc., St. Louis, Missouri for the Federal Aviation Administration. The work was administered under the direction of Mr. Ralph A. Russell, Project Manager, Propulsion Section, Aircraft Branch, National Aviation Facilities Experimental Center, (NAFEC) Atlantic City, New Jersey.

The authors appreciate the overall direction and advice given them by Dr. B. L. Scallet, Associate Director of Research of Anheuser-Busch, Inc., in the course of this investigation. They are also grateful to Professor J. D. Ferry of the University of Wisconsin for his critical review of the experimental data, to Professor J. J. Cooney of the University of Dayton for the supply of micro-organisms, and to Dr. K. Shieh of Anheuser-Busch, Inc., for his microbiological examination.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
Purpose	1
Background	1
RHEOLOGICAL CHARACTERIZATION - PART A	2
Results and Discussions	2
Program	2
Plasticity and Yield Stress	2
Shear Rate and Shear Stress Relationship	2
Thixotropy	15
Viscoelasticity	23
Experimental Procedures	32
RHEOLOGICAL CHARACTERIZATION - PART B	38
Results and Discussions	38
Program	38
Plasticity and Yield Stress	38
Shear Rate and Shear Stress Relationship	38
Thixotropy	42
Viscoelasticity	42
SYSTEM COMPATIBILITY STUDY	47
Results and Discussion	47
Vibrational Stability	47
Thermal Stability	47
Filterability	47
Residual Gel Measurement	47
Material Compatibility	52
Physical Properties	52
Microbial Activity	55
Electron Microscopy	61
Experimental Procedures	70
SUMMARY	74
CONCLUSIONS	76
APPENDIX A Calculation of Constants for Power Law Equations	1-1
APPENDIX B Derivation of Equations for Linear Flow	2-1
APPENDIX C Glossary of Symbols	3-1
APPENDIX D Bibliography	4-1

LIST OF ILLUSTRATIONS

Figure		Page
1	Yield Stresses of Gels at Various Temperatures	4
2	Shear Rate vs. Shear Stress at Various Temperatures - Gel A	5
3	Shear Rate vs. Shear Stress at Various Temperatures - Gel B	6
4	Shear Rate vs. Shear Stress at Various Temperatures - Gel C	7
5	Shear Rate vs. Shear Stress at Various Temperatures - Gel D	8
6	Shear Rate vs. (Shear Stress Less Yield Stress) at Various Temperatures - Gel A	9
7	Shear Rate vs. (Shear Stress Less Yield Stress) at Various Temperatures - Gel B	10
8	Shear Rate vs. (Shear Stress Less Yield Stress) at Various Temperatures - Gel C	11
9	Shear Rate vs. (Shear Stress Less Yield Stress) at Various Temperatures - Gel D	12
10	Calculated Flow Rate of Gel Through 10-Foot Long Straight Pipe	16
11	Thixotropy of Gels A, B, C and D at 25°C. Temperature	17
12	Stress Recovery of Gels	18
13	Hysteresis Loop of Gel A	19
14	Hysteresis Loop of Gel B	20
15	Hysteresis Loop of Gel C	21
16	Hysteresis Loop of Gel D	22
17	Viscoelasticity Measurements of Gel A - 20 sec. ⁻¹ Shear Rate at 10°C. Temperature	24
18	Viscoelasticity Measurements of Gel A - 264 sec. ⁻¹ Shear Rate at 10°C. Temperature	24
19	Viscoelasticity Measurements of Gel A - 20 sec. ⁻¹ Shear Rate at 40°C. Temperature	25

LIST OF ILLUSTRATIONS (continued)

Figure		Page
20	Viscoelasticity Measurements of Gel A - 264 sec. ⁻¹ Shear Rate at 40°C. Temperature	25
21	Viscoelasticity Measurements of Gel B - 20 sec. ⁻¹ Shear Rate at 10°C. Temperature	26
22	Viscoelasticity Measurements of Gel C - 20 sec. ⁻¹ Shear Rate at 10°C. Temperature	26
23	Viscoelasticity Measurements of Gel D - 20 sec. ⁻¹ Shear Rate at 10°C. Temperature	27
24	Correlation of Viscoelasticity With Crash-Fire Safety	31
25	Rotovisco Viscometer With Cone and Plate Attachments	33
26	Rotovisco Viscometer With Yield Stress Attachment	34
27	Rotovisco Viscometer With Viscoelastic Attachment	35
28	Viscoelastic Measuring Head - Rotovisco Viscometer	36
29	Yield Stress of Gel E at Various Temperatures	39
30	Shear Rate vs. Shear Stress at Various Temperatures - Gel E	40
31	Shear Rate vs. (Shear Stress Less Yield Stress) at Various Temperatures - Gel E	41
32	Hysteresis Loop of Gel E at Various Temperatures	43
33	Thixotropy of Gel E at 25°C. Temperature	44
34	Viscosity Measurements of Gel E at Various Temperatures	45
35	Viscoelastic Measurement of Gel E - 4000 sec. ⁻¹ Shear Rate at -20°C. and 58°C. Temperatures	46
36	Flow Rate of Gel C in Relation to Pressure Drop	48
37	Influence of Concentration on Amount of Residual Gels	50
38	Influence of Temperature on Amount of Residual Gels	51
39	Temperature and Gelled Fuel Density Relationship	53
40	Net Heat of Combustion for Gels	58

LIST OF ILLUSTRATIONS (continued)

Figure		Page
41	Growth Curve of <u>Pseudomonas Aeruginosa</u> in the Aqueous Phase of Jet A and Gelled Jet A	59
42	Growth Curves of <u>Bacillus sp.</u> in the Aqueous Phase of Jet A and Gelled Jet A	60
43	Structure of Hydroxysterate Grease - Magnification: 15000X	64
44	Structure of Silica Base Grease - Magnification: 15000X	65
45	Structure of Indanthrene Blue-Base Grease - Magnification: 15000X	66
46	Structure of AB Gelling Agent in Jet A Fuel - Magnification: 39000X	67
47	Structure of AB Gelling Agent in Jet A Fuel - Magnification: 56000X	68
48	Structure of AB Gelling Agent in Jet A Fuel - Magnification: 77000X	69
1-1	Dependence of (k) on the Inverse of Temperature	1-2

LIST OF TABLES

Table		Page
1	Yield Stresses at Various Temperature and Gelling Agent Concentration Levels	3
2	Temperature and Concentration Effects on the Values of Slope (n)	14
3	Temperature and Concentration Effects on the Values of Intercept (k)	14
4	Equilibrium Stress at Various Temperature and Concentration Levels	28
5	Relaxation Time at Various Temperature and Concentration Levels	29
6	Yield Stresses at Various Temperatures	38
7	Effect of Temperature on Values of Intercept (k)	42
8	Residual Gel on Aluminum Coupons	49
9	Comparison of the Variation of Density With Temperature for Gelled and Jet A Fuels	54
10	Ash Content of Gelled Fuel	54
11	Components of Ash in Gelled Fuel	56
12	Thermal Conductivity of Gelled Fuel	57
13	Net Heat of Combustion of Gelled Fuel	57
14	Effect of Gelled Fuel on Growth of <u>Hormodendrum SP.</u>	62
15	Growth of <u>Hormodendrum SP.</u> in Solid Test Systems	63
16	Summary of Gel Properties (Gel E)	75

INTRODUCTION

Purpose

The purpose of this study was to use the fuel thickened with the Anheuser-Busch (AB) gelling agent as a model; perform on it rheological characterization, describe the pertinent parameters and set forth a preliminary profile specification to guide future development.

Background

Since 1964, the Federal Aviation Administration has actively carried out a research program designed to reduce the fire hazard associated with the crash of aircraft. As a result of this continuous study, thickened fuels were shown¹ to be both effective and safe. Of all the methods of thickening, gellation with suitable agents appears to be particularly promising.

Recent FAA sponsored research² indicated that gelled fuels, in addition to possessing the prerequisite crash-safe properties, must be fluid enough to drain from fuel cells without extensive modification of the aircraft fuel system. Therefore, it is imperative that a gelled fuel be developed that meets this criterion. The rheological properties of the fuel must be quantitatively defined so that the fuels can be screened and only the best candidate be subjected to further testing.

A few of the numerous gelling agents examined by the FAA approach the qualifications required for safety and system compatibility. The Corn Products Research Section of the Central Research Department of Anheuser-Busch, Inc. has specifically developed a carbohydrate-based polymeric gelling agent for jet fuels. Fuel containing this gelling agent has met the preliminary NAFEC safety and rheological requirements. It has been demonstrated to be a versatile and promising gelling agent.

The main text of the report is divided into five major sections. The first two sections describe rheological characterizations; the third covers the physical properties, compatibility and structure of the gelled fuels. The measured properties are discussed and the detailed experimental procedures are described in separate parts entitled, "Experimental Procedures." The summary section integrates the individual findings and presents an overall discussion of the gelled fuel. Findings of this investigation are itemized and listed in the concluding section.

Results and Discussions

Program - A broad range of gel consistency is represented by four selected gel samples prepared with the AB gelling agent. The broad range is designed to permit ready interpolation of the data to the gel which is ultimately chosen. The four gel samples are identified in this section as A, B, C and D with the gelling agent concentrations of 2.73%, 2.03%, 1.67% and 1.11%, respectively. Concentrations are expressed as weight per cent throughout this report. Wherever possible, the gel properties are measured at five temperature levels (-52°C. to 52.8°C.).

Plasticity and Yield Stress - The gelled fuels exhibit non-Newtonian (i.e., variable shear-stress/shear-rate ratio) and plastic behavior with a small but definite amount of associated yield stress. The yield stresses (ψ) for each of the gels at various temperatures, are given in Table 1 and illustrated in Figure 1. The data indicate that in the higher temperature range (0-52°C.), the yield stress value of 230 ± 50 dynes/cm² is relatively independent of temperature and concentration. However, as the temperature drops below 0°C., the yield stress increases rapidly to approximately 2000 dynes/cm². The reduced temperature also magnifies the influence of concentrations on yield stress.

Shear Rate and Shear Stress Relationship - The non-Newtonian flow properties of the gelled fuel are demonstrated by the measurements of the shear rate and shear stress (σ) relationships. The shear rate was varied in 10 steps, covering a range of 74 sec.⁻¹ to 12,000 sec.⁻¹. Figures 2, 3, 4 and 5 illustrate the relationship for each gel at several temperature levels. Within these limits the corresponding stresses developed in the gel ranges from 200 to 10,000 dynes/cm². From these graphs, one may obtain the "apparent viscosity" ($\bar{\eta}$), which is the ratio of shear stress to shear rate. The ratio is not a constant value; it is dependent on the shear rate. As expected of non-Newtonian and thixotropic fluids, the shear stress of these gels does not increase as rapidly at higher shear rate as at lower shear rate.

The data given above may be presented conveniently and usefully as a family of straight lines which permits easy interpolation and some degree of extrapolation. When the difference between shear stress and yield stress ($\sigma - \psi$) is plotted against the shear rate on a logarithmic scale (Figures 6, 7, 8, 9), the lines are represented by the following linear equation:³

$$\log (\sigma - \psi) = \log k + n \log \dot{\gamma} \quad (1)$$

where: σ = shear stress

ψ = yield stress

$\dot{\gamma}$ = shear rate

k, n are constants

TABLE 1

YIELD STRESSES AT VARIOUS TEMPERATURE AND GELLING AGENT CONCENTRATION LEVELS

<u>T</u> °C.	YIELD STRESSES, dynes/cm ²			
	Concentration, Weight %			
	<u>2.73(A)</u>	<u>2.03(B)</u>	<u>1.67(C)</u>	<u>1.11(D)</u>
52.8	290	240	190	170
25.0	250	210	190	180
0.0	260	240	210	170
-20.7	800	600	500	380
-52.0	2200	2100	1700	1300

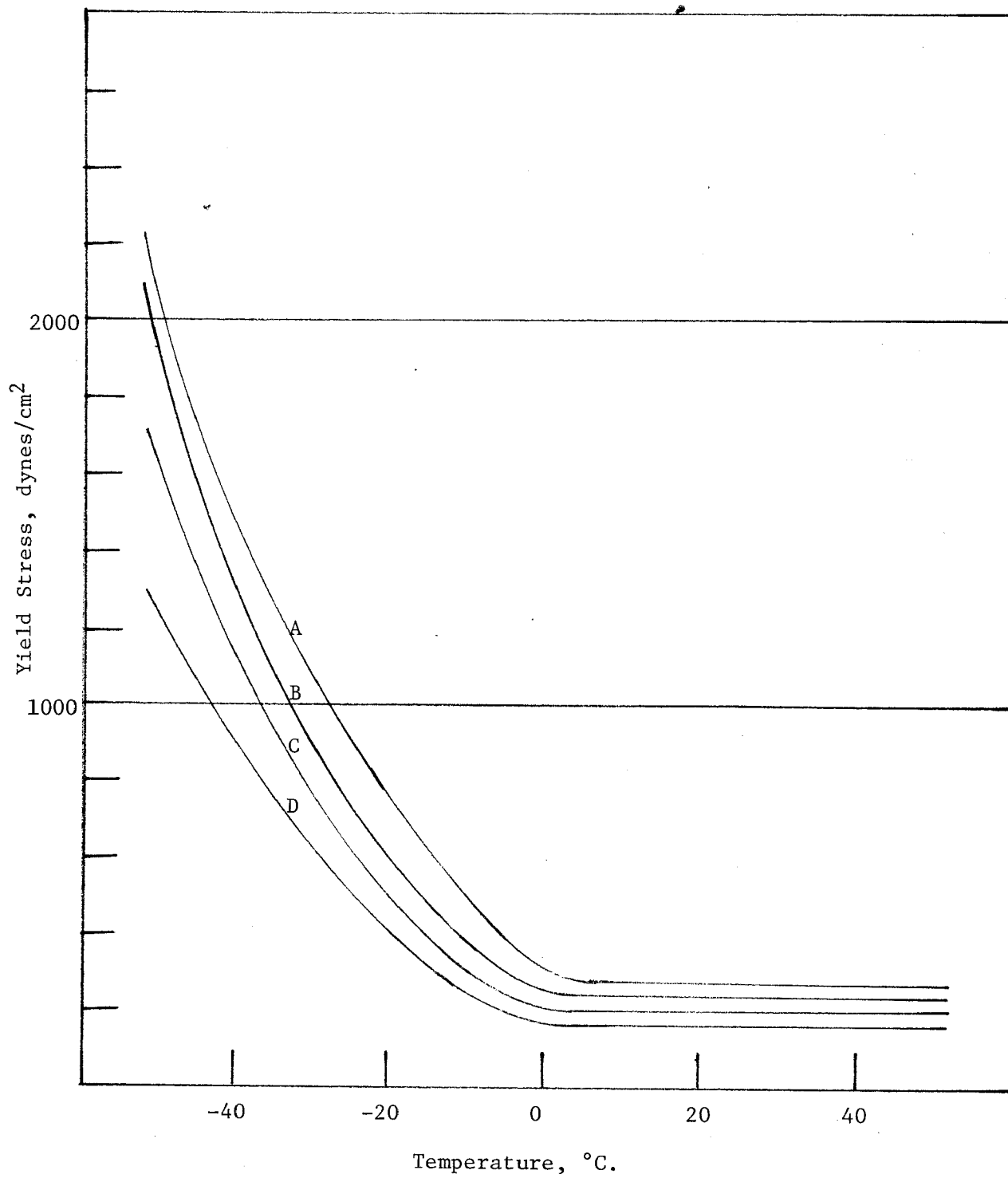


Fig. 1 - Yield Stresses of Gels at Various Temperatures

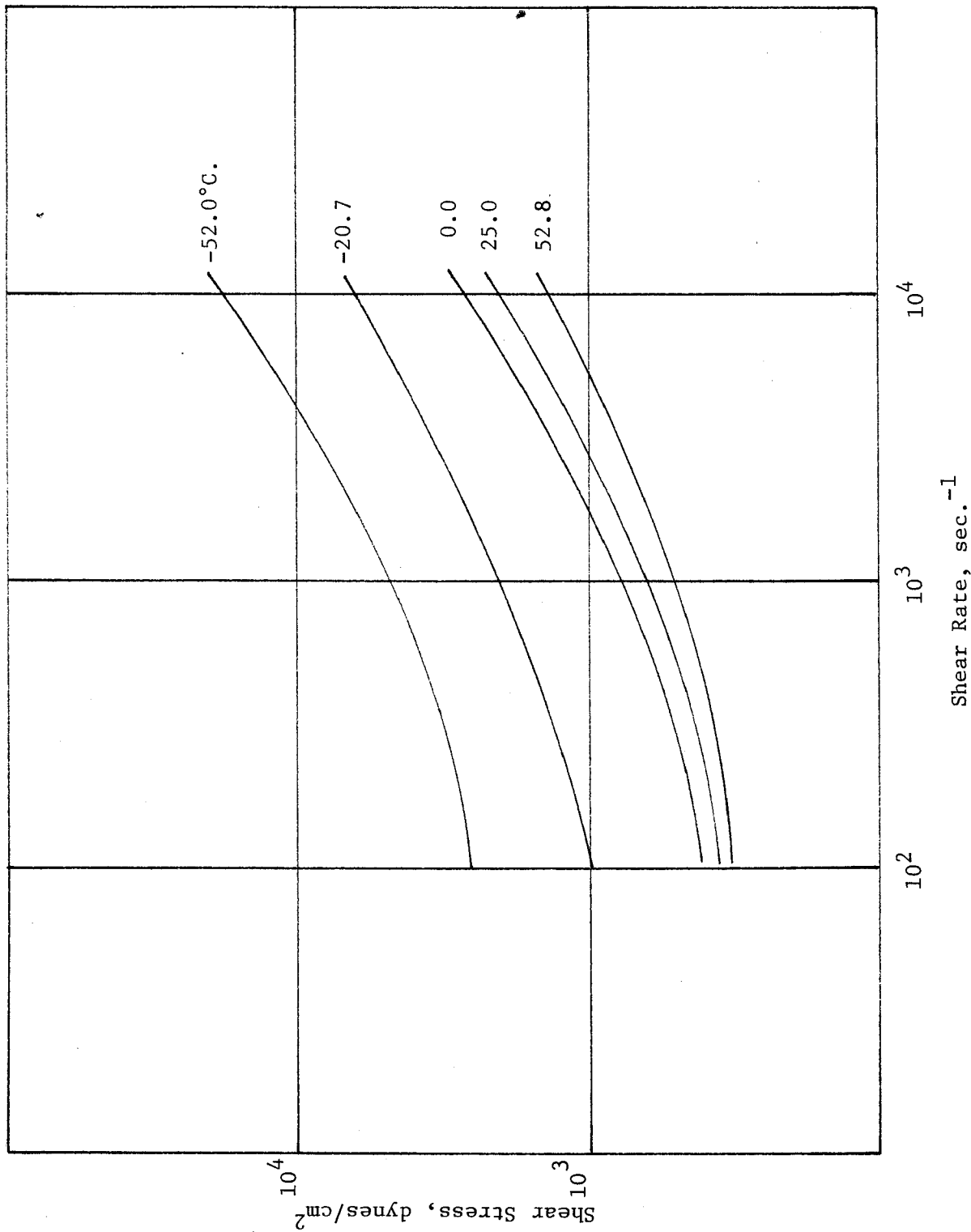


Fig. 2 - Shear Rate vs. Shear Stress at Various Temperatures - Gel A

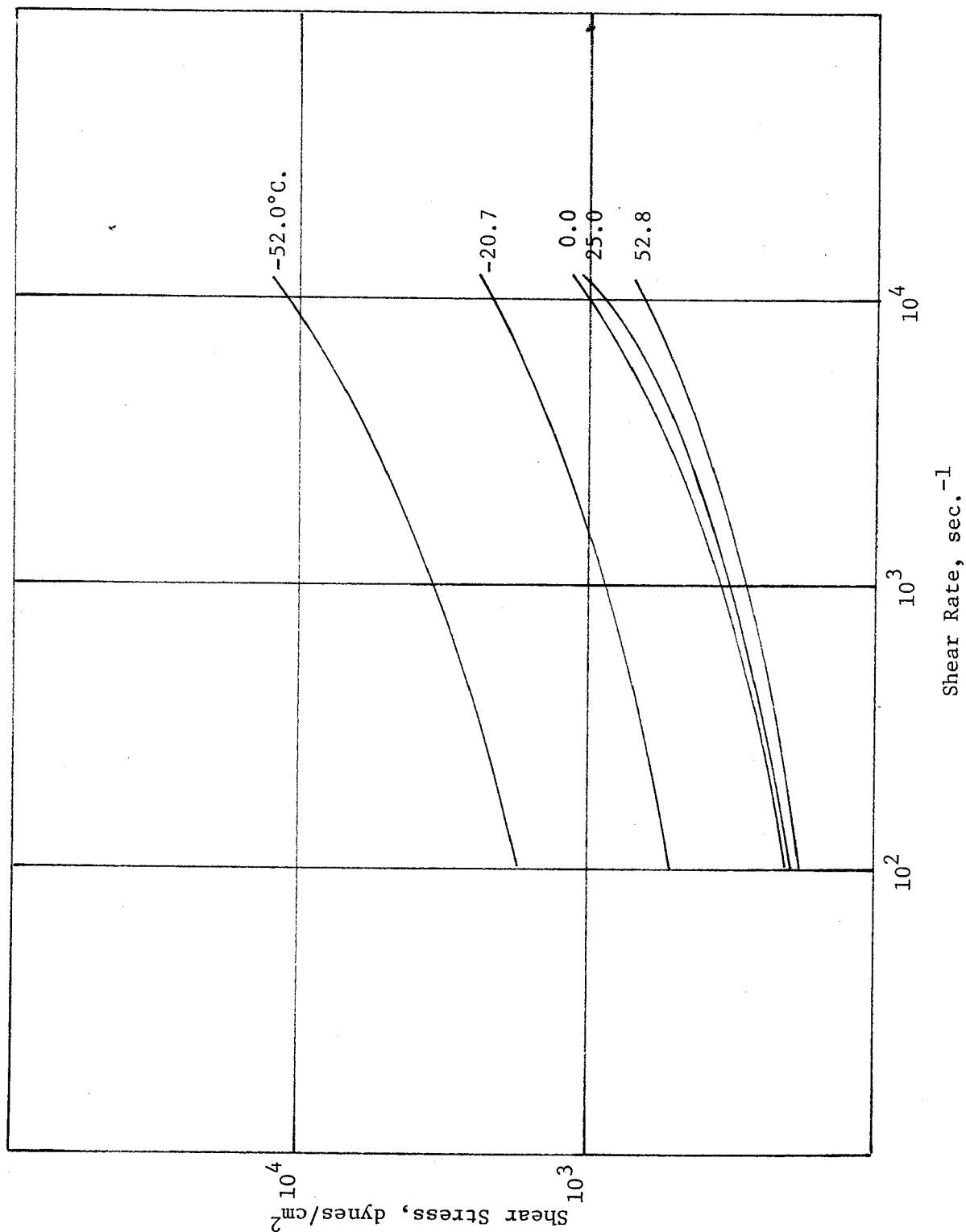


Fig. 3 - Shear Rate vs. Shear Stress at Various Temperatures, Gel B

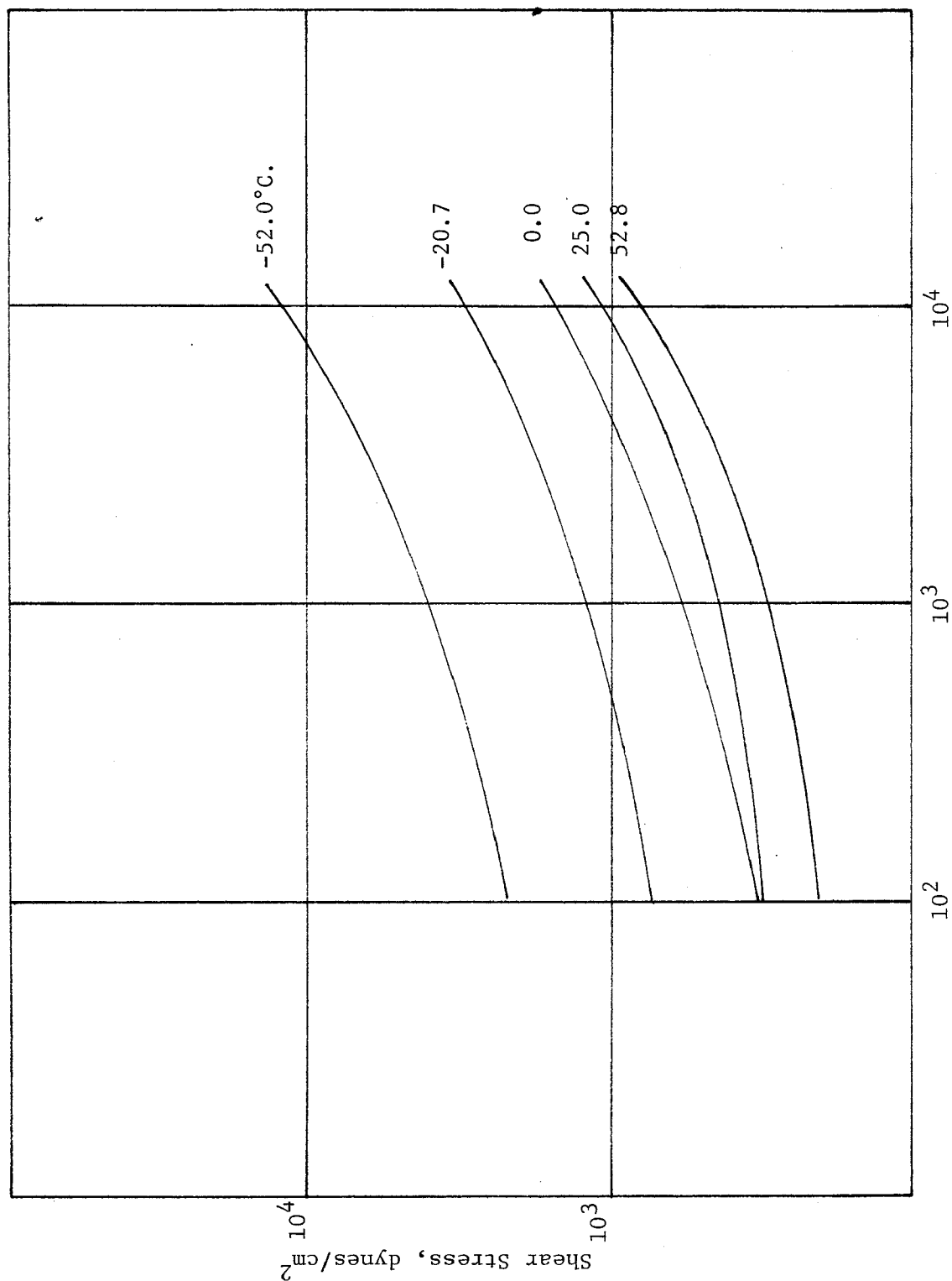


Fig. 4 - Shear Rate vs. Shear Stress at Various Temperatures - Gel C

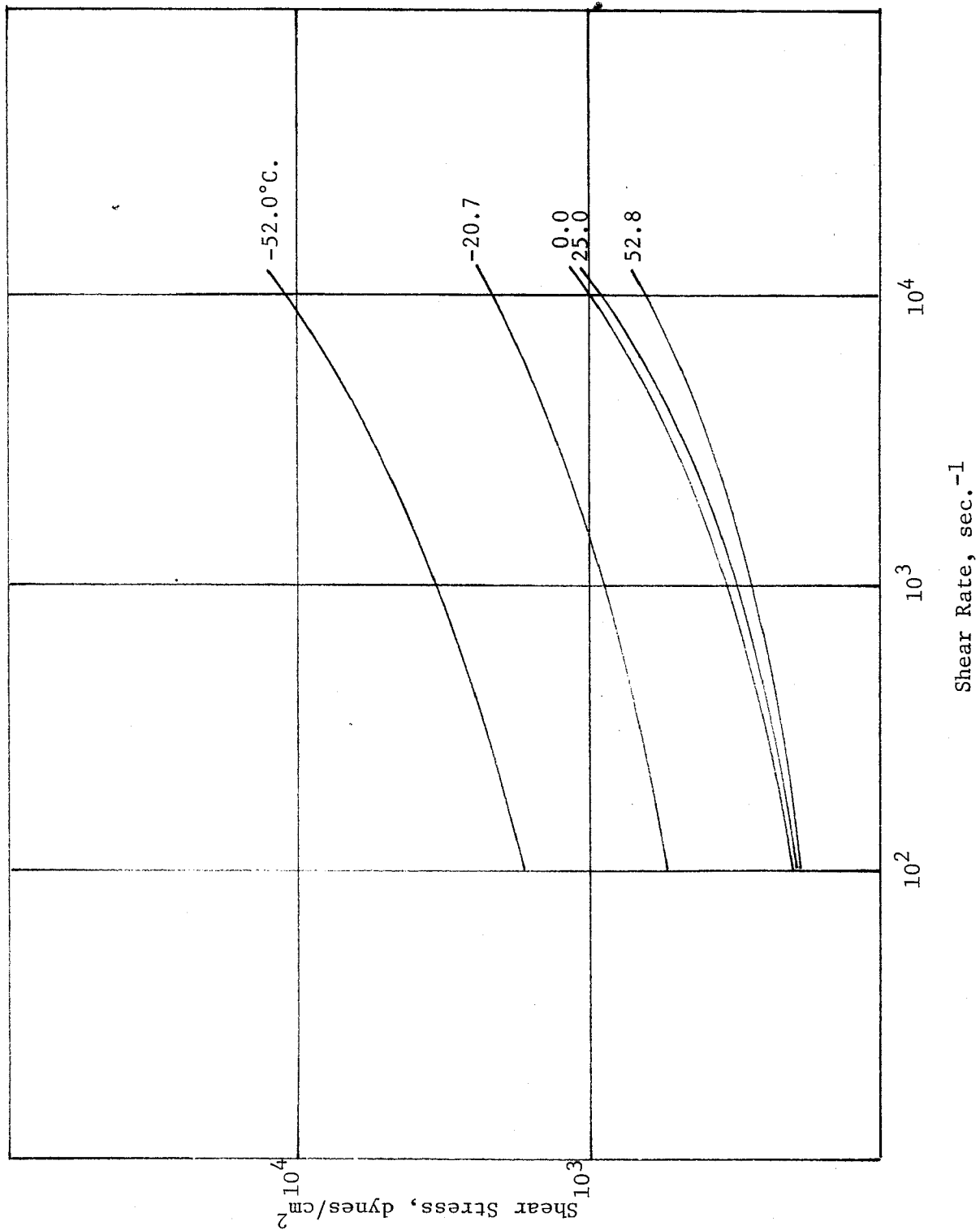


Fig. 5 - Shear Rate vs. Shear Stress at Various Temperatures - Gel D

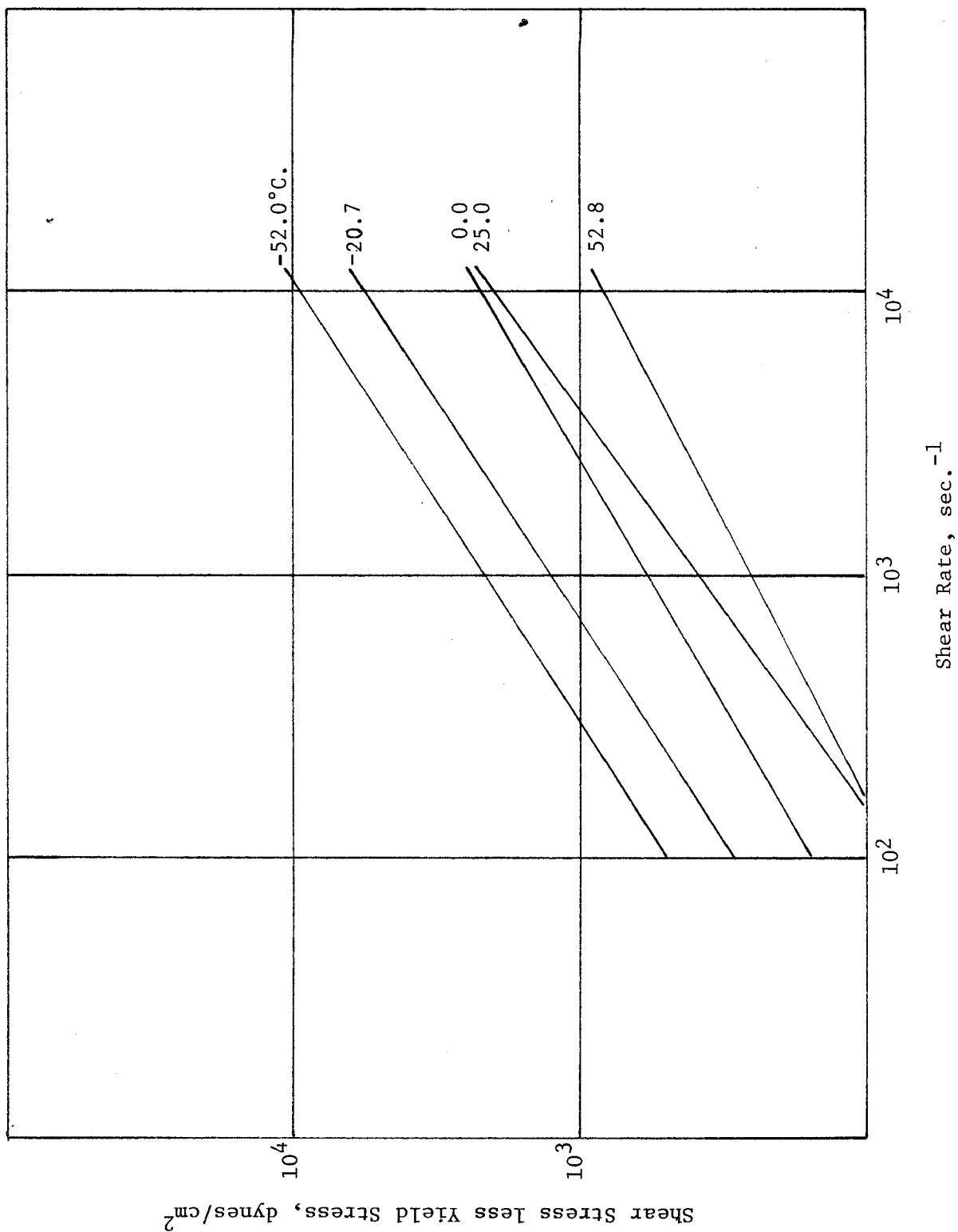


Fig. 6 - Shear Rate vs. (Shear Stress less Yield Stress) at Various Temperatures - Gel A

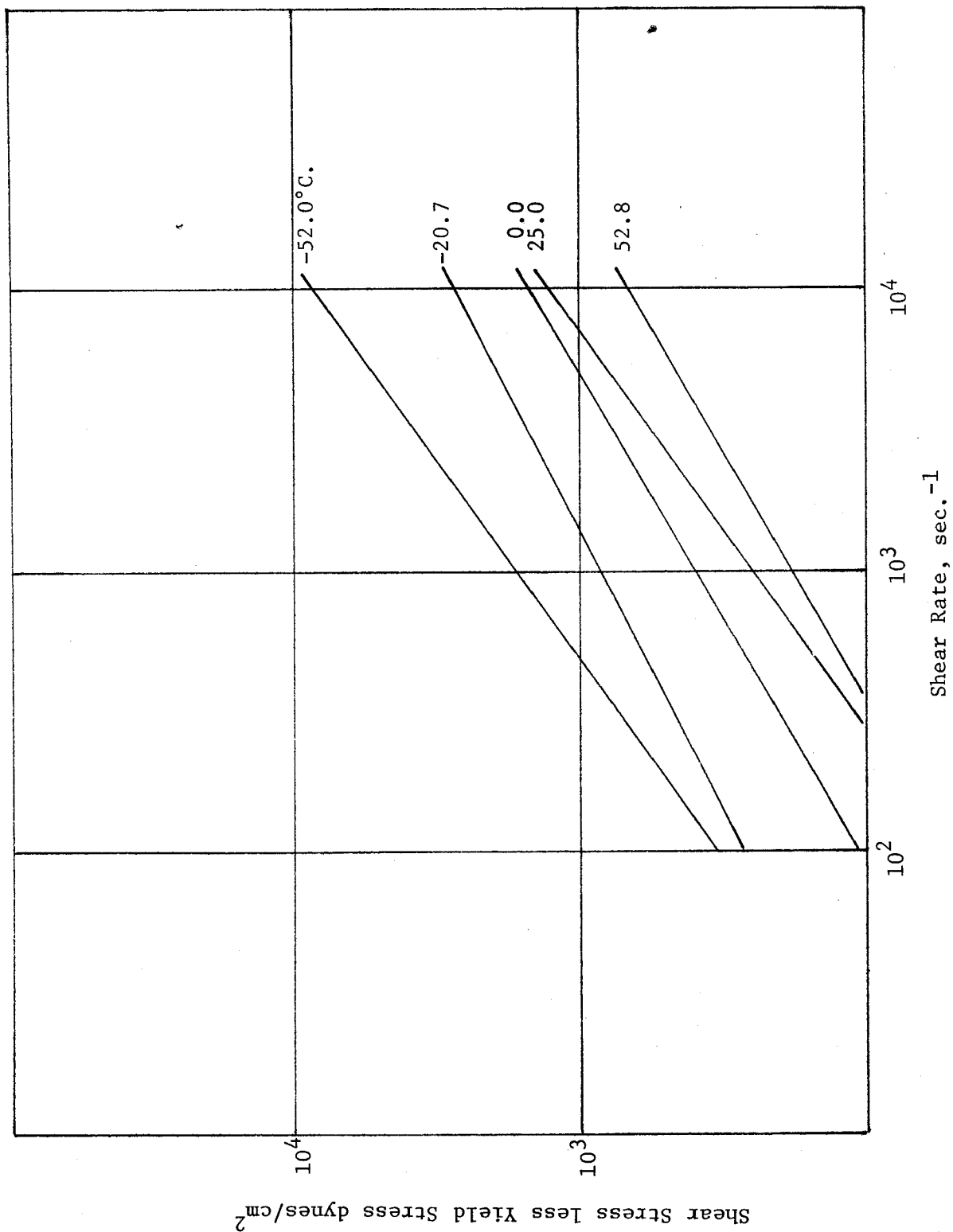
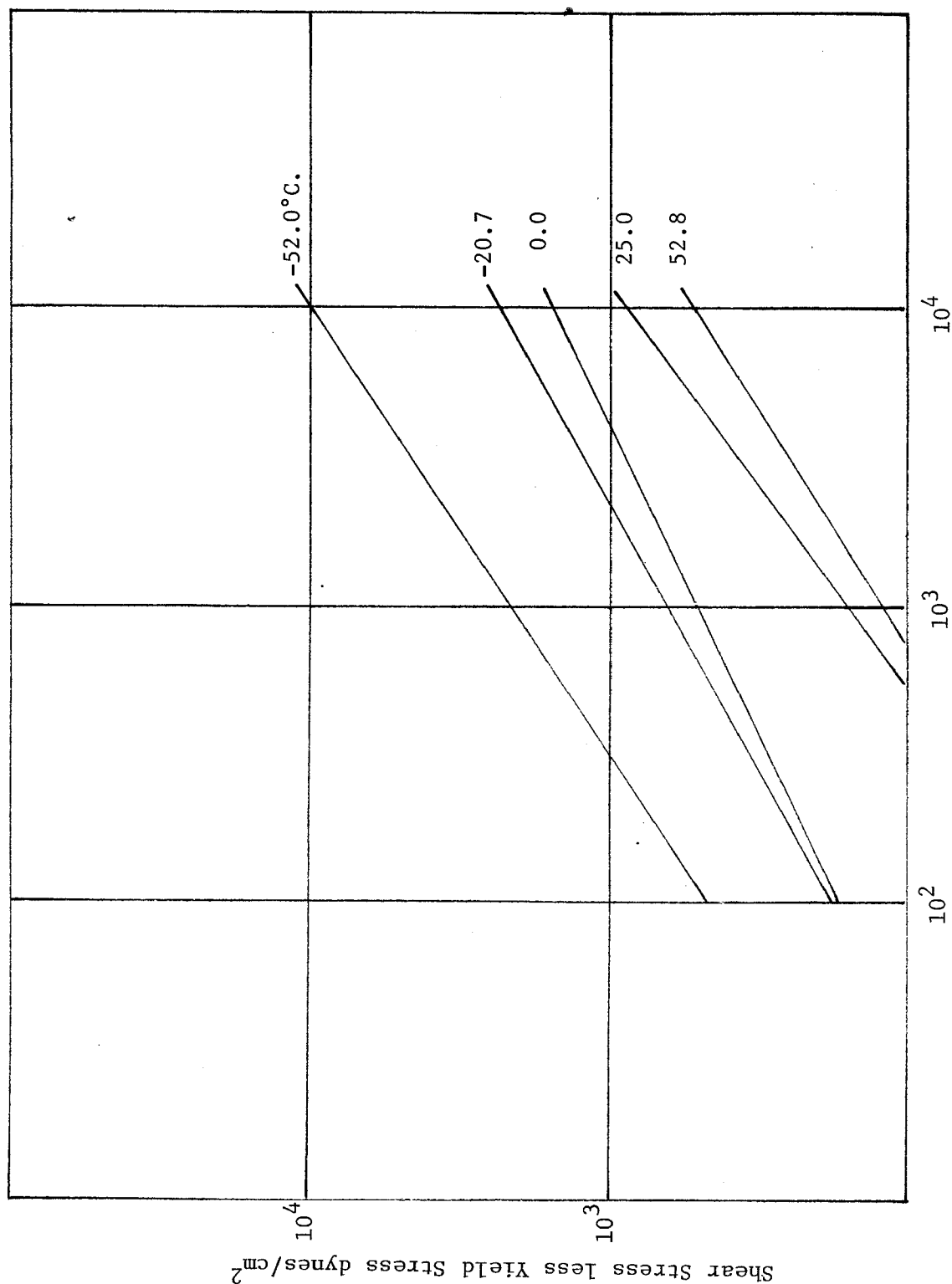


Fig. 7 - Shear Rate vs. (Shear Stress less Yield Stress) at Various Temperatures - Gel B



Shear Rate, sec.⁻¹

Fig. 8 - Shear Rate vs. (Shear Stress less Yield Stress) at Various Temperatures - Gel C

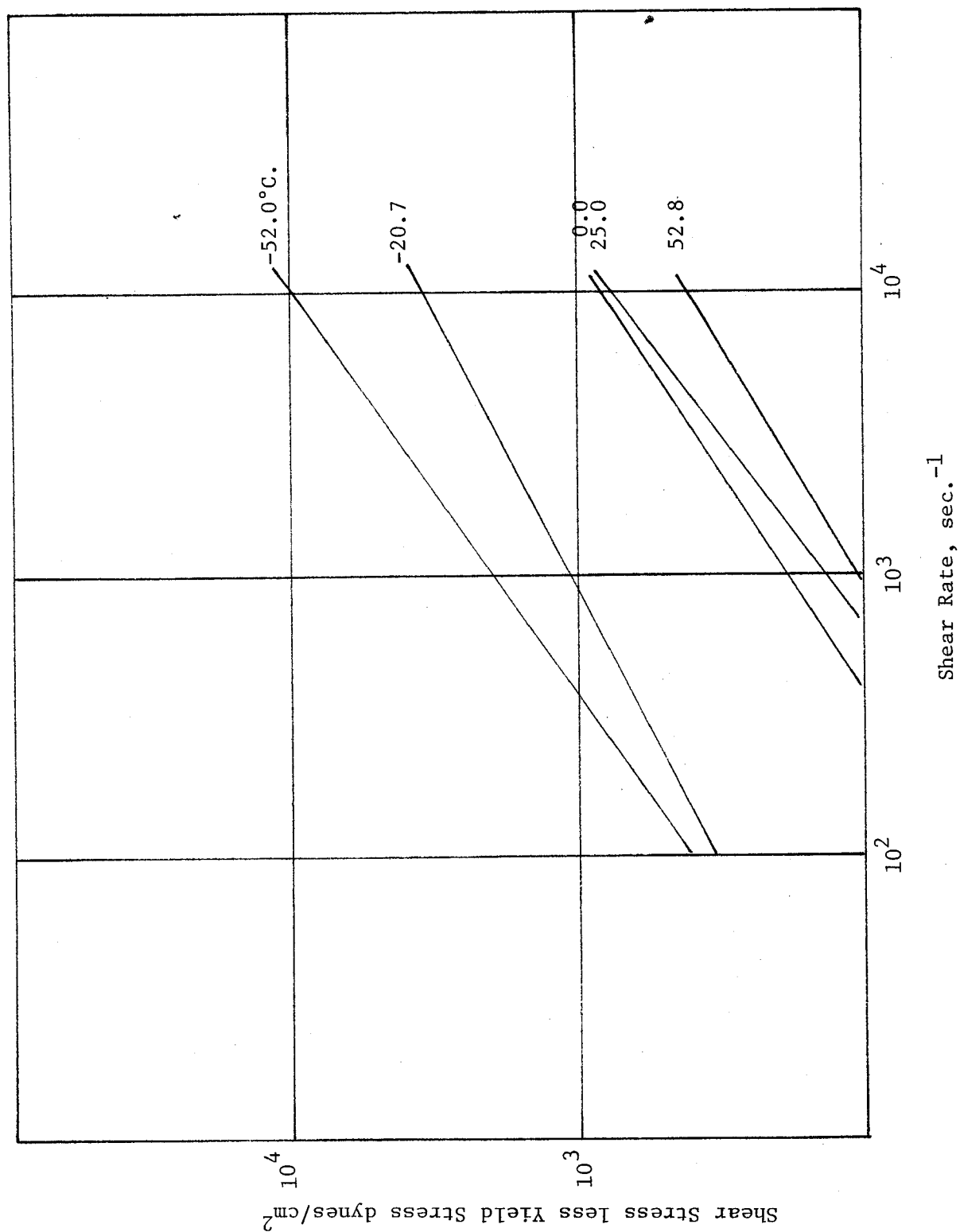


Fig. 9 - Shear Rate vs. (Shear Stress less Yield Stress) at Various Temperatures - Gel D

Equation (1) may also be written as:

$$(\sigma - \psi) = k \dot{\gamma}^n \quad (2)$$

which is its more familiar form, commonly referred to in rheology as the power law.⁴

The data in Figures 6, 7, 8 and 9 were analyzed by the method of least squares. The constants in Equation (1) are given in Tables 2 and 3. They hold true for the gelled fuel within the concentration range of 1.11 to 2.73%, the temperature range of -52°C. to 53°C., and shear rates from 75 sec.⁻¹ to 12,000 sec.⁻¹. A more detailed mathematical analysis of the data is given in Appendix A.

While the logarithmic plots represented by Equation (1) conveniently relate the shear stress to shear rate under various conditions, one finds it difficult not to speculate on the usefulness or the significance of the slope (n) and intercept (k) of the plot (Appendix A). We believe that these functions may aid the estimation of the flow rate of gels in pipes.

Wohl⁵ had proposed an equation characterizing the flow of non-Newtonian fluid as:

$$Q/\pi R^3 = 1/\sigma_w \int_0^{\sigma_w} \sigma_a^2 F(\sigma_a) d\sigma_a \quad (3)$$

where: Q = volumetric flow rate

R = radius of pipe

σ_w = shear stress at wall of pipe

σ_a = shear, stress in axial direction
at radius r.

TABLE 2

THE TEMPERATURE AND CONCENTRATION EFFECT ON THE VALUES OF SLOPE (n)

SLOPE (n) $\times 10^{-2}$

TEMP.	Concentration, Weight %			
°C.	<u>2.73</u>	<u>2.63</u>	<u>1.67</u>	<u>1.11</u>
52.8	62.0 $\pm$ 2.6	57.7 $\pm$ 0.7	61.9 $\pm$ 4.9	49.4 $\pm$ 5.3
25.0	72.1 $\pm$ 2.3	68.6 $\pm$ 3.9	73.3 $\pm$ 3.1	70.4 $\pm$ 3.3
0.0	56.5 $\pm$ 0.6	55.7 $\pm$ 1.5	63.7 $\pm$ 2.7	57.1 $\pm$ 2.3
-20.7	65.0 $\pm$ 1.1	50.5 $\pm$ 2.1	58.0 $\pm$ 4.9	49.0 $\pm$ 5.8
-52.0	64.7 $\pm$ 2.1	65.0 $\pm$ 2.2	66.7 $\pm$ 2.4	73.9 $\pm$ 3.8

TABLE 3

THE TEMPERATURE AND CONCENTRATION EFFECT ON THE VALUES OF INTERCEPT (k)

TEMP.	INTERCEPT, k $\times 10^2$ Concentration, Weight %			
°C.	<u>2.73</u>	<u>2.03</u>	<u>1.67</u>	<u>1.11</u>
52.8	55.0 $\pm$ 8.5	54.5 $\pm$ 2.4	24.5 $\pm$ 12.8	63.7 $\pm$ 17.7
25.0	41.1 $\pm$ 7.3	35.3 $\pm$ 11.9	1.5 $\pm$ 9.2	2.5 $\pm$ 10.1
0.0	108.1 $\pm$ 5.8	95.4 $\pm$ 4.8	61.8 $\pm$ 7.3	55.4 $\pm$ 6.9
-20.7	115.3 $\pm$ 10.6	142.8 $\pm$ 71.0	105.7 $\pm$ 16.4	157.4 $\pm$ 19.1
-52.0	138.7 $\pm$ 6.5	138.6 $\pm$ 7.0	132.0 $\pm$ 7.5	103.6 $\pm$ 11.6

This equation (3) can be modified (Appendix B) to allow its application to AB gelled fuel systems.

The flow rates of Gel C at 25°C. were calculated for 1-in. and 2-in. diameter pipes and the results are shown in Figure 10. The mathematical exercise described herein and in Appendices A and B exemplifies the potential application of the logarithmic plot beyond its obvious value in stress-rate relationships.

Thixotropy - The AB gelled fuel responds quickly to shearing action as was demonstrated in terms of the resultant shear stress (Figure 11). The shear stress declines as the shearing action persists, even though the rate of shear is constant. This is the phenomenon of thixotropy, and it is a useful property because it facilitates the transfer of gelled fuel.

In Figure 11, Gel A exhibits the greatest thixotropy while Gel D shows the least at a temperature of 25°C. and a constant shear rate of 525 sec.⁻¹. The more thixotropic the gel, the longer will be the shearing time required to reach an asymptotic shear stress value. The time required for Gel A to reach one-half of its asymptotic shear stress of 550 dynes was 29 seconds; the time for Gel C to reach its final shear stress of 210 dynes was 20 sec.

This shear thinning, however, is reversible. After a short period of rest the gels completely regain the original viscosity, as is illustrated in Figure 12. The gels at higher concentrations recover less rapidly than those at lesser concentrations. Gel A (2.73%) requires 8 minutes to reach its original stress value at the shear rate of 3.3 sec.⁻¹; whereas Gel C requires 5 minutes. The time required to shear thin is relatively insensitive to the shear rate.

The shear stress-shear rate relationship of the gel is dependent not only upon time but also its previous shearing history. A thixotropic system can be studied under gradually increasing and then decreasing rate of shear without waiting for equilibrium to be reached. The so-called hysteresis loops obtained from such measurements are shown in Figures 13, 14, 15, 16. In Figure 13, as the shear rate is gradually increased, the initial shear stress is large. When the shear rate reaches beyond 2000 sec.⁻¹, the change in shear stress is nearly constant. When the shear rate is reduced gradually, the corresponding shear stress is significantly less than the stresses developed along the upward path. The initial high stress reflects the structural resistance of the solution to the shearing action. As the structure is disrupted by the shearing, its resistance to shear becomes weaker and hence the reduced rate of increase in stresses. The difference in stresses between the upward and downward path indicates the extent of structural disruption. There is much less structural disruption in the gels of lower concentrations (Figures 15, 16) than in cases of higher concentrations (Figures 13, 14).

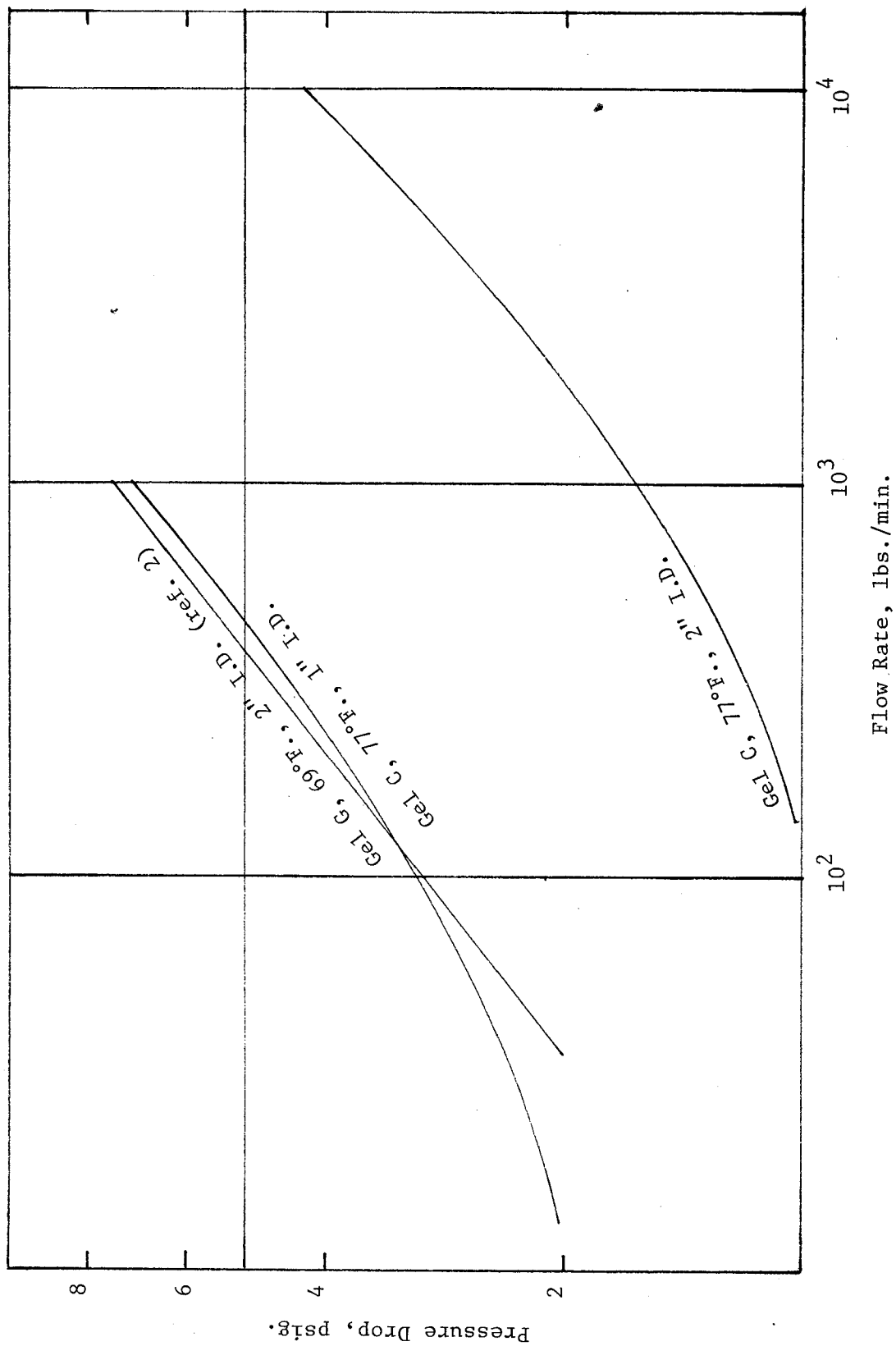


Fig. 10 - Calculated Flow Rate of Gel Through 10-Foot-Long Straight Pipe

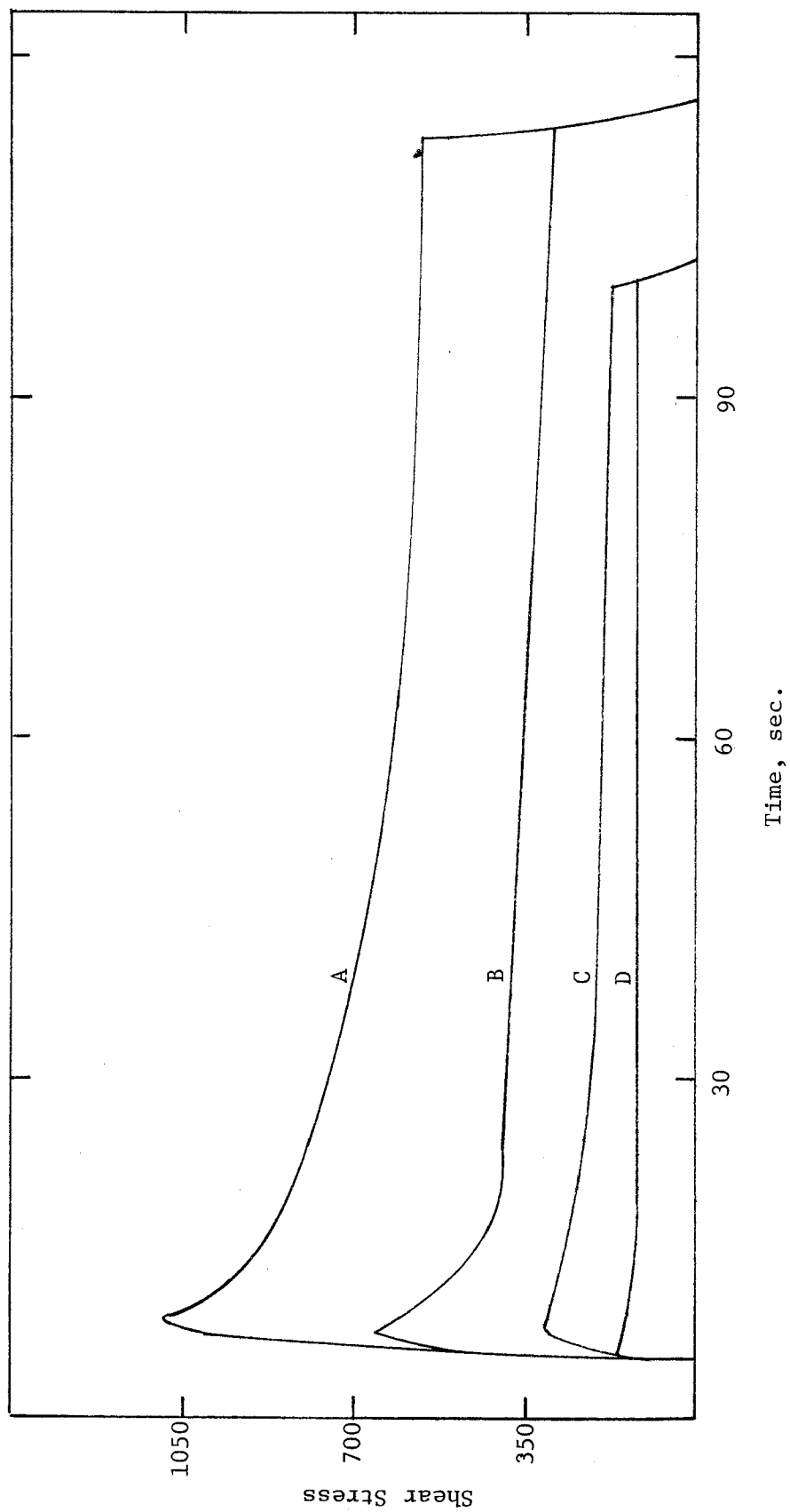


Fig. 11 - Thixotropy of Gels A, B, C and D at 25°C. Temperature

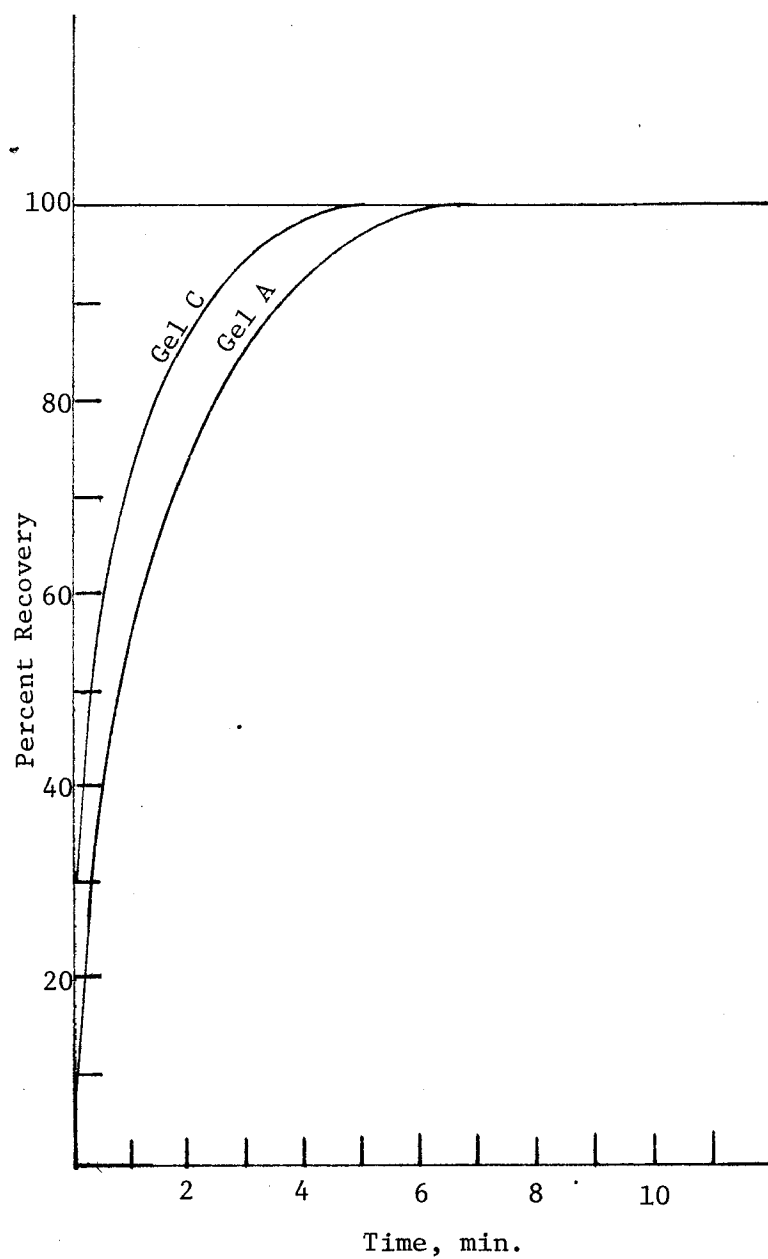


Fig. 12 - Stress Recovery of Gels

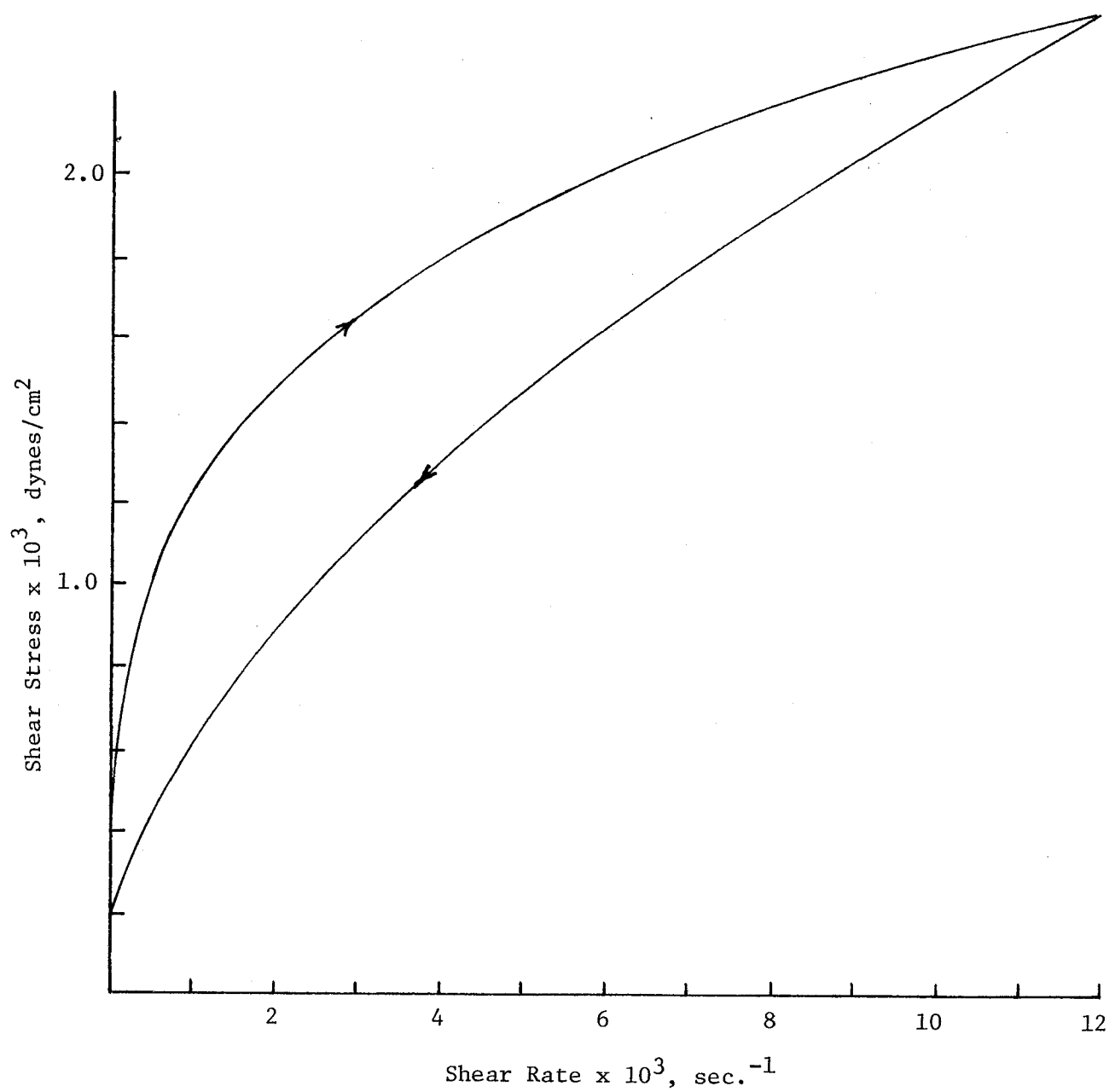


Fig. 13 - Hysteresis Loop of Gel A

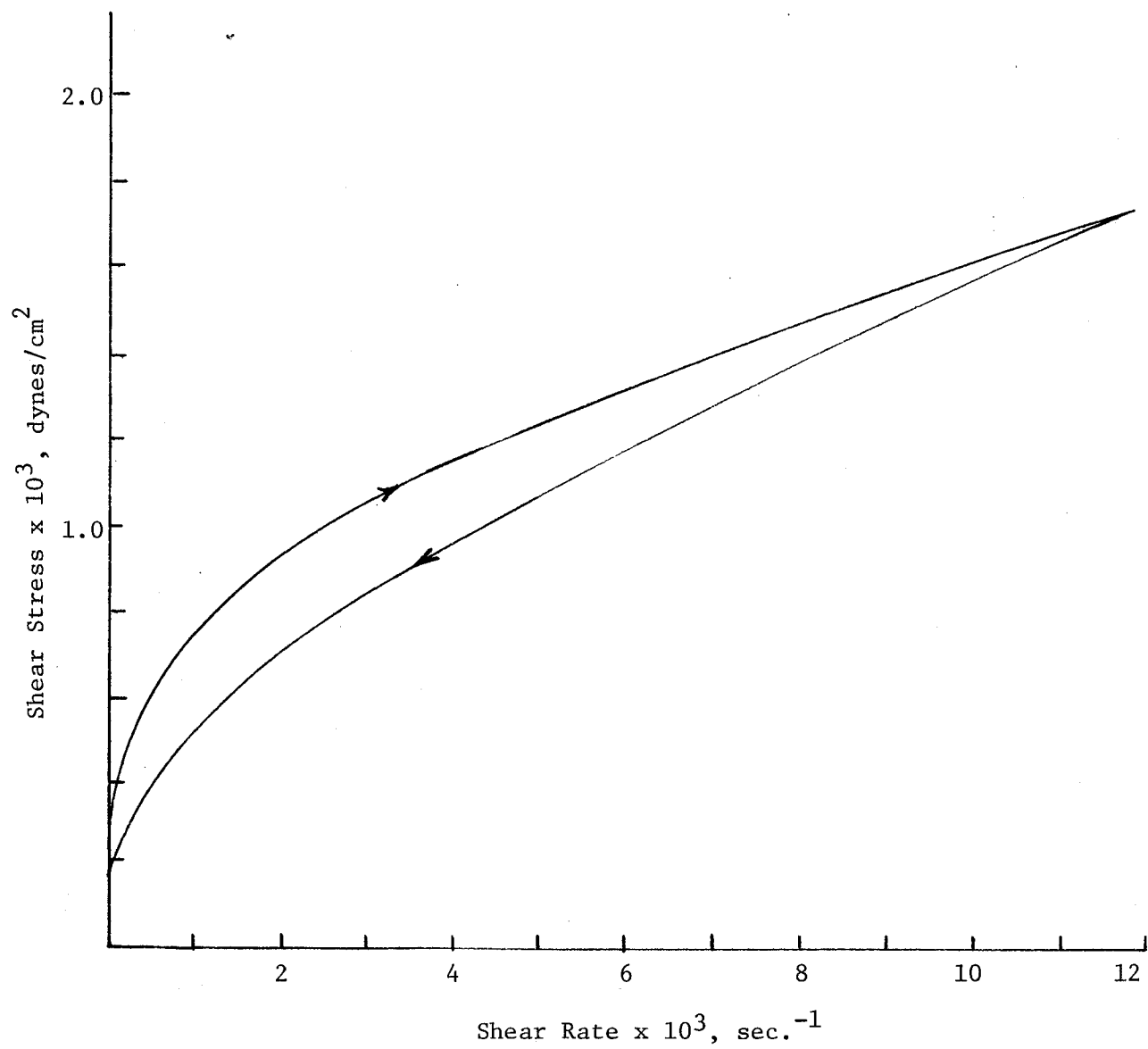


Fig. 14 - Hysteresis Loop of Gel B

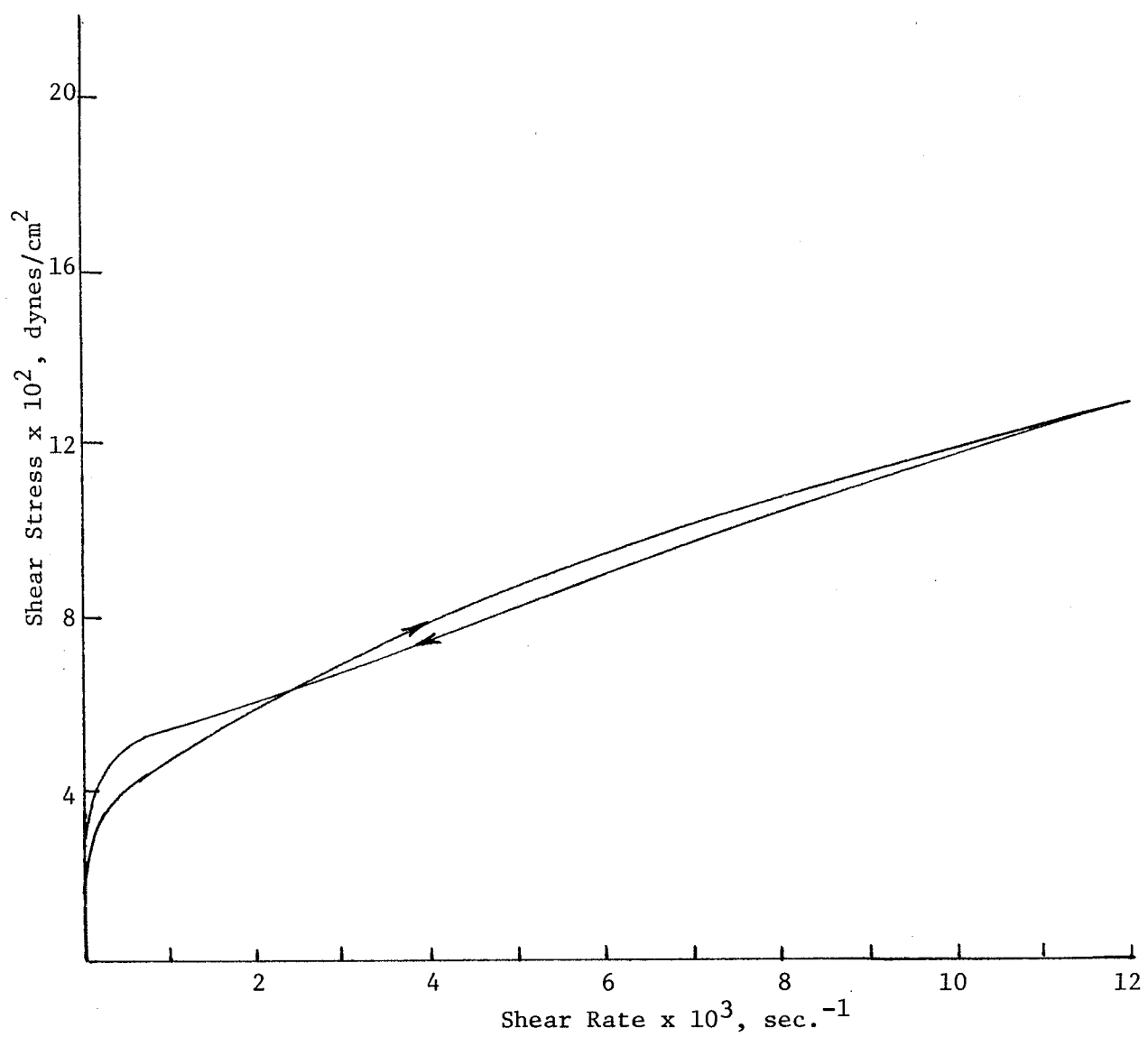


Fig. 15 - Hysteresis Loop of Gel C

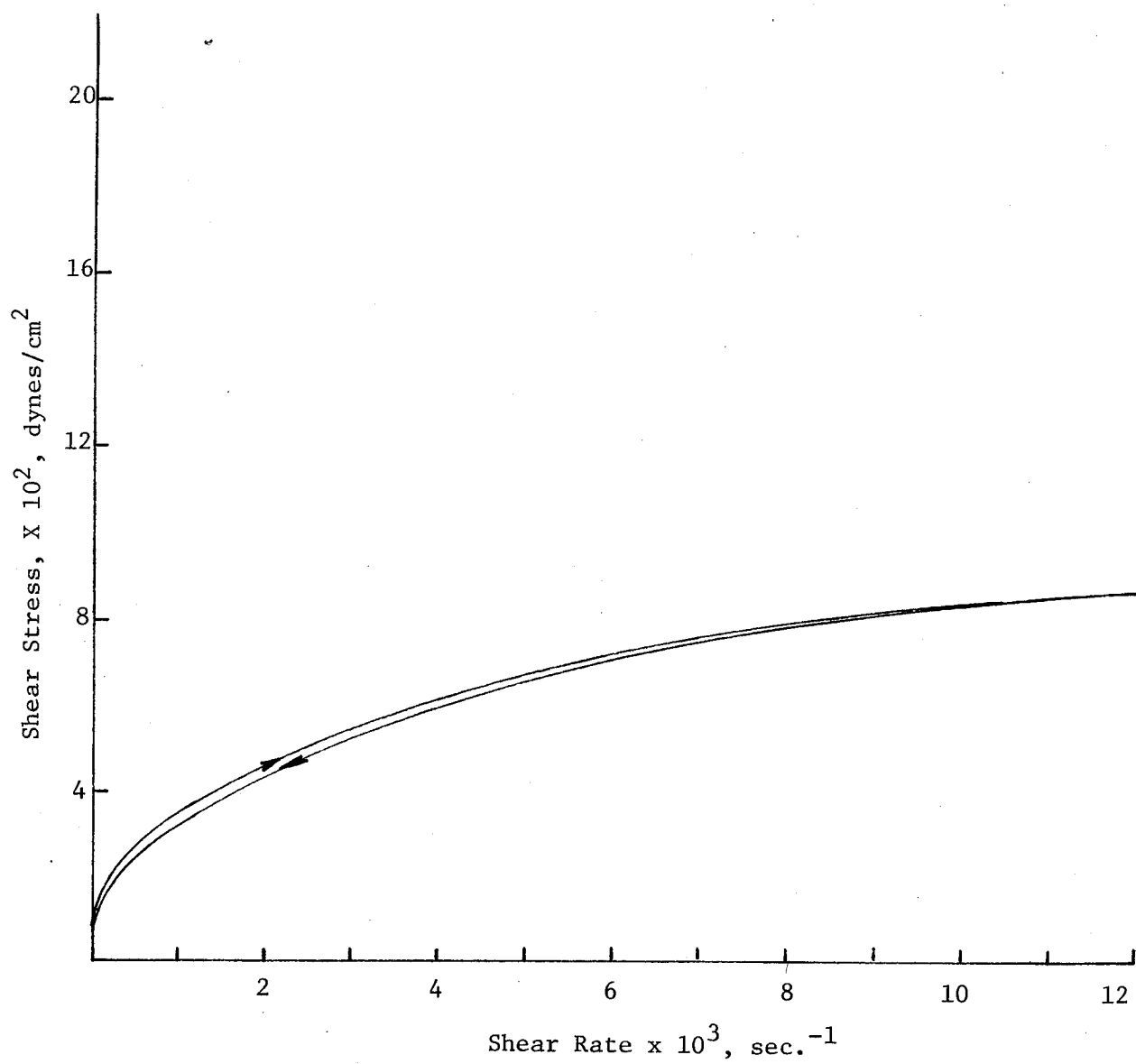


Fig. 16 - Hysteresis Loop fo Gel D

Viscoelasticity - The difficulty in relating rheological measurements to crash-fire safety tests has been quite apparent to investigators for some time. Gelled fuels of similar viscosity and yield stress do not produce similar safety scores. It is also evident that gels have various degrees of structural coherence that significantly affect their flow behavior, their tendency to adhere to the walls of containers, and their misting pattern under impact. So far this degree of structural coherence has eluded quantitative evaluation. We have attempted to deal with the evaluation of this structural coherence under the rather general term, "viscoelasticity."

A viscoelastic⁶ substance exhibits both viscous and elastic properties. For example, when it is subjected to force, it deforms continuously (viscosity), but when the force is removed it tends to return spontaneously, though not completely to its original state (elasticity).

A number of sophisticated instruments⁷ are available for the measurement of viscoelasticity. In order to meet the contract deadline, it was decided to carry out the preliminary study of viscoelasticity on the available Rotovisco-Viscometer with its viscoelastic attachment.

Viscoelasticity in this case is manifested by two parameters, the equilibrium stress (σ_{∞}) and the relaxation time (τ_{rx}). They were arbitrarily chosen for the time being and there could be others added latter for consideration. When an applied shear at constant rate is suddenly terminated, the induced stress in the gel decays rapidly. The stress does not decay to zero but to a final finite level. This is not a commonly observed occurrence in fluids and the final stress at equilibrium is termed the "equilibrium stress." The time required for the stress to decay to a predetermined fraction ($1/e$ or 36.9%) of the stress differential ($\sigma_0 - \sigma_{\infty}$) is defined as the relaxation time. The symbol σ_0 stands for the steady state stress at constant shear rate just prior to the cessation of the shearing action. Figures 17, 18, 19 and 20 depict the viscoelastic behavior of Gel A at 10° and 40°C. Figures 21 to 23 show the influence of concentration on equilibrium stress. Equilibrium stress varies directly with gel concentration, and has no measurable value in gels more dilute than Gel C. The relationships of the two viscoelastic parameters with gel concentration and temperature are shown in Table 4 and Table 5. The equilibrium stress is dependent upon temperature and concentration but is independent of shear rate up to a critical value where it becomes zero.

The equilibrium stress of the gels above the critical shear rate and temperatures is zero. Gels above these temperatures (sheared above the critical rate) flow as viscous non-Newtonian liquids and exhibit no viscoelasticity.

The relaxation time is a function of concentration, temperature and shear rate. In all cases where the equilibrium stress is nil, a measurable relaxation time, e.g. 1.2 sec., was observed. This small measurement of 1.2 sec. can be considered as some limiting constant of the instrument.

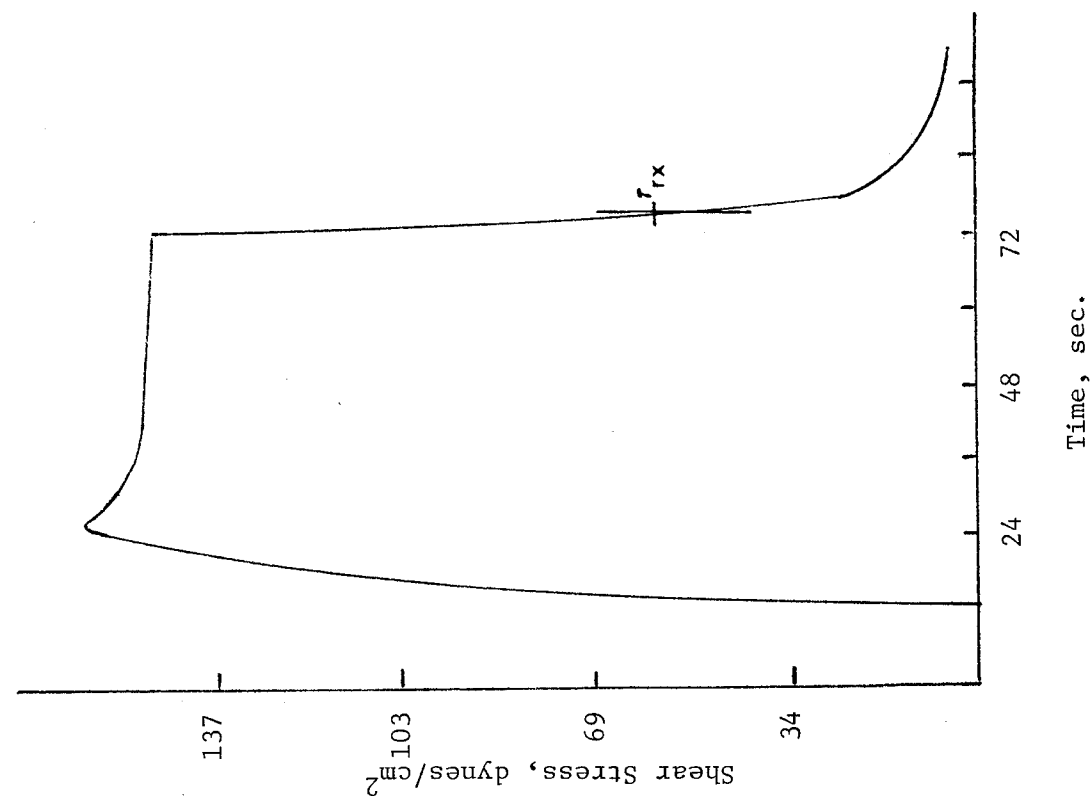


Fig. 17 - Viscoelasticity Measurements
of Gel A - 20 sec.⁻¹ Shear
Rate at 10°C. Temperature

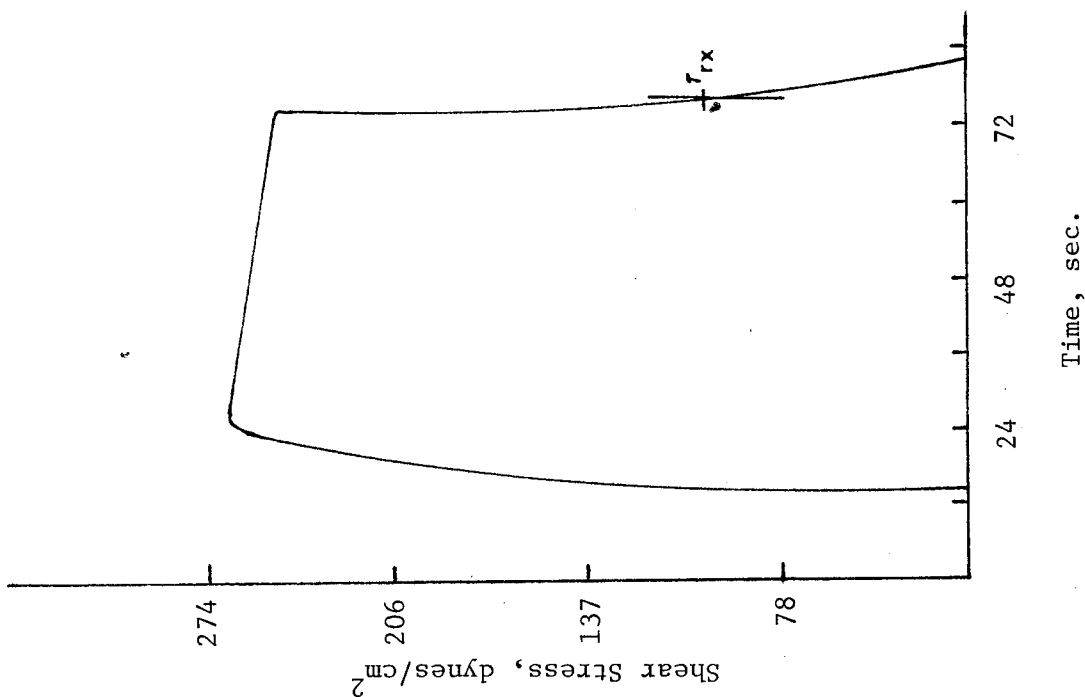


Fig. 18 - Viscoelasticity Measurements
of Gel A - 264 sec.⁻¹ Shear
Rate at 10°C. Temperature