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HIGHWAY RESEARCH CIRCULAR

Number 82

August 1968

Subject Classification:
Bituminous Materials

COMMITTEE ACTIVITY

Special Committee No. 5
on
Asphaltic Materials

VISCOSITY GRADED ASPHALTS

This report was prepared by J. York Welborn and John M. Griffith and has been approved by the committee for publication.

INTRODUCTION

Since the turn of the century, the use of asphalt in highway and street construction and maintenance has grown to more than seventeen million tons annually. Accompanying this rapid growth has been the development of a variety of types and grades and a multitude of tests by which to measure and specify the desired properties of these materials. Included among these are several tests devised to provide a measure of the consistency for the different asphalt types. All of these consistency tests are empirical, with a variety of arbitrary conditions established for each. Furthermore, the results of each tests are in different units of measurement.

Special Committee No. 5 of the Highway Research Board, sponsor of this circular, has a strong interest in the advancement of asphalt technology. In 1957, the committee agreed that research efforts should be directed to the development of fundamental and more meaningful consistency tests for asphaltic road materials. Improved consistency test methods were considered to be most important because they are the basis on which the different types and grades of asphalt are classified and selected for specific use.

HIGHWAY RESEARCH BOARD
NATIONAL RESEARCH COUNCIL NATIONAL ACADEMY OF SCIENCES - NATIONAL ACADEMY OF ENGINEERING
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Included in the minutes of the 1957 committee meeting is a general description of what the committee had in mind, as follows:

> "Consistency - We now have certain measurements for consistency which have traditional acceptance. Research is needed, however, to provide basic means of measuring consistency for (1) more suitable application control and (2) better understanding and utilization of asphalt-aggregate combinations as affected by climate."

Despite the empirical and arbitrary nature of these consistency tests, they have served a most useful purpose in developing asphalt technology to its present state. However, it seemed timely to reexamine the system and determine if improvements could be made.

The committee members generally agreed that viscosity probably would be a much more appropriate measure of asphalt consistency than the existing group of empirical tests.

A viscosity system of measuring and controlling consistency appeared to offer several advantages. Among these were:

(1) Viscosity could be determined over a broad range of temperature for all types and grades of asphalts in the same basic and comparable unit of measurement. This is important because asphalt consistency is a significant property of the material both during construction and in service in a pavement.
(2) Viscosity provides a fundamental means of measuring consistency, considered by the committee to be desirable.
(3) The viscosity of asphalts over the temperature range encountered during plant mixing and compaction may provide a better insight into the role of asphalt on mixture behavior.
(4) The committee believed that development of the viscosity system would provide for more suitable application control and better understanding and utilization of asphalt-aggregate combinations as affected by climate.

TEMPERATURE CONSIDERATIONS

One of the initial areas to be explored was the temperature(s) at which viscosity measurements might be of significance. It was the consensus of the committee that the temperature of 140°F should be considered for grading and specifying all asphaltic road materials. The temperature of 140°F is about the maximum reached near the surface of an asphalt pavement in all but the hottest climates. It is the temperature at which the asphaltic binder contributes least toward the strength properties of the pavement. The temperature of 140°F is also used for the Marshall and Hveem tests for design of the paving mix. Of particular importance is the fact that paving asphalt cements normally are known to behave as simple, Newtonian liquids at and above this temperature. Conversely, at extremely low temperatures asphalt cements are known to possess elastic characteristics. Also in the intermediate temperature zone, asphalt cements from different sources exhibit varying degrees of complex or non-Newtonian flow properties and their viscosity is dependent on the rate of shear. Thus, there was substantiating evidence to support the concept of measuring the viscosity of asphalt cements at 140°F and to base the grading of these products on viscosity ranges at this temperature.

Because the viscosity of asphalt was known to be an important factor in all phases of construction, consideration was also given to the importance of specifying viscosity at a temperature encountered in construction operations. No single temperature could be selected which would be directly related to all operations encountered in construction. It was known, however, that there is an orderly relationship between temperature and viscosity at temperatures above 140°F where asphalt flow properties are essentially Newtonian in nature. Using a special viscosity-temperature chart on which viscosity values plot as a straight line, viscosities at intermediate temperatures can be readily determined by interpolation.

For specification purposes a temperature of 275°F has been used for the high-temperature viscosity measurements. Test values for viscosity at 140°F and 275°F should then provide the basis for determining viscosity of the asphalt at any temperature in the construction range.

Because asphalt cements from different sources were believed to exhibit different shear and temperature susceptibilities, it was desirable to know the consistency at some temperature well below 140°F. This would permit a study of the relationship between shear and temperature susceptibility of asphalt cements and their performance as binders in pavements at low temperatures. As previously indicated, asphalt cements usually exhibit complex flow properties and extremely high apparent viscosity at low temperatures.

Concurrent with the development of temperature considerations for asphalt cements, attention also was given to significant temperatures for liquid asphalts. Like asphalt cements, liquid asphalt grade classifications are based on ranges of consistency. However, unlike asphalt cements there did not appear to be any one specific temperature of particular significance. It was therefore concluded that the most appropriate course would be to grade the liquid asphalts on the basis of viscosity ranges at 140°F to coincide with the temperature selected for grading asphalt cements. It was recognized that the temperature-viscosity slopes for the Rapid Curing (RC), Medium Curing (MC), and Slow Curing (SC) asphalts are substantially the same, as illustrated on Figure 1. Thus, knowledge of the viscosity at any given temperature permits a close estimate of viscosity at any other temperature.

INSTRUMENTATION AND TEST METHODS

An extensive program was initiated to select or device appropriate equipment and test methods by which to determine viscosities at the selected temperatures. This far-reaching program involved the Asphalt Institute laboratories, and those of about twenty Institute Member Companies and the U.S. Bureau of Public Roads. Many other agencies and individuals also contributed to this broad-scale activity.

Gravity-flow capillary viscometers were then in use to measure the viscosity of petroleum and other products. It was known that some of these viscometers would be suitable for determining the viscosity of liquid asphalt grades at 140°F and asphalt cements at 275°F. Testing procedures, as well as the viscometers, had been standardized by the American Society for Testing and Materials (ASTM). With some modifications, the method was readily adapted and standardized by ASTM and AASHO for use with liquid asphalts at 140°F and asphalt cements at 275°F. (ASTM Method D 2170, AASHO Method T 201).

At 140°F, however, asphalt cements usually are too viscous for the gravity-flow viscometers to be suitable. Earlier studies had shown, however, that a capillary viscometer in which flow was induced by means of a partial vacuum, rather than by gravity, could be used for determining the viscosity of asphalt cements at 140°F. This instrument was known as the Koppers Vacuum Capillary Viscometer.

To supplement this viscometer, two new vacuum capillary viscometers were developed. One was designed by the Cannon Instrument Company and is known as the Cannon-Manning Vacuum Viscometer, The other was evolved by The Asphalt Institute and is known as the Asphalt Institute Vacuum Viscometer. Extensive studies indicated that the new viscometers were suitable for measuring the absolute viscosity of asphalt cements at 140°F. On the basis of thorough cooperative studies, a suitable test method was then developed and standardized as ASTM Method D 2171 and AASHO Method T 202 which provides for the use of the three viscometers as alternates.

Many problems were encountered in the development of suitable and meaningful viscosity tests for use at low temperatures. Several types of viscometer were studied within the range of temperatures of 32°F to 140°F. Included were:

(1) The Sliding Plate Microviscometer, developed by the Shell Oil Company.
(2) The Cone-Plate Viscometer, developed by the American Oil Company.
(3) The Falling-Plunger Viscometer, developed by the Chevron Research Corporation.
(4) A modification of the Sliding-Plate Microviscometer, developed by the U.S. Bureau of Public Roads. In the Public Roads procedure, the load is applied to the plates at a constant rate of strain, as contrasted with load application at a constant rate of stress in Method 1 above.

Details of these four methods have been published by ASTM and appear as "Proposed Methods" in the Related Material section of part 11, 1968 Book of ASTM Standards.

In conjunction with the research and development of viscosity tests, ASTM also developed a tentative viscosity temperature chart for asphalts, ASTM Designation: D 2493-66T 1/

1/ ASTM Standards, Part 11, March, 1968.

SPECIFICATION DEVELOPMENT

Laboratory studies of RC, MC, and SC liquid asphaltic road materials indicated a reasonably good correlation to exist between Saybolt Furol viscosity values and Kinematic Viscosity values, at the same temperature. Kinematic Viscosity values in Centistokes for these liquid asphalts are approximately twice the Saybolt Furol Viscosity values in seconds. Because of this relationship, and the tentative decision that viscosity measurements for liquid asphaltic road materials were required only at a single temperature, it appeared that a transition to a fundamental viscosity basis in specifications for these materials would not be difficult.

Figure 2 illustrates on the right side the viscosity ranges at 140°F for the grades commonly in use at that time, designated as Old Grades. After careful consideration, and many asphalt user-producer conferences, agreement was reached to propose the upper four viscosity ranges shown on the left side of Figure 2 as New Grades. The designation system for the new grades retains the type designation (RC, MC, and SC) followed by new numbers that indicate the lower kinematic viscosity limit for the grade at 140°F. For each grade the upper viscosity limit is twice the lower limit.

The Asphalt Institute formally proposed adoption of specifications for liquid asphalt materials in January 1962 based on viscosity grading at 140°F. By 1965, substantially all major asphalt users and specification writing agencies had either adopted the proposed specifications, or planned to do so. Some agencies believed that there was a need for an MC grade, lower in viscosity than the MC-70, for use in some priming applications. Some state specifications, and those of national agencies, have therefore been modified to include an MC-30 grade also shown on Figure 2.

In 1963, The Asphalt Institute issued Study Specifications for asphalt cement based on grading by absolute viscosity at 140°F and with minimum values for kinematic viscosity at 275°F. As shown in Table 1, the grade designation system is similar to that developed for the liquid asphalts. The "AC" prefix designates asphalt cement while the numerical part of the designation indicates the lower limit of the viscosity range at 140°F. The upper limit of this range, however, is 50 percent greater than the lower limit. Another feature of the study specifications was the use of viscosity to measure and control the degree of hardening during the Thin Film Oven Test. This is expressed in the form of a ratio:

$$\frac{\text{Viscosity at } 140^{\circ}\text{F After Thin Film Oven Test}}{\text{Viscosity at } 140^{\circ}\text{F Before Thin Film Oven Test}}$$

The specification also includes requirements for flash point, ductility and solubility. As a result of a recommendation by HRB Special Committee No. 5, the Chairman of the AASHO Committee on Materials distributed the "Study Specifications" to all State Highway Materials Engineers.

The "Study Specifications" also were used as a basis for cooperative Asphalt Institute-Bureau of Public Roads study of asphalt cements. The study was directed primarily to an investigation of the low temperature characteristics of asphalt cements graded by viscosity at 140°F. In addition to the four low-temperature viscosity tests, penetration, ductility, Fraas breaking point and glass transition temperature were used to study the rheological properties of asphalt cements at low temperatures.

The low temperature studies indicated the need for a requirement to control the low temperature properties and the Study Specifications were revised to include a maximum viscosity requirement at 60°F. Asphalt cements from different sources exhibit varying degrees of non-Newtonion flow at low temperatures. However, the viscosity requirement was specified at a single shear rate. Because there appeared to be a need for a less viscous asphalt cement, a grade lower in viscosity than that of the AC-5 was added to the specifications. Also, representatives of the Bureau of Public Roads suggested that the grade designation be based on a median viscosity with an allowable plus and minus tolerance. It was believed that such a system would be more compatible with statistical type specifications then under consideration by the Bureau.

The revised Study Specifications were then designated as "Research Specifications" as shown in Table 2. The Asphalt Institute distributed the proposed specifications to the States and other agencies concerned with asphalt specifications in December 1965. The Institute's transmittal letter pointed out the need for field trials to evaluate the Research Specifications. A majority of the States expressed an interest in the development and willingness to cooperate in field evaluations. Discussions among Bureau of Public Roads and Asphalt Institute officials regarding this widespread State interest led to a meeting sponsored by the Bureau on October 10, 1966. Indicative of the continuing interest, twenty-one States were represented at the meeting. It was the consensus at this meeting that the States should prepare their own program outline, dependent upon their means for carrying out such investigations. Several are presently planning field evaluation programs and others are conducting laboratory studies of the viscosity characteristics of asphalt cements normally supplied.

During and since the development of the Asphalt Institute specifications some States have taken steps to develop and use specifications based on viscosity grading at 140°F. Early in 1964 the Texas Highway Department permitted its Districts the option of specifying asphalt cements based on grading by viscosity at 140°F in lieu of penetration at 77°F. Beginning in 1965, substantially all asphalt cement was specified by the Texas Highway Department on the viscosity basis as shown in Table 3.

In 1963 the California Division of Highways proposed a specification using viscosity as a basis. The specification was revised in 1965 and asphalt cements meeting the specification were used in experimental paving projects. This year, the State has included the specification as contract requirements on a selected number of experimental paving projects. The requirements for the specifications being used are given in Table 4. The significant feature in this specification is that the viscosity grading is made on the residue from the rolling thin-film test.

This year the Pennsylvania Department of Highways also proposed a specification based on the use of viscosity grading as given in Table 5. In this instance the penetration at 77°F has been retained to provide some control of consistency below 140°F.

BASIC PRINCIPLES SUPPORTING VISCOSITY GRADING OF ASPHALT CEMENT

Studies of the properties of asphalt cements indicate there are several findings that support the basic concept of using viscosity for grading and control of consistency.

Figures 4, 5, and 6 portray the relative effect on the uniformity of consistency values of grading on the basis of penetration values as compared to high temperature absolute viscosity. The figures also illustrate the fact that penetration at 77°F in most cases fails to control consistency values at other temperatures or at more than one rate of shear. The asphalts portrayed were selected to illustrate a basic principle to which most asphalts, but not all, conform.

Figure 4 illustrates the viscosity-temperature characteristics of four 85-100 penetration grade asphalt cements; two North American, one Middle East and one Venezuelan. The portion of the curves below 120°F are projections of the high temperature portions which are actual plots of viscosity measurements. The variations in consistency values within a single penetration grade are usual. It is, however, pointed our that asphalts of widely dissimilar character do not differ in temperature susceptibility, in terms of viscosity, as widely as has been generally believed.

Figure 5 illustrates the viscosity temperature characteristics of eight viscosity graded asphalts, four of which are AC 12 produced from the same crude oils as those in Figure 4. This move to viscosity grading provides a degree of uniformity, at temperatures from approximately 100-300°F. This uniformity is not generally present when penetration values are used to control the grade.

Figure 6 is a plot of two asphalts; one highly shear susceptible at low temperatures, the other moderately shear susceptible. In this plot measured "viscosity" values at stipulated rates of shear have been added. The asphalts have a penetration at 77°F of 100. The asphalts also have the same viscosity at 77°F, about 1.1 megapoises, but only when measured at a shear rate of 0.1 $Sec.^{-1}$ which is approximately the equivalent of shear rate imposed by the penetrometer at 100 pen. 100 g. 5 sec. The two asphalts have a common consistency under only one set of circumstances, that is, at 77°F at a shear rate of 0.1 reciprocal seconds. It is questioned whether this is sufficient justification for classifying them as being the same grade.

By connecting the common point on the 77°F ordinate with the points representing the respective viscosities at 275°F, two lines with considerably different slopes will be created. This procedure has in the past supported the variable temperature susceptibility concept developed in the absence of viscosity values at intermediate temperatures, e.g. 140°F. Thus, shear susceptibility, not temperature susceptibility, may be the fundamental characteristic of principal concern.

The utility of consistency values, whether viscosity or penetration, at temperatures below 100°F, for defining grades may be questionable. A significant rate of shear, related to field performance, may ultimately be selected, at which time the foregoing conclusion would be subject to review.

FUTURE DEVELOPMENTS

Developments from the field and laboratory evaluation program should establish the advantages or disadvantages of viscosity-graded asphalt cements and may indicate required modifications of the Asphalt Institute's Research Specifications. Further research also is needed for additional modifications of specifications for liquid grades of asphalt. At present, consistency requirements on distillation residues are based on penetration at 77°F. Additional study is needed to determine whether changing to a viscosity basis, compatible with those for acceptable viscosity-graded asphalt cements, is warranted.

Also specifications for the SC grades of liquid asphalt contain a Float Test requirement on the distillation residue. As an immediate step it seems desirable to substitute viscosity requirements for the present Float Test requirements for these SC materials. In this regard, the user agencies at the Seventh Pacific Coast Conference on Asphalt Specifications, May 10-11, 1968, established Kinematic Viscosity specifications for the SC liquid grades and deleted the Float Test on Distillation Residue at 122°F from the specifications. This change was effective January 1, 1968. Also, this change now has been made in Asphalt Institute specifications.

There also is a need to develop a more meaningful test for low temperature properties to replace the viscosity requirements at 60°F in the current Research Specifications. As this summary has pointed out, asphalts exhibit complex flow properties at the lower service temperatures. In actuality, their behavior is viscoelastic, with the viscous and elastic components varying with temperature and for asphalts from different sources and produced by different refining methods. This is indeed a complex but fruitful area for further research. It is, however, one which may well take substantial time to resolve.

Also, there is a need to develop an improved method for measuring the consistency of asphalt emulsions. Because of the thixotropic nature of these materials capillary viscometers do not appear to be suitable.

Furthermore, consideration should be given to a change in the consistency basis presently used to grade and specify blown or oxidized asphalts by the Ring and Ball Softening Point Test. It seems desirable to replace this empirical requirement with a fundamental measure of viscosity.

It is evident from the above that further research studies are needed. The primary effort at this time should be devoted to a field appraisal of the "Research Specifications" for asphalt cements. Special Committee No. 5 urges all States and other asphalt user agencies to complete this appraisal at an early date. If these research specifications are then judged to provide a better basis for specifying the consistency of asphalt cements, nationwide adoption should follow.

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13. "Laboratory Methods for Grading Setting Qualities of Paving Asphalts," L.E. Santucci and R.J. Schmidt, ASTM STP No. 424, 1967

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Table 1
Study Specifications
for
Asphalt Cements
Based on Absolute Viscosity at 140°F

The Asphalt Institute
January 1963

Characteristics	Grade AC-5	AC-10	AC-20	AC-40
Viscosity at 140°F, poises	500-750	1000-1500	2000-3000	4000-6000
Viscosity at 275°F, centistokes	150+	200+	300+	400+
Ductility at 77°F	--	100+	100+	100+
Ductility at 60°F	60+	--	--	--
Solubility in CCl_4, %	99.5+	99.5+	99.5+	99.5+
Flash Point, COC, °F	375+	425+	450+	450+
Visc. at 140°F after TFOT* / Visc. at 140°F before TFOT*	5-	5-	5-	5-

Note: Low temperature tests and specification requirements are under study.

* Thin Film Oven Test

TABLE 2. RESEARCH SPECIFICATIONS FOR ASPHALT CEMENTS
THE ASPHALT INSTITUTE AUGUST 17, 1965

CHARACTERISTICS	AASHO TEST METHOD	ASTM TEST METHOD	GRADES				
			AC-3	AC-6	AC-12	AC-24	AC-48 (1)
scosity at 140°F, poises	T 202	D 2171	300±75	600±150	1200±300	2400±600	4800±1200
scosity at 275°F, centipoises	T 201	D 2170	80+	110+	150+	200+	275+
scosity at 60°F, megapoises (2)(3)			30-	60-	90-	100-	125-
ctility at 77°F, 5cm/min., cm (4)	T 51	D 113	100+	100+	100+	100+	100+
lubility in CCl_4, %	T 44	D 2042	99.5+	99.5+	99.5+	99.5+	99.5+
ısh Point, COC, °F	T 48	D 92	350+	375+	425+	450+	450+
.n Film Oven(TFO) Test	T 179	D 1745					
Viscosity at 140°F after TFO Test / Viscosity at 140°F before TFO Test			5-	5-	5-	5-	5-

For industrial uses and special paving applications.

The maximum viscosity limits at 60°F apply when measured at shear rates of 0.05 $sec.^{-1}$

At present four test methods may be used for viscosity measurement at 60°F. These methods are described in ASTM preprint No. 33S, published as information only, June 1965. Alternatively, the penetration test may be used to provide an approximate measurement of viscosity at 60°F. The conversion of penetration at 60°F, 100 gm., 5 sec. to viscosity in megapoises at 60°F at shear rates of 0.05 $sec.^{-1}$ or lower may be made by use of the formula:
$\text{Log Vis.}_{60} \sim 3.6-1.7 \text{ Log Pen.}_{60}$. For convenience, a chart for making this conversion is shown on figure 3.

If the ductility at 77°F is less than 100 cm., the material will be acceptable if its ductility at 60°F is 60+ cm.

TABLE 3

TEXAS HIGHWAY DEPARTMENT

SPECIAL PROVISION

TO

ITEM 300

ASPHALTS, OILS AND EMULSIONS

For this project, Item 300, "Asphalts, Oils and Emulsions", is amended with respect to the clauses cited below except for OA-30 and OA-400 and for Item 350 "Hot Mix-Cold Laid Asphaltic Concrete Pavement" when the material is placed cold and no other clauses or requirements of this item are waived or changed.

Article 300.2. Materials. (1) Oil Asphalt is voided and replaced by the following except as provided above:

(1) Asphalt Cement. The material shall be homogeneous, shall be free from water, shall not foam when heated to 347 F and shall meet the following requirements:

SUGGESTED APPLICATION	Distributor		Plant Mix (Light)		Plant Mix (Heavy)		Plant Mix (Very Heavy)	
TYPE-GRADE	AC-5		AC-10		AC-20		AC-40	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Viscosity at 275F, stokes	1.5	---	2.0	---	3.0	---	4.0	---
Viscosity at 140F, stokes	500	750	1000	1500	2000	3000	4000	6000
Solubility in CCl4%	99.5	---	99.5	---	99.5	---	99.5	---
Flash Point C.O.C., F	375	---	425	---	450	---	450	---
Ductility, 77 F., 5cm/min.,cm.	100*	---	100	---	100	---	100	---
	Usual Max.	Absolute Max.	Usual Max.	Absolute Max.	Usual Max.	Absolute Max.	Usual Max.	Absolute Max.
Relative Viscosity (after oxidation, 15 u films for 2 hours at 225 F., viscosities determined at 77 F.)	4.0	5.0	4.5	5.5	5.0	6.0	6.0	7.0

*For AC-5 grade only, a minimum ductility value of 60 cm. at 60 F. will be acceptable in lieu of 100 cm. at 77 F.

TABLE 4
Specification Proposed By
The California Division of Highways

Paving Grade Asphalt Shall Conform
to the Following Requirements

Test	Test Method	Specification
Flash Point, P.M.C.T. °F. Min.	AASHO T 73	450
Stain Number of Original Sample Max. after 120 hrs.-140°F.-50 /sq. in	ASTM D 1328-58T	10
Rolling Thin Film Test 325°F., 75 min.	Calif. Test Method No. 346	
Duct. Residue, 77°F., Min.	AASHO T 51	75
Viscosity, Residue	ASTM D 445	
140°F, Poises		4,000 - 6,000
275°F, Centistokes		425 - 800
Durability Test	Calif. Test Method No. 347	
Viscosity of Residue After Durability Test, Megapoises at 77°F		
Shear Rate 0.05 $Sec.^{-1}$max.	Calif. Test Method No. 348	25
Shear Rate 0.001 $Sec.^{-1}$max.		60
Micro Ductility of Residue 1/2 cm./Min. 77°F, Minimum, mm	Calif. Test Method No. 349	10
Solubility, CCL_4 , Orig. Sample, % Min.	AASHO T 45	99

TABLE 5. PENNSYLVANIA DEPARTMENT OF HIGHWAYS

SPECIFICATIONS FOR ASPHALT CEMENT, BM-1 (AC - 2000)

These specifications cover petroleum asphalt cement for use in bituminous base course, bituminous penetration surface course DP-1, bituminous surface courses FJ-1, HE, ID-2, and premix patch 1P-A, 1P-B, and 1P-C.

The maximum delivery temperature of the material shall not be more than 10 F above the maximum mixing temperature. When the temperature of the material falls below the temperature which yields a viscosity between 150 and 280 centistokes, it shall be heated to yield the proper viscosity.

The asphalt cement shall be homogeneous and shall not foam when heated. It shall conform to the following requirements:

	AC-2000	
Absolute Viscosity at 140 F (60C), poises (Refinery and Project)	2000±400	
	Minimum	Maximum
Water, percent by weight	-	0
Flash point, (COC), deg Fahr	400	-
Penetration at 77 F (25C), 100 g, 5 sec	60	120
Kinematic viscosity at 275 F (135C), centistokes	300	-
Ductility at 60 F (15.5C), 5 cm per min, cm	75	-
Solubility in carbon tetrachloride, percent	99.0	-
Insoluble in N. Pentane, percent	15	-
Spot Test, standard naphtha solvent	Negative	
Thin-Film oven test at 325 F (163C), 50 ml, 5 hrs		
Loss, percent by weight	-	1.5
Retained penetration, percent of original	50	73
Ductility of residue at 60 F (15.5C), 5 cm per min, cm	10	-
Absolute viscosity ratio at 140 F (60C), TFO/orig.	1.5	4.5

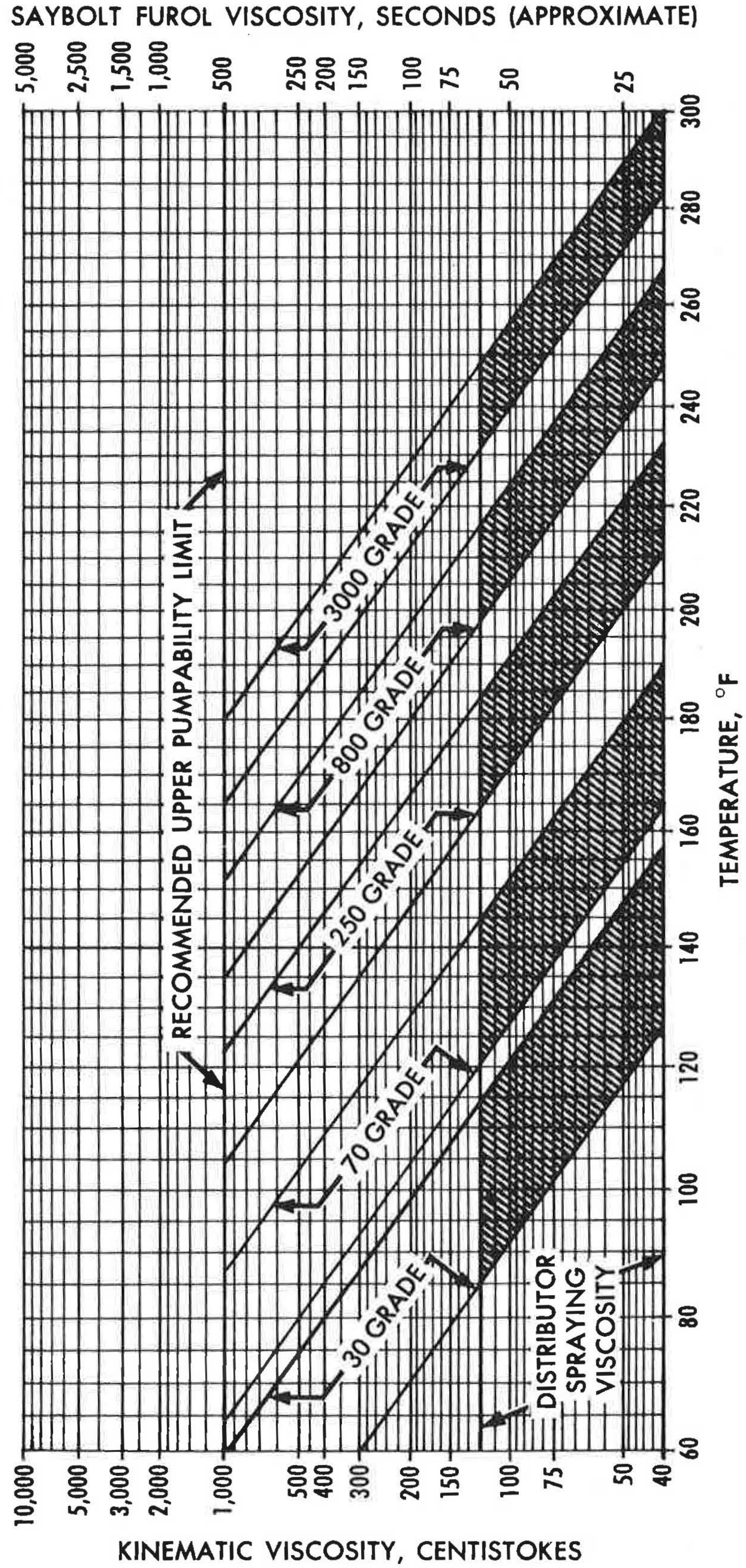

Figure 1 —Temperature-Viscosity of Liquid Asphalts

$$\text{Kinematic viscosity, centistokes} = \frac{\text{Absolute viscosity, centipoises}}{\text{density}}$$

Saybolt Furol viscosity $\simeq$ 0.5 centistokes viscosity

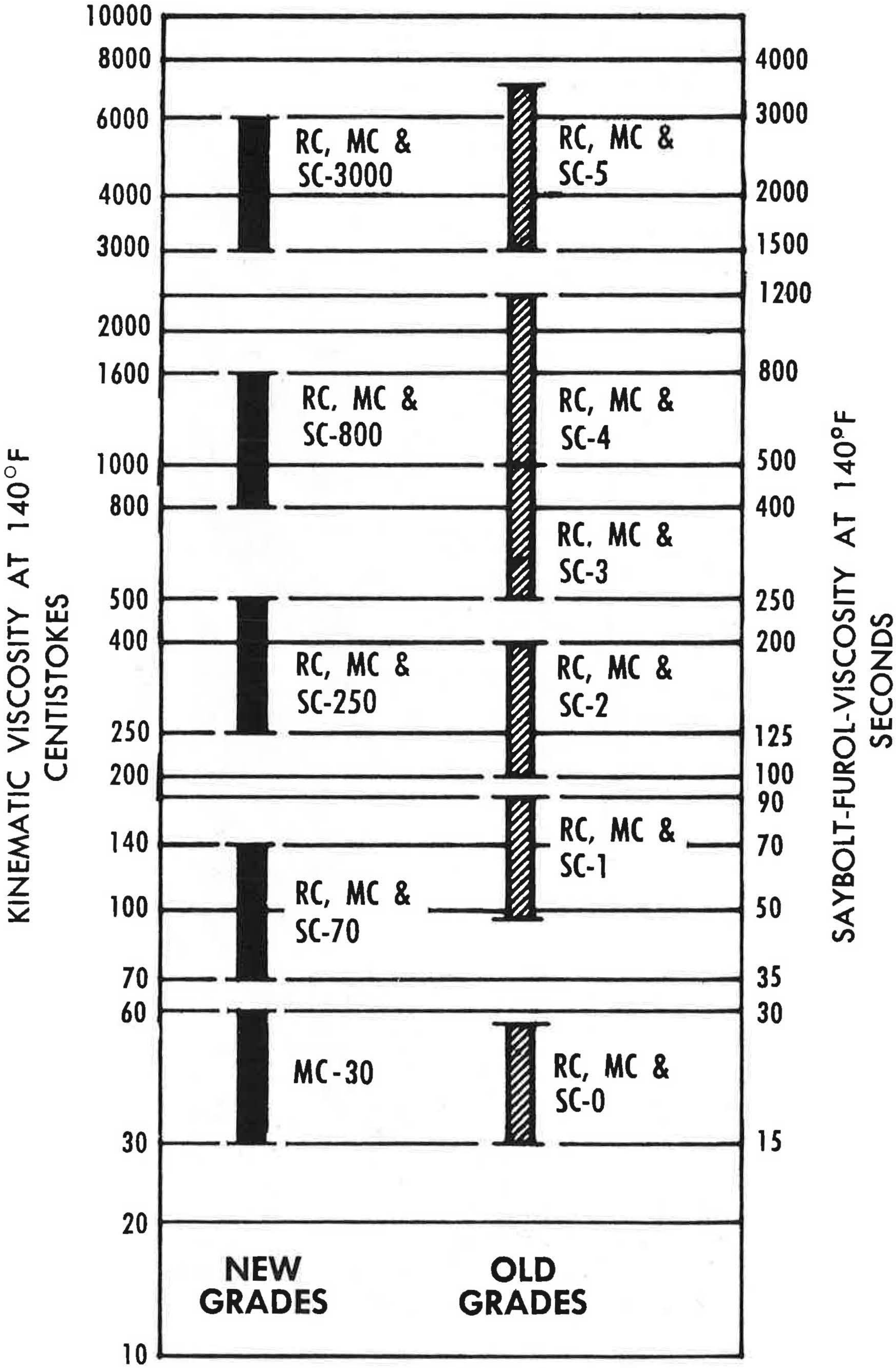

Figure 2 —Comparison of New and Old Liquid Asphalt Grades at 140°F (60°C)

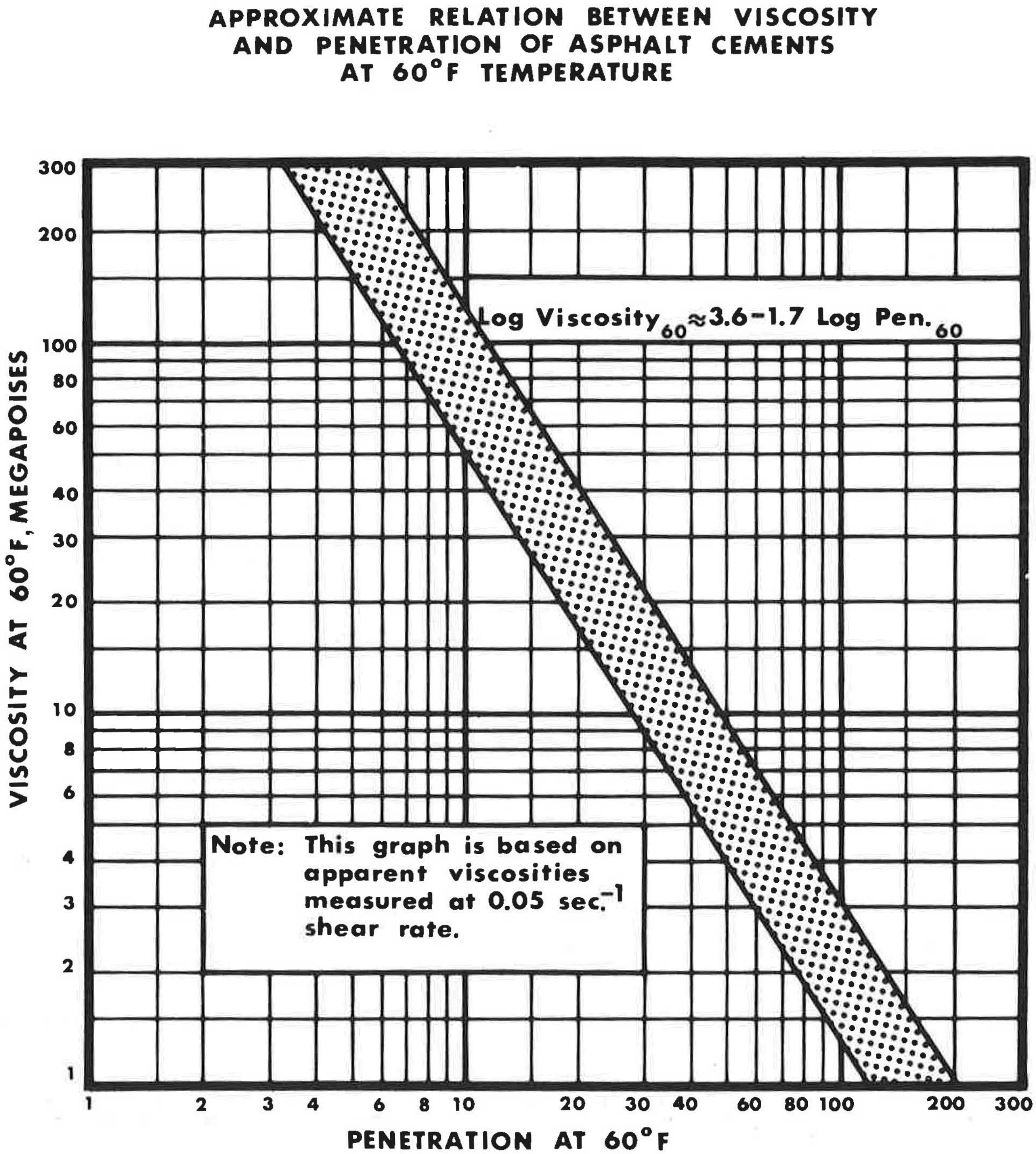
APPROXIMATE RELATION BETWEEN VISCOSITY AND PENETRATION OF ASPHALT CEMENTS AT 60°F TEMPERATURE
Log Viscosity60 ≈ 3.6 − 1.7 Log Pen.60
Note: This graph is based on apparent viscosities measured at 0.05 sec.-1 shear rate.
VISCOSITY AT 60°F, MEGAPOISES
300
200
100
80
60
40
30
20
10
8
6
4
3
2
1
1
2
3
4
6
8
10
20
30
40
60
80
100
200
300
PENETRATION AT 60°F

Figure 3

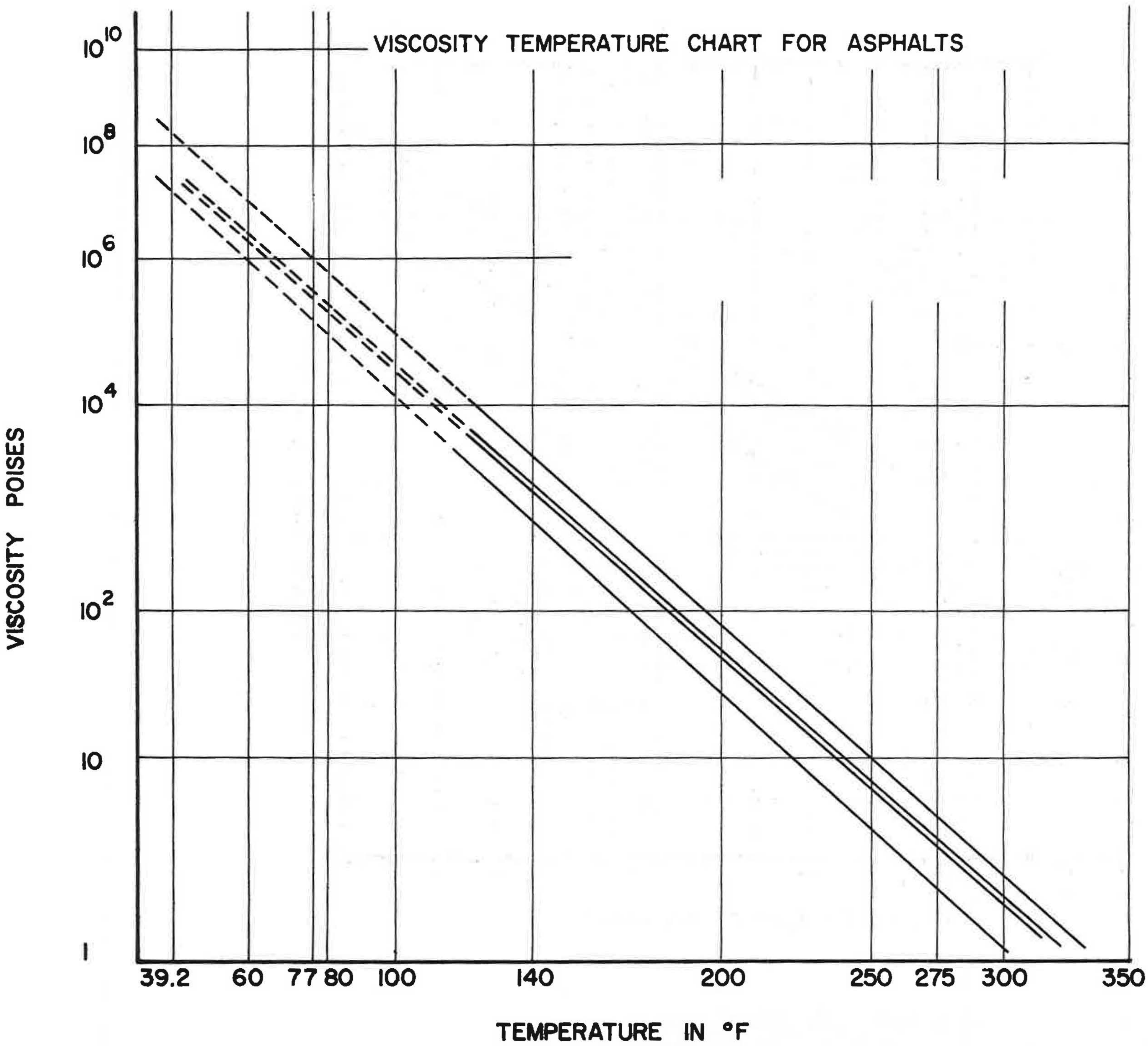

Figure 4 - Four 85-100 Penetration Grade Asphalts

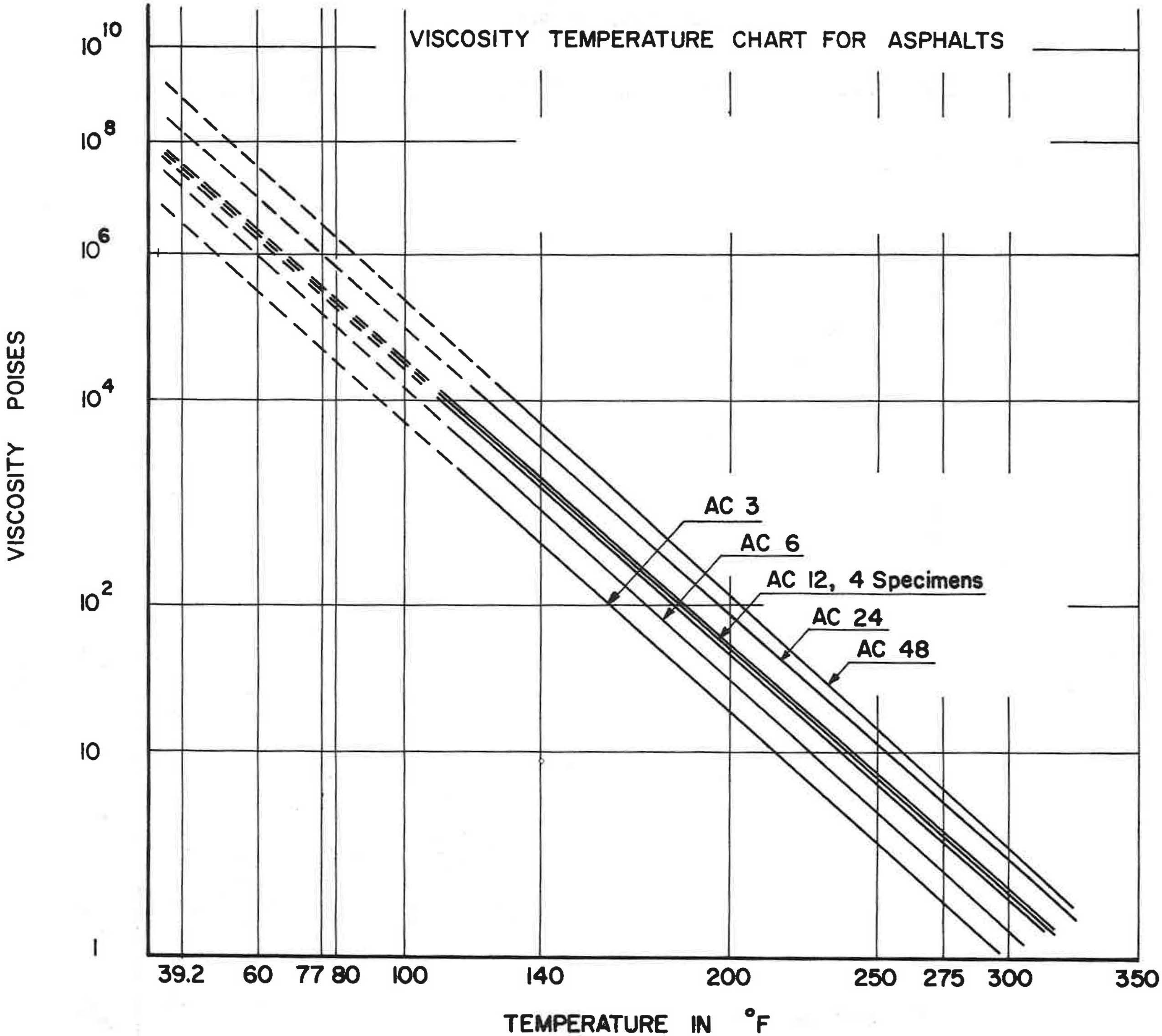

Figure 5 - Viscosity Graded Asphalts. All Grades, Specified in Research Specification.

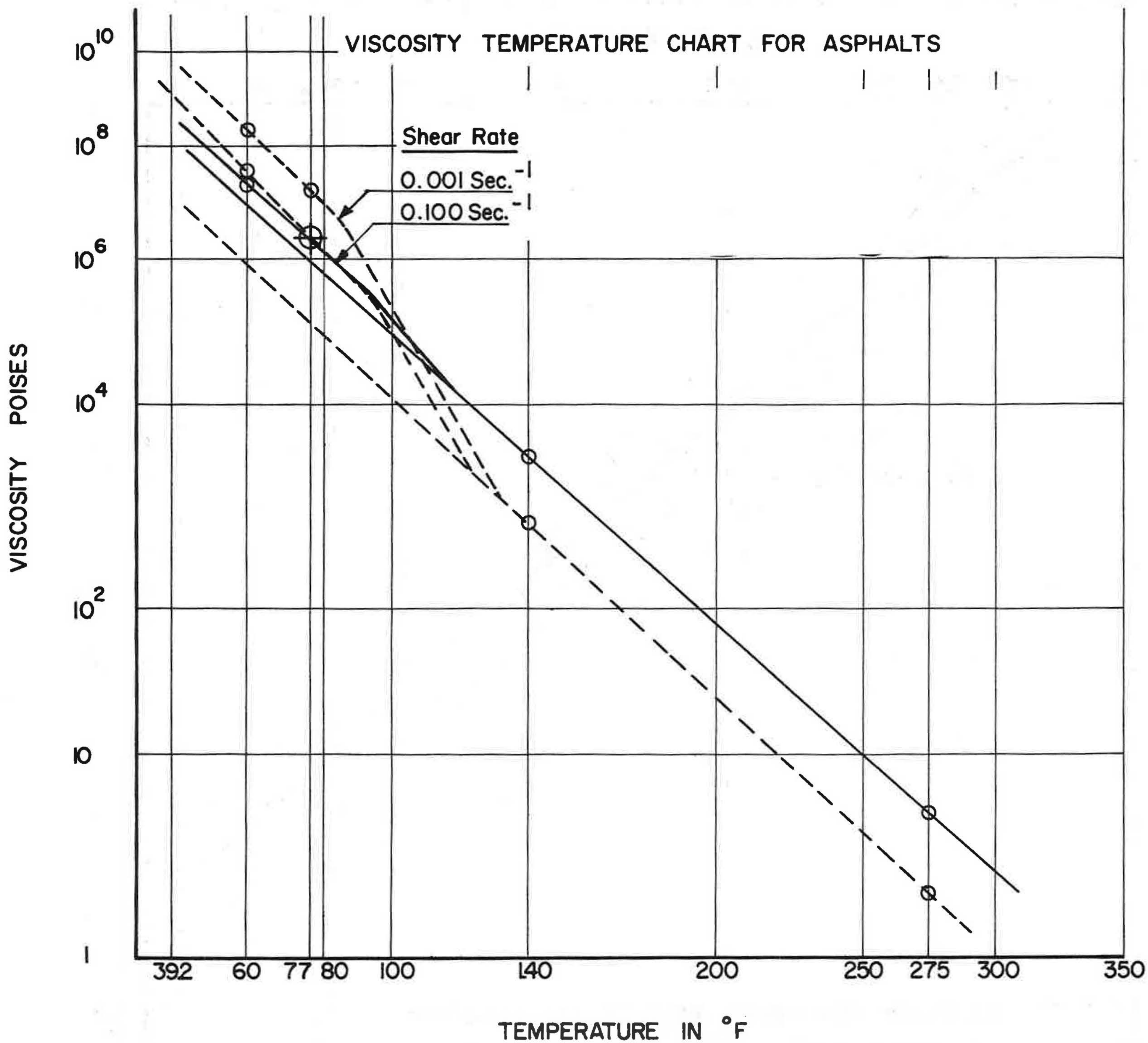

Figure 6 - Illustrated comparison between high and low shear susceptible asphalts both having 100 Pen. at 77°F. Viscosity equivalent to 100 Pen. app. 1.1 megapoise at 0.1 Sec^{-1}.

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* Status August 1, 1968