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A STANDARDIZED GASOLINE SIMULANT FOR USE IN LABORATORY INVESTIGATION OF FLAME FUELS

FAE & FLAME BRANCH
MUNITIONS DIVISION

DECEMBER 1974

FINAL REPORT: May to November 1973

AIR FORCE ARMAMENT LABORATORY
AIR FORCE SYSTEMS COMMAND • UNITED STATES AIR FORCE
EGLIN AIR FORCE BASE, FLORIDA

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents the results of a study to develop a gasoline simulant for laboratory evaluation of flame fuels. Variations in the chemical make-up of gasoline due to brand, regional, and seasonal formulations indicate the need for a gasoline substitute in the laboratory. A number of pure solvents were selected to approximate the constituents in gasoline; testing was conducted on several mixtures alone and in different flame fuel formulations. By varying the composition of the mixture, the chemical, physical, and rheological properties of the simulant were formulated with properties that closely approximate those of gasoline. The final composition (by weight) of the simulant is

(Continued)

Item 20. Continued

n-pentane, 40%; hexanes, 20%; isooctane, 5%; toluene, 10%; xylene, 20%; and paraffin oil, 5%. This laboratory substitute for gasoline will serve as a standard for comparing potential flame fuels and correlation of data from different laboratories.

PREFACE

This technical report is based on a study conducted at the Air Force Armament Laboratory, Armament Development and Test Center in support of Project 10820302.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

FENDRICK J. SMITH, JR., Colonel, USAF
Chief, Munitions Division

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SECTION I

INTRODUCTION

Considerable effort is being directed toward maximizing the favorable properties of old and new flame fuels through laboratory, air gun, sled track, and full-scale testing. A very important step in this systematic investigation is the quantitative evaluation of certain physical properties of the fuel in the laboratory. The reliability of these studies has always suffered because of the wide variation in the constituents of commercial gasolines. This variation is due to the preparation of flame agents with commercial gasolines that have different compositions, depending on the commercial brand, season of the year, and region of the country from which the gasoline is procured.

In a recent study designed to characterize and optimize Napalm B (Reference 1), gas chromotography and ultraviolet spectrometry were used to analyze a variety of regular grade commercial gasolines. Comparison of the 26 component fractions revealed a 3 to 14 percent variation in aromatic content and a 0 to 8 precent variation of volatile components. The adverse effect of these gasoline variations on flame fuel research was recognized by Edgewood Arsenal in 1965 (Reference 2) and by the Air Force Armament Laboratory in more recent studies to evaluate the rheological properties of flame fuels with a capillary extrusion rheometer (Reference 3). Rheological investigations of incendiary gels and napalm at Edgewood Arsenal (Reference 2) resulted in the formulation of a standardized mixture of pure hydrocarbons as a substitute for gasoline for use as a solvent in rheological studies. This mixture was designated the Napalm Test Solvent (NTS). Its composition by volume is benzene, 15.0%; cyclohexane, 18.8%; n-heptane, 61.1%; and isooctane, 5.2%. Due to low volatility and high aliphatic character, NTS does not simulate many of the physical characteristics of gasoline. Therefore, a new study in this area was considered necessary.

Bartich and Bourn (Reference 1) provide guidelines on the required percentages of various chemical components for a gasoline simulant. Four commercial types of regular grade gasoline (ESSO, Phillips 66, Sinclair, and Gulf) were analyzed by gas-liquid chromatograph, ultraviolet spectroscopy, and infrared spectroscopy. That work furnished the following average percentages of components in gasoline: C_4-C_{10} hydrocarbons, 40%; C_{10}-C_{17} hydrocarbons, 19%; toluene, 12%; and xylene and other aromatic hydrocarbons 29%.

References:
1. H. A. Bartich and M. Bourn (Atlantic Research Corporation), Characterization and Optimization of Napalm B (U), Air Force Armament Laboratory Technical Report AFATL-TR-67-91, August 1967 (Confidential).
2. F. H. Gaskins, Rheological Properties and Performance of Napalm B in Comparison to Standard Flame and Incendiary Agents, Edgewood Arsenal Technical Report EATR 4155, February 1968 (Unclassified).
3. T. Floyd, Techniques in Evaluation Rheological Properties of Flame Fuels with a Capillary Extrusion Rheometer. Air Force Armament Laboratory Technical Report AFATL-TR-75-17, January 1975 (Unclassified).

The objective of the effort discussed in this report was to develop a simulant to replace the gasoline constituent of flame fuels investigated in the laboratory and thereby to eliminate the variables associated with gasoline. The desired end product was a gasoline substitute made up of a minimum number of pure solvent components that would closely approximate the physical properties of commercial gasoline. Such a simulant is necessary in the preparation of experimental flame fuel formulations, since it is important to hold the formulation properties constant. It is important to note that the simulant is for laboratory experimentation and not for the final flame fuel in inventory firebombs.

SECTION II

TEST PROCEDURES

The first step in this investigation was to identify the properties that a gasoline simulant must have in order to function as a good substitute for gasoline. Tests have shown that the properties of gasolines may vary considerably; therefore, five commercial gasolines were selected as standards. Measurements of physical and chemical properties were then made on these gasolines alone and on Napalm B formulated using each of the different standard gasolines. This section contains a listing of each of the properties determined, along with a description of each test. The properties of each gasoline simulant candidate were also evaluated with these tests.

1. GASOLINES

Chevron	Regular
Phillips 66	Regular
Union 76	Regular
Gulf	Good Gulf
Motor Pool Gasoline	Federal Specification VV-G76A

2. PROPERTIES STUDIED OF GASOLINE

a. Specific gravity	ASTM Test D153 (25 ml pycnometer)
b. Flash point	ASTM Test D56-70 (Tag closed test) ASTM Test D1310 (Tag Open-Cup)
c. Vapor pressure	ASTM Test D323-58 (Reid Method)
d. Aniline and mixed aniline points	ASTM Test D611-64 (Test performed by Mckinley Climatic Laboratory, Eglin AFB)
e. Viscosity	ASTM Test D1343 (Falling ball viscometer)
f. Heat of combustion	ASTM Test 240-64 (Parr bomb calorimeter)

g. Evaporation Rate.

A 75 mm by 15 mm aluminum dish was placed on a top loading balance having a precision of $\pm$ 5 mg. A 10 cc sample was placed in the dish, and the weight was recorded. After 5 minutes, the sample weight was rechecked, and the evaporation weight was expressed in grams evaporated per minute.

h. Burn Time.

Utilizing a disposable syringe, 10 cc of test solvent or formulation was placed in a 75 mm by 15 mm aluminum dish, which was placed in the center of a burn chamber. The sample was ignited with a Bunsen burner and monitored with recorders for millivolt output; burn time was recorded with an electrical digital timer accurate to $\pm$ 0.1 second.

i. Heat Flux.

The experimental burn setup consisted of four Thermowest narrow view angle (5^{o}) radiometers, which were placed 5 cm from the burn pan edge with the sensing disc of the radiometers 1.5 cm above the pan edge. These radiometers were mounted in aluminum blocks with set screws. Both the blocks and the face of each radiometer were then sprayed with Aerodag G (aerosol of graphite, emissivity of 0.89) to minimize energy reflections. The radiometers were calibrated for an air flow of 1 liter per minute and connected to a water supply for cooling at a rate of 250 cc per minute. The millivolt output from each recorder was converted directly to heat flux (cal/cm^2 sec) from the calibration curve supplied with each radiometer. The average curve height over the period of burn was then multiplied by the burn time in seconds to get the flux for each radiometer. The total heat flux (cal/cm^2) was taken as the sum of the four radiometer outputs averaged over three burns of the same formulation.

3. PROPERTIES OF NAPALM B FORMULATIONS

The Napalm B formulations were prepared according to Purchase Description Assignment No. 5 (27 April 1966). The constituents of the standard Napalm B formulations were polystyrene (Dow 666), 46%; one of the standard gasolines, 33%; and benzene, 21%. The experimental formulations were the same except that gasoline simulant candidates were used instead of gasoline. Polymer solutions of 200 grams were prepared by adding the appropriate chemicals to 8-ounce glass jars, sealing with Teflon lined lids, and then placing the jars on a slowly rotating wheel. This mixing technique prevented polymer degradation due to shear forces during mixing. A homogeneous solution resulted within 2 to 3 days of mixing depending on the gasoline or simulant candidate utilized.

It should be noted that the production Napalm B formulation used in this study was of unknown age and the gasoline used was unknown. Production Napalm B viscosity will vary due to age, handling techniques, and volatility of the gasoline utilized for formulation. Observations in this laboratory indicated slight evaporation of gasoline and benzene due to poor handling technique which could easily result in a substantial increase in viscosity. Production Napalm B utilized in an earlier work (Reference 4) exhibited properties of varying volatility and inhomogeneity within a batch of the flame agent. However, all other samples in this study were freshly prepared and monitored for evaporation by weighing the samples.

a. Burn Time

The burn time test described in Section II.2.h. was also used to get burn times for all Napalm B formulations.

b. Heat Flux

The heat flux of all Napalm B formulations was measured by the heat flux test described in Section II.2.i.

Reference:

4. R. L. Long (Monsanto Research Corporation), Flame Agents for High Velocity/Low Temperature Use, Air Force Armament Laboratory Technical Report AFATL-TR-71-55, May 1971 (Unclassified).

c. Viscosity Versus Shear Rate

Formulation flow data were obtained with a capillary rheometer (Monsanto Research Corporation) modified for low temperature and high shear conditions. The test method is detailed in an earlier study (Reference 3) done in this laboratory. Test runs were made at 23.9°C, 0°C, and -3.9°C. Lower Temperatures were not possible because of condensation in the rheometer barrel. Data for evaluation were the apparent viscosity (N_a) in centipoise units and the shear rate ($\dot{\gamma}_w$) in reciprocal seconds. From these data, a flow curve (log-log plot) of apparent viscosity versus shear rate permitted analysis of the degree of shear thinning experienced over the shear rate range measured.

d. Elasticity (Recoverable Shear)

The die-swell method used for this test is also detailed in an earlier study. The technique involved photographing the liquid strand as it emerged from the capillary under pressure. By measuring the amount of die-swell/expansion after shearing, the percent memorty was determined. This calculation involved the diameter of the extruded straind (D_i), the capillary orifice diameter (D_o), and the following equation:

$$\text{Percent Memory} = \frac{D_i - D_o}{D_o} \times 100$$

The percent memory was then plotted as a function of the shear rate.

4. RESULTS

Table 1 lists the physical property data (excluding data obtained with the capillary rheometer) for motor pool gasoline and Chevron regular gasoline. For simplicity, only two of the five standard gasolines were utilized in this initial table. All of the standard gasolines were used for rheological property, mixed aniline point, and vapor pressure data since these comparisons were more important. These results appear in later tables.

Properties for NTS are also listed in Table 1 for comparison with gasoline. Obvious differences of NTS include a significantly lower vapor pressure and a higher mixed aniline point. The rather high mixed aniline point is indicative of low aromatic content, 15% by volume, compared to approximately 40% by volume in gasolines. This test (Reference 5) is a measure of the aromatic content of a solvent, i.e., the lower the aniline point, the higher the aromatic content. The aniline point for a solvent is thus an indication of its "solvent power" for dissolving certain rubbers, resins, high polymers, etc.

The differences in values of mixed aniline point for the motor pool and Chevron regular gasoline (Table 1) suggested two extremes of solvent power. The mixed aniline points obtained for the other three standard gasolines (Table 2) fell between the two original values (motor pool gasoline and Chevron regular). Thus, the desired mixed aniline point for the gasoline simulant was a median value between the two gasolines in Table 1.

Reference:

5. R. L. Long (Monsanto Research Corporation), Flame Agents for High Velocity/Low Temperature Use, Air Force Armament Laboratory Technical Report AFATL-TR-71-55, May 1971 (Unclassified).

TABLE 1. PHYSICAL PROPERTIES OF NTS[a], MOTOR POOL, AND CHEVRON GASOLINE

TEST	NTS[a]	MOTOR POOL	CHEVRON
Specific Gravity	0.7280	0.7536	0.7326
Reid Vapor Pressure (lb/in^2)	1.8	8.5	8.6
Viscosity, 25.6°C (cp)	0.6055	0.5862	0.5823
Burn Time (10 cc sample) (sec)	72.5	92.0	110.0
Evaporation Rate (10 cc sample) (g/min)	--	0.185	0.190
Heat of Combustion (cal/g)	11,143	10,821	10,741
Mixed Aniline Point	136.5°F 58.1°C	113.7°F 45.4°C	133.3°F 56.3°C
Heat Flux (10 cc sample) (cal/cm^2)	54.6	69.9	89.0
Formulation Burn Time (sec) (10 cc sample)	207.4	184.0	208.7
Formulation Heat Flux (cal/cm^2) (10 cc sample)	186.7	189.5	200.4
Formulation Viscosity, 25.6°C (cp)	19,300	22,467	19,733
Flash Point	-28.9°C	-28.9°C	-28.9°C

[a]Napalm Test Solvent

TABLE 2. GASOLINES UTILIZED FOR COMPARISON WITH THE SIMULANT

GASOLINE	VAPOR PRESSURE	MIXED ANILINE POINT
Motor Pool	8.5 lb/sq in	113.7°F (45.4°C)
Good Gulf	9.3 lb/sq in	121.0°F (49.4°C)
Phillips 66 (Regular)	9.9 lb/sq in	123.5°F (50.8°C)
Union 76 (Regular)	8.7 lb/sq in	132.5°F (55.8°C)
Chevron (Regular)	8.6 lb/sq in	133.3°F (56.3°C)
GS	8.4 lb/sq in	127.2°F (52.9°C)

SECTION III

EXPERIMENTAL

The previous section identified the properties that a gasoline simulant must have if the simulant is to function as a good substitute for the gasoline constituent of flame fuels; thus, chemicals were selected to approximate the composition of gasoline. As these chemicals were combined in different proportions, the properties of the resulting mixtures were adjusted in the middle of the range of standard gasolines (Table 3).

1. CHOICE OF SIMULANT COMPONENTS

Initial simulant formulations were composed of various combinations of the following solvents:

n-pentane	Certified spectroanalyzed
hexanes	Certified ACS B.P. range 66.6° to 68.0°C
toluene	Certified ACS
xylene	Certified ACS B.P. range 138.9° to 140.0°C
paraffin oil	N.F., white, light Saybolt viscosity $\frac{125}{135}$
isooctane (2,2,4-trimethyl pentane)	Certified ACS 0.8619 to 0.867 (specific gravity)

The hexanes and n-pentane were chosen for the C_4-C_{10} hydrocarbon fraction; they were essential to attain a reasonable vapor pressure Paraffin oil was chosen to represent the C_{10}-C_{17} hydrocarbon fraction; toluene and xylene were chosen to simulate the aromatic hydrocarbons. An isooctane (2,2,4-trimethyl pentane) component was added in the final simulant candidates to raise the mixed aniline point to a median value between that recorded for motor pool and Chevron gasolines.

2. EVALUATION OF SIMULANTS

The initial screening of simulants, as outlined earlier, involved the determination of basic physical properties for comparison with the data for motor pool and Chevron gasolines listed in Table 1. During the course of the study, additional tests on the more promising simulants included viscosity, evaporation rate, mixed aniline point, and heat flux. The criterion employed through all evaluations was that the more promising the simulant, the more screening tests performed.

Napalm B formulations prepared with the more promising simulants were evaluated for formulation heat flux, viscosity, and burn time. These data, along with the basic physical property data, were used to select the final gasoline simulant. An extensive rheological evaluation was made with Napalm B formulated with the final simulant and with each of the standard gasolines. A detailed analysis appears in the next section.

TABLE 3. PERCENTAGE CONTENT BY VOLUME OF SOLVENTS IN CANDIDATE SIMULANTS

Candidate Simulant	n-Pentane	Hexanes	Iso-Octane	Toluene	Xylene	Paraffin Oil
1	20	20	0	15	25	20
2	0	40	0	15	25	20
3	0	50	0	0	30	20
4	40	0	0	0	40	20
5	40	0	0	0	30	30
6	30	10	0	20	25	15
7	40	10	0	10	30	10
8	40	20	0	0	30	10
9	45	10	0	10	25	10
10	45	10	0	40	0	5
11	40	15	0	40	0	5
12	43	10	0	40	0	7
13	45	10	0	30	10	5
14	40	15	0	30	10	5
15	45	10	0	35	5	5
16	40	25	0	10	20	5
17[a]	40	20	5	10	20	5
18	40	10	15	10	20	5
19	45	5	20	10	15	5
20	40	15	15	10	15	5
21	35	25	5	10	20	5

[a]Gasoline Simulant for Flame Fuels

SECTION IV

RESULTS AND DISCUSSION

1. SCREENING OF CANDIDATE SIMULANTS

Table 3 gives the component percentages by volume of each candidate simulant. The initial five simulants were evaluated with the four screening tests presented in Table 4. Comparison of the data with the tests performed on motor pool gasoline and Chevron regular (Table 1) indicated comparable results only for the heat of combustion. First, the specific gravity of the gasoline simulant candidates was too high, while vapor pressure was low except in simulants 4 and 5 where n-pentane comprised the bulk of the hydrocarbon fraction below the C_{10} level. Due to the high percentage of paraffin oil, the burn times of simulants 1 through 5 were approximately twice as long as the gasolines.

Component percentages of simulants 6 though 10 were varied with the hope of more closely simulating the properties of the gasolines in Table 1. The results are recorded in Table 5. Specific gravity of these simulants was reduced to a value near that of gasoline. Simulant 10 data (Table 5), appeared acceptable, with respect to specific gravity, viscosity, burn time, heat of combustion, formulation burn time, and formulation heat flux. However, the heat flux was significantly higher than the gasolines, and the vapor pressure and formulation viscosity were both lower than for gasoline for this simulant. The mixed aniline point was acceptable, but a median value between the two gasolines (Table 1) was preferred.

Variation in the component percentages for the next five candidates brought simulants 12 and 15 close to the gasoline in all screening tests except burn data, formulation viscosity, and mixed aniline points (Table 6). Since the simulant would be formulated with different polymers in future evaluations, a value between that for the two gasolines would be indicative of a simulant with solvent power compatible with more polymers.

Table 7 shows data on the simulant with properties most comparable to that of gasoline. Formulation viscosity was slightly increased to a range exhibited by Napalm B. An increase in the mixed aniline point was observed with the addition of 5 percent isooctane and the adjusted (2:1) aromatic ratio of xylene to toluene (Table 3). Formulations with a simulant which contained more than 5 percent isooctane did not remain homogeneous on standing; these formulations were cloudy while a true solution of Napalm B is clear. Thus, simulant 17 was chosen as the gasoline simulant for flame fuels and is recorded as GS (gasoline simulant) in all subsequent tables and figures.

2. RHEOLOGICAL ANALYSIS

Present research efforts indicate the optimization of flame agents may depend mainly on viscosity and elastic properties at different shear rates over a temperature range of 0^{o} to $140^{o}F$. Earlier work (Reference 4) with flame agents for high velocity and low temperature use supports this indication. The most important evaluation of the gasoline simulant formulation was the rheological behavior exhibited at $-3.9^{o}C$ ($25^{o}F$) and $23.9^{o}C$ ($75^{o}F$) over a shear rate range of 10^{3} to 10^{5} sec^{-1}.

TABLE 4. DATA FOR CANDIDATE SIMULANTS 1 TO 5					
	CANDIDATE SIMULANTS				
Test	1	2	3	4	5
Specific Gravity	0.7834	0.7892	0.7715	0.7774	0.7762
Vapor Pressure (lb/in^2)	6.0	2.6	3.5	8.5	8.8
Burn Time (sec)	159.2	168.2	164.4	169.5	191.3
Heat of Combustion (cal/g)	10718	10712	10637	10633	10736

TABLE 5. DATA FOR CANDIDATE SIMULANTS 6 TO 10					
	CANDIDATE SIMULANTS				
Test	6	7	8	9	10
Specific Gravity	0.7827	0.7644	0.7402	0.7491	0.7466
Vapor Pressure (lb/in^2)	6.5	7.7	7.0	8.3	8.1
Viscosity (cp)	--	--	--	--	0.5832
Burn Time (sec)	149.2	141.6	136.7	136.2	104.6
Heat of Combustion (cal/g)	10653	[a]10958	[a]11093	[a]11023	10588
Mixed Aniline Point (^oF, ^oC)	--	--	--	--	115.8^oF 46.6^oC
Heat Flux (cal/cm^2)	129.8	117.5	108.0	113.0	104.5
Formulation Burn Time (sec)	--	--	--	--	198.3
Formulation Heat Flux (cal/cm^2)	--	--	--	--	197.3
Formulation Viscosity[b] (cp)	--	--	--	--	16200

[a]Calculated Values
[b]Brookfield Method

Calculated Values - Variation in heats of combustion calculated and those obtained via the bomb calorimeter were in agreement within less than 1%. Thus, most of the heats of combustion for candidate simulants were calculated except for the paraffin oil. It was determined by the bomb calorimeter to be 10,999 $\pm$ 22 cal/g.

TABLE 6. DATA FOR CANDIDATE SIMULANTS 11 TO 15

Test	CANDIDATE SIMULANTS 11	12	13	14	15
Specific Gravity	0.7466	0.7507	0.7419	0.7390	0.7410
Vapor Pressure (lb/in^2)	7.4	8.6	8.1	8.0	8.0
Viscosity (cp)	--	0.5402	0.5364	0.5588	0.5399
Burn Time (sec)	103.3	118.5	114.4	108.5	108.4
Heat of Combustion[a] (cal/g)	10947	10939	10963	10960	10957
Mixed Aniline Point (^oF, ^oC)	114.9^oF 46.1^oC	116.3^oF 46.8^oC	116.0^oF 46.7^oC	115.5^oF 46.4^oC	114.2^oF 45.7^oC
Heat Flux (cal/cm^2)	87.70	101.9	93.8	86.8	88.9
Formulation Burn Time (sec)	--	179.0	195.0	183.4	193.8
Formulation Heat Flux (cal/cm^2)	--	161.0	169.7	161.4	184.1
Formulation Viscosity[b] (cp)	--	16700	14200	14000	15500

[a]Calculated Values
[b]Brookfield Method

TABLE 7. DATA FOR CANDIDATE SIMULANTS 16 TO 21

Test	CANDIDATE SIMULANTS 16	17	18	19	20	21
Specific Gravity	0.7014	0.7043	--	--	--	--
Vapor Pressure (lb/in^2)	9.1	8.4	7.8	6.6	7.9	6.8
Viscosity (cp)	0.5452	0.5475	--	--	--	--
Burn Time (sec)	106.5	105.7	107.5	94.4	95.1	--
Heat of Combustion[b] (cal/g)	11107	10922	11095	11157	11157	11100
Mixed Aniline Point (^oF, ^oC)	137.5°F 58.6°C	127.2°F 52.9°C	141.0°F 60.6°C	142.5°F 61.4°C	143.2°F	-- --
Heat Flux (cal/cm^2)	87.3	89.9	89.2	80.2	75.1	--
Formulation Burn Time (sec)	200.0	202.6	211.5	188.1	192.5	--
Formulation Heat Flux (cal/cm^2)	202.0	202.6	222.1	195.6	192.5	--
Formulation Viscosity[c] (cp)	13000	16970	--	--	--	--

[a]Gasoline Simulant (GS)
[b]Calculated Values
[c]Brookfield Viscosity (Centipoise)

The flame fuel formulations were evaluated critically for their rheological properties by the use of a capillary extrusion rheometer. The initial screening was attempted using the Brookfield Viscometer LVT model and a No. 4 spindle, but difficulties were encountered due to evaporation, causing a skin of polystyrene to form on the sample; the tendency of the material to climb the spindle shaft, the difficulty of constant temperature control, and the low-shear rate range prompted the work with the capillary rheometer.

A number of tests were run to determine the limits of reproducibility of the rheological procedures with the capillary extrusion rheometer. The tests involved duplicate or triplicate runs for materials from the same batch and for formulations prepared in independent batches. Formulation reproducibility was determined at $0^{o}C$ ($32^{o}F$) and $23.9^{o}C$ ($75^{o}F$), respectively, as shown in Figures 1 and 2. Good reproducibility is demonstrated by the flow curves and indicates consistent test methods and handling techniques.

Viscosity versus shear rate data for flame fuels formulated with GS and the five gasolines are represented graphically in Figures 3 and 4. Flow curves for each formulation are presented at $0^{o}C$ ($32^{o}F$) and $23.9^{o}C$ ($74^{o}F$), respectively. A comparison of viscosities over the shear rate range from 10^{4} sec^{-1} to 10^{5} sec^{-1} permitted the calculation of the percent viscosity decrease which is a measure of the degree of shear thinning over this range. Table 8 was constructed by obtaining the appropriate viscosities from Figures 3 and 4. With the exception of the Chevron gasoline formulation at 0^{o}, viscosity reduction approaches a constant value at the temperature considered. The viscosity reduction of the GS formulation is median to the values obtained for the other formulations.

Since the degree of shear thinning is virtually the same for all except the Chevron gasoline formulation at $0^{o}C$, a relative comparison of viscosities was initiated for a shear rate of 10^{4} sec^{-1}. At each temperature, the formulation with Phillips 66 gasoline was considered the relative standard with a designation of 100 percent since its mixed aniline point was median to all the gasolines tested. The recorded viscosities and relative percentages of the formulations are given in Table 9, which also shows an average viscosity for formulations of the five standard gasolines. The data gathered at 0^{o} and $23.9^{o}C$ and the viscosity reduction give a favorable comparison between relative percentages of GS and the standard average.

Good reproducibility in experimentation with a minimal number of variables allows the postulation that variation in the formulation data in Tables 8 and 9 may be related to the mixed aniline points of the respective gasolines. In Table 9, the Chevron and Union 76 formulations were not only the most viscous, but all the other formulations displayed a trend of viscosities decreasing with a decreasing mixed aniline point of the gasoline in the formulation. Chevron and Union 76 have the highest mixed aniline points of the gasolines studied. Thus, they should be the poorest solvents for a polymer such as polystyrene. In mixing solutions on the rotating wheel, a homogeneous solution was obtained in 2 days for all formulations except those mixed with Chevron and Union 76 gasoline, which required 3 days. This poor solvent power is indicated in Table 8 by the notably lower value of viscosity reduction for the Chevron gasoline formulation at the lower temperature, $0^{o}C$.

Elasticity (percent memory) at $23.9^{o}C$ of Napalm B, GS, Phillips 66, Union 76, Gulf, and Chevron flame agent formulations is presented in Figure 5. The GS plot is median with respect to the other formulations; however, there is a comparable increase in percent memory with an

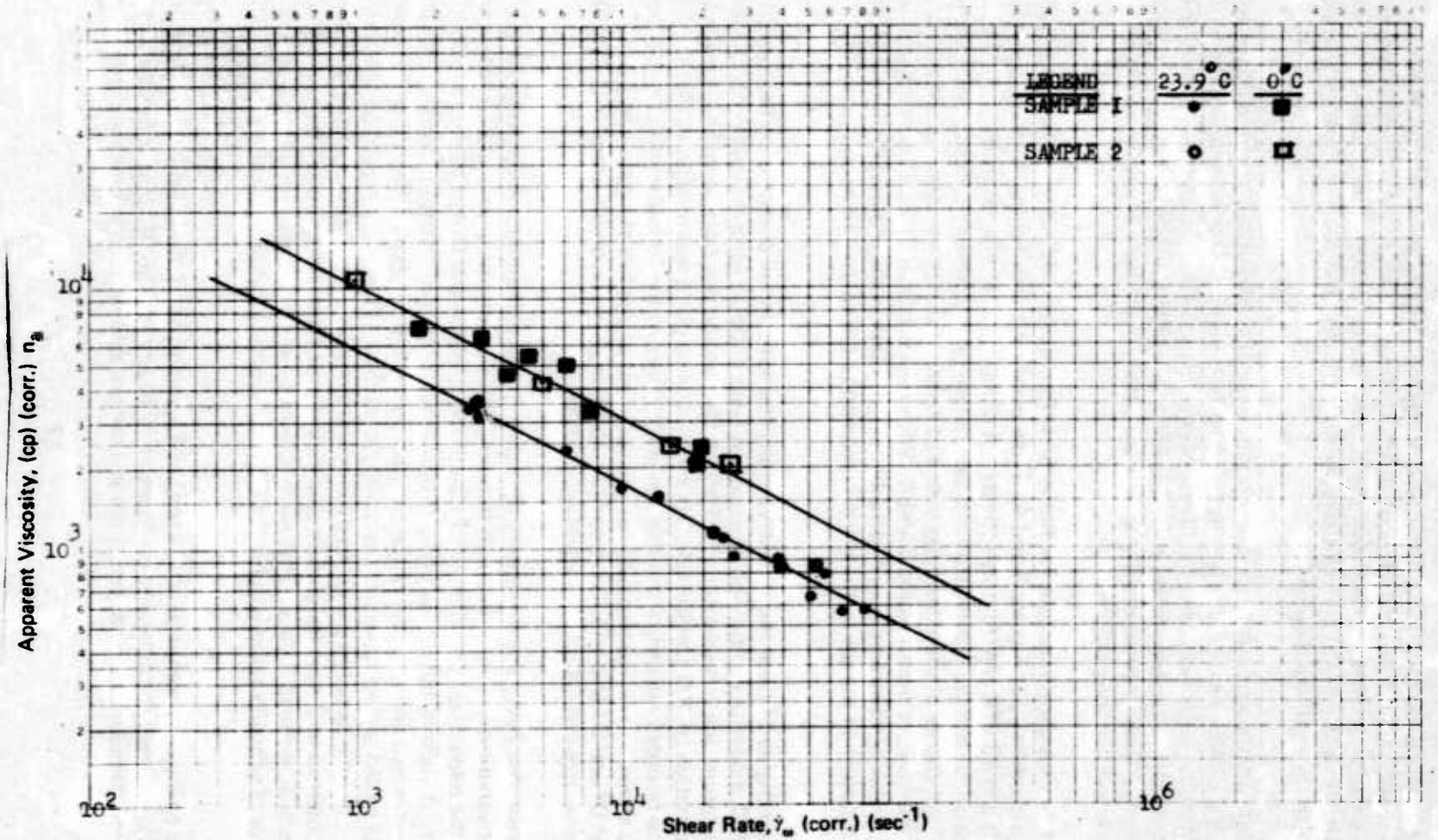

Figure 1. Viscosity Versus Shear Rate for Napalm B Formulated with GS (Several Runs for each Formulation)

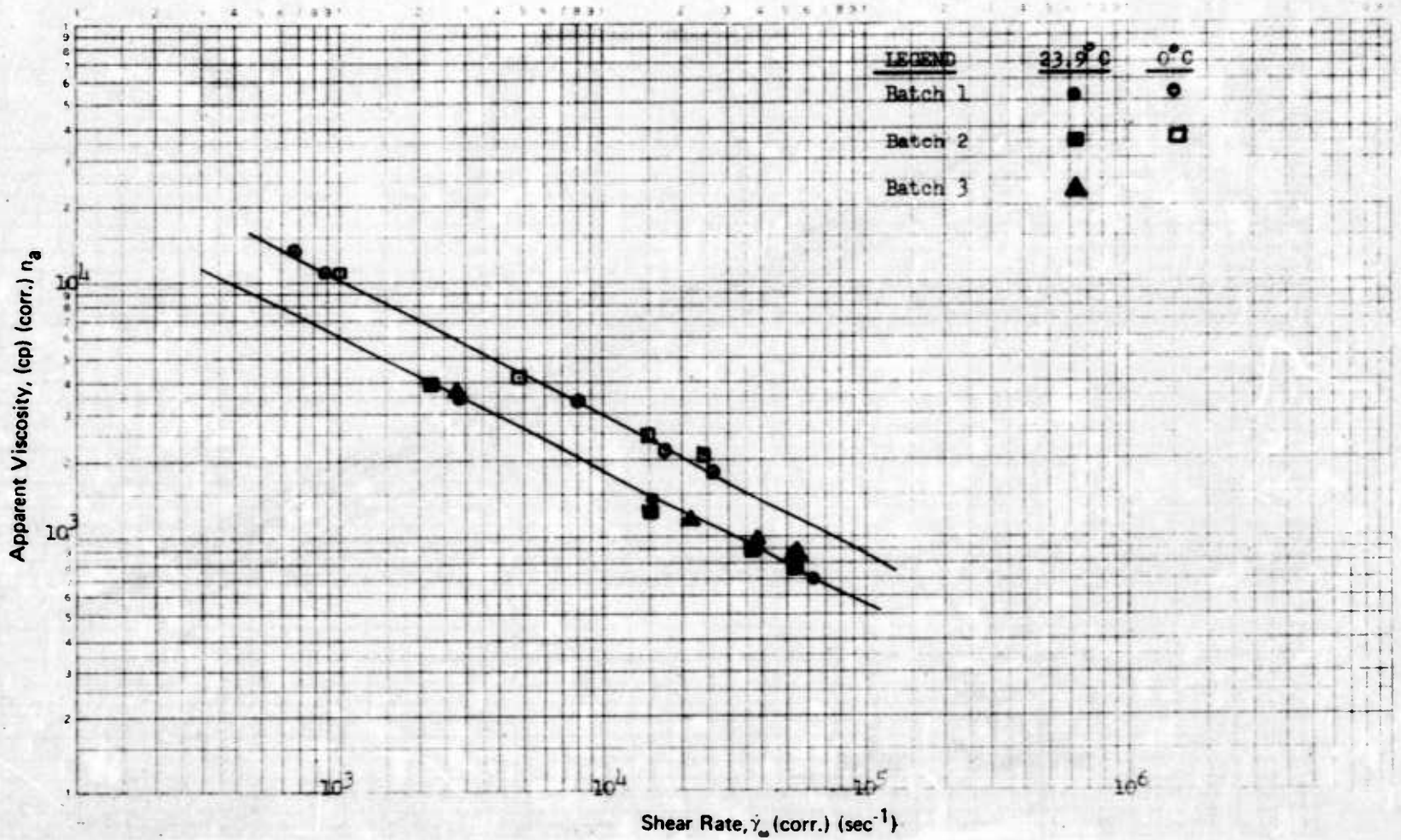

Figure 2. Viscosity Versus Shear Rate for Napalm B Formulated with GS (Data for Several Formulations)

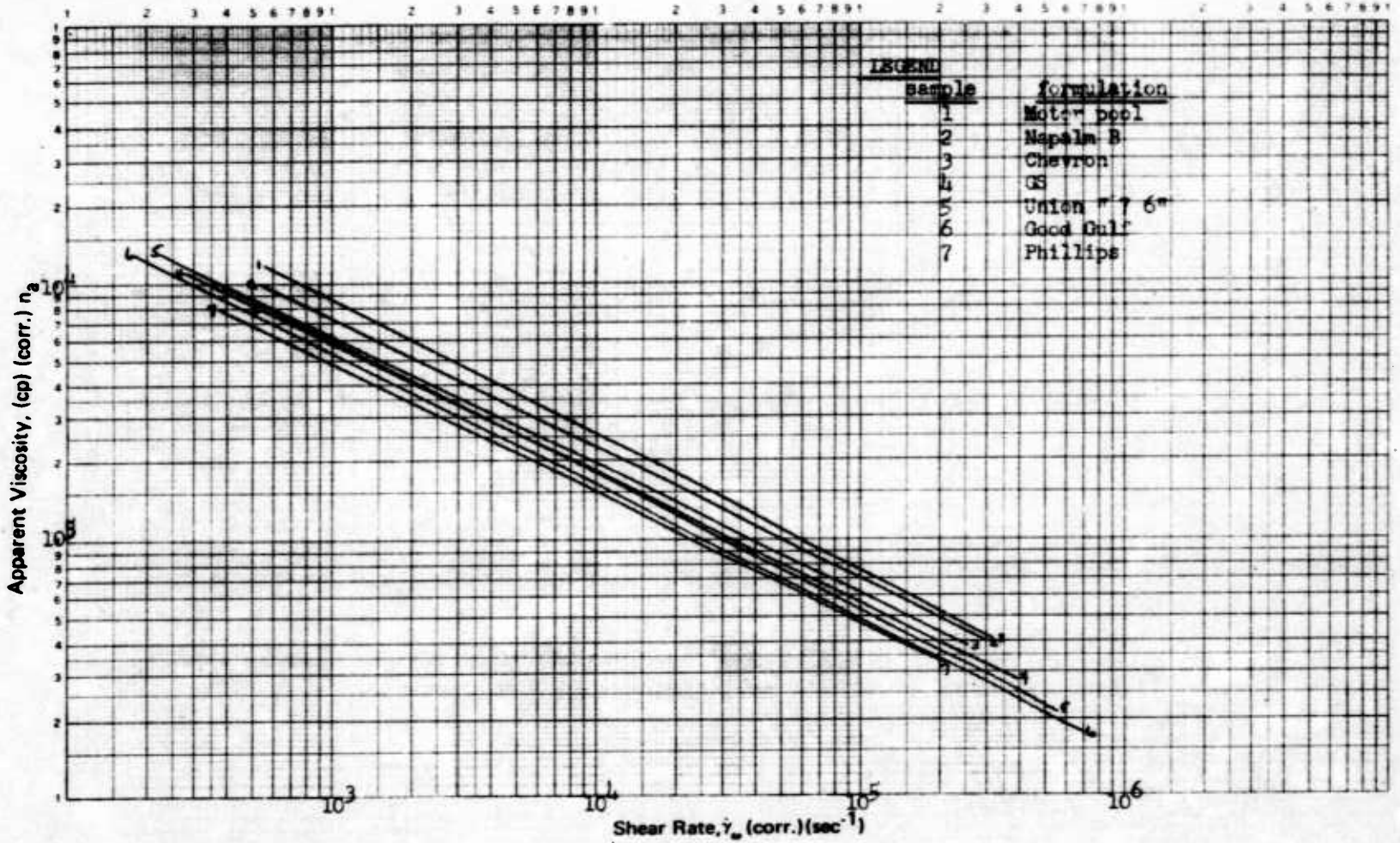

Figure 3. Comparative Plots of Viscosity Versus Shear Rate for Napalm B Formulated with GS and Various Gasolines (at 23.9°C)

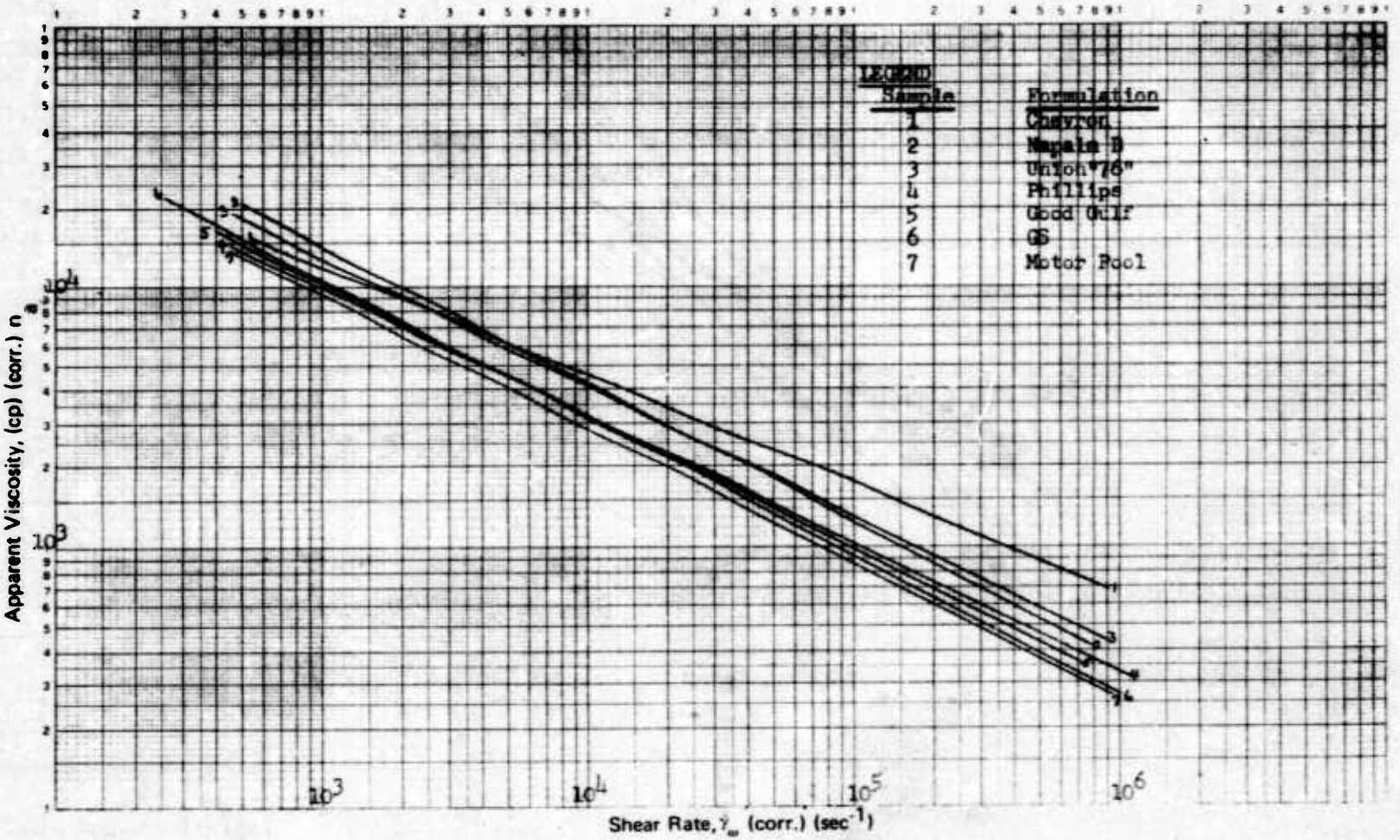

Figure 4. Comparative Plots of Viscosity Versus Shear Rate for Napalm B Formulations with GS and Various Gasolines (at 0°C)

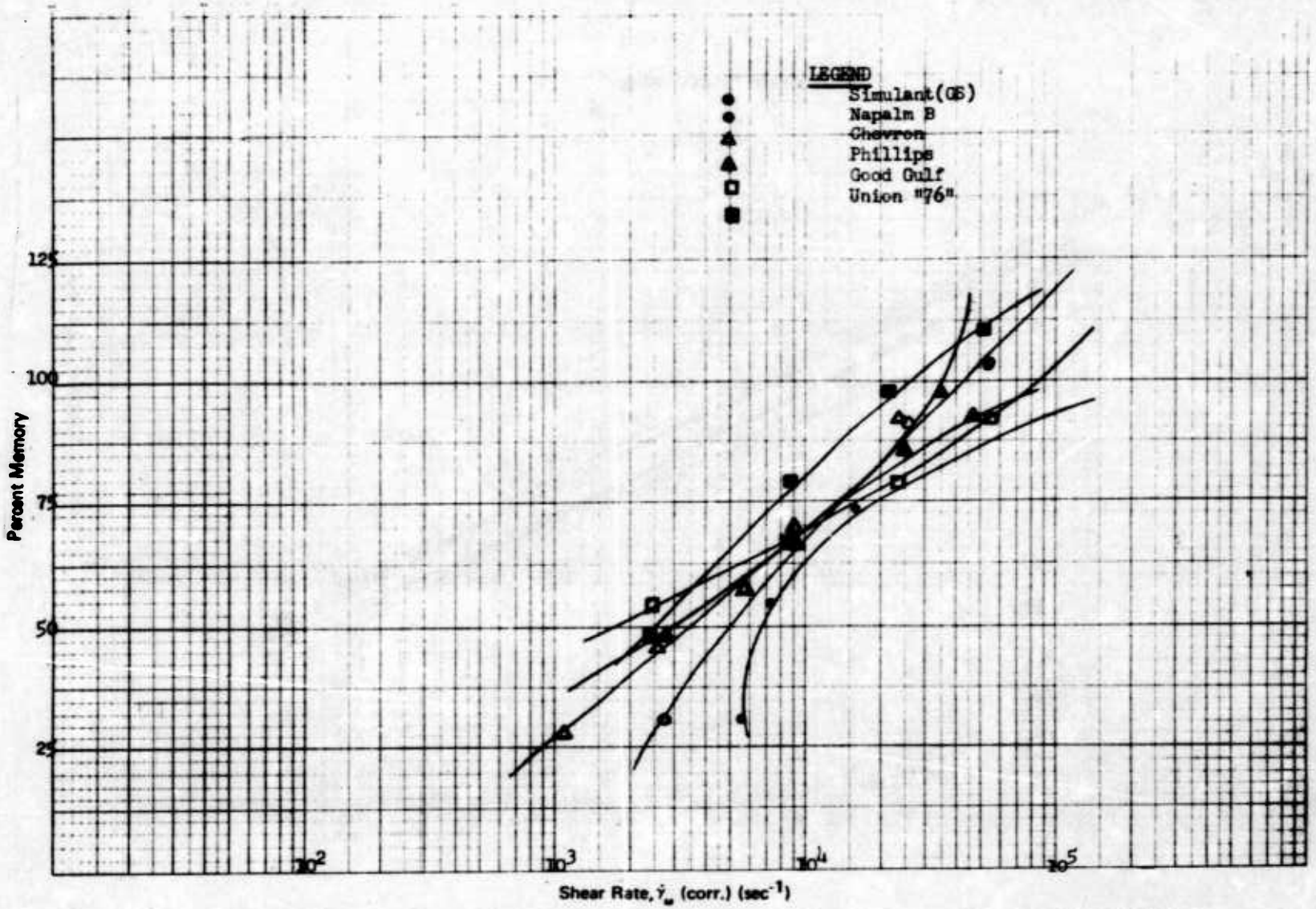

Figure 5. Percent Memory Versus Shear Rate for Napalm B Formulated with GS and Various Gasolines (at 23.9°C)

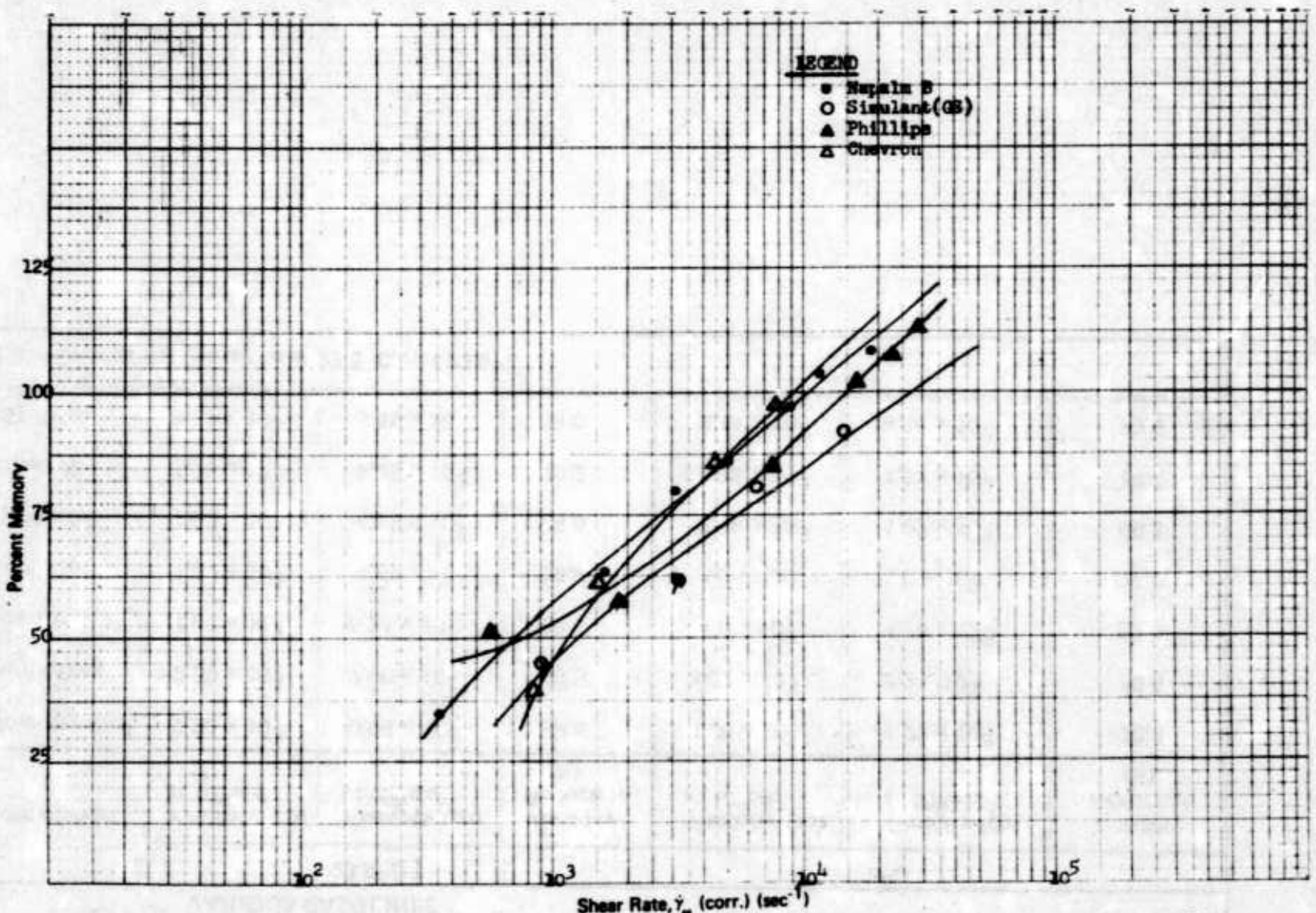

Figure 6. Percent Memory Versus Shear Rate for Napalm B Formulated with GS and Various Gasolines (at -3.9°C)

TABLE 8. COMPARISON OF SHEAR THINNING FOR NAPALM B FORMULATED WITH GS AND VARIOUS GASOLINES

Formulation	23.9°C			0°C		
	Viscosity (cp) at $10^4 sec^{-1}$	Viscosity (cp) at $10^5 sec^{-1}$	Viscosity Reduction (%)	Viscosity (cp) at $10^4 sec^{-1}$	Viscosity (cp) at $10^5 sec^{-1}$	Viscosity Reduction (%)
Dow Napalm[a]	2.28×10^3	6.96×10^2	69.5	4.28×10^3	1.27×10^3	70.3
Motor Pool	2.59×10^3	7.90×10^2	69.5	3.02×10^3	9.2×10^2	69.5
Chevron	1.97×10^3	6.21×10^2	68.5	4.6×10^3	1.74×10^3	52.2
Good Gulf	1.62×10^3	4.87×10^2	69.9	3.6×10^3	1.0×10^3	72.2
Phillips 66	1.52×10^3	4.79×10^2	68.5	3.48×10^3	1.07×10^3	69.3
Union 76	1.76×10^3	5.25×10^2	70.2	4.18×10^3	1.32×10^3	68.4
TS17(GS)	1.79×10^3	5.55×10^2	69.0	3.11×10^3	9.18×10^2	70.5

[a]Experimental data obtained at 23.3°C, not 23.9°C

TABLE 9. COMPARISON OF VISCOSITIES OF NAPALM B FORMULATED WITH THE GS AND VARIOUS GASOLINES AT 10^4 SEC^{-1}

Formulation	23.9°C		0°C		%
	Viscosity (cp)	Compared Viscosity (%)	Viscosity (cp)	Compared Viscosity (%)	Viscosity Reduction from 32°F to 75°F
Motor Pool	2590	170.4	3020	86.8	14.2
Dow Napalm B	2280	150.0	4280	123.0	46.7
Chevron	1970	129.6	4600	132.2	57.2
TS17(GS)[a]	1790	117.6	3110	89.4	42.4
Union 76	1760	115.8	4180	120.1	57.9
Good Gulf	1620	106.6	3300	94.8	49.1
Phillips 66	1520	100.0	3480	100.0	56.3
Average	1892	124.5	3716	106.8	46.9

[a]Not included in average

increase in shear rate. Percent memory at -3.9°C of Napalm B, GS, Chevron, and Phillips 66 formulations is presented in Figure 6. The formulation with GS has a comparable percent memory with the other formulations at low shear rates but is slightly lower at the higher shear rates.

Any situation where a polymer solubility problem is encountered with GS may be overcome by varying the respective weights of benzene and GS (considering Napalm B-type formulations) while keeping the total weight in solution constant. Air gun tests at ambient and -17.8°C with 400 to 600 gram samples of Napalm B formulated with GS behaved similar to samples formulated with commercial gasolines. Evaluation of GS with polymers other than polystyrene has proved satisfactory to date.

SECTION V

SUMMARY

A gasoline simulant for flame fuel laboratory research was developed from six commercially available solvents. Rigorous tests on a range of physical, chemical, and rheological properties validated the suitability of the simulant as a substitute for gasoline in a laboratory evaluation of flame agents. By weight, the simulant is composed of 40% n-pentane, 20% hexanes, 5% isooctane, 10% toluene, 20% xylene, and 5% paraffin oil. The simulant will overcome variations in the chemistry of gasolines due to different brand, regional, and seasonal formulations. Its use will also allow (1) standardized laboratory comparison of a variety of potential flame fuels, (2) direct comparison of flame fuel data produced by laboratories in different geographical locations, and (3) an opportunity to isolate and observe the polymer part of flame agents.

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