TEMPERATURE–VISCOSITY RELATIONSHIPS OF SELECTED ASPHALT CEMENTS

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INTRODUCTION

It has been common to purchase asphalt cements for asphalt concrete construction by specifying the penetration grade and to further specify limiting values for flash point, solubility, ductility, thin film loss, and penetration of residue after thin film test. The penetration test is, of course, a measure of the consistency or viscosity at the test temperature of 77°F. The other tests assure a product free of contaminants and having suitable ductility and resistance to excessive hardening. None of these tests, however, provide a measure of the consistency of the asphalt cement at the elevated temperatures required for mixing, placing and rolling the asphalt concrete. It is known that two asphalts having the same penetration at 77°F may have significantly different viscosities at other temperatures. The viscosity of the asphalt during mixing, placing, and rolling is very important in obtaining a quality pavement. In most standards, limiting temperature ranges are specified for these operations but this control fails to distinguish between asphalts having widely varying high temperature viscosities.

To gain information on the appropriate temperature to obtain a given desirable viscosity for the various asphalt cements commonly used in Oregon, viscosities were determined at three or more temperatures near the mixing temperature. From the values determined by test, a plot of log-log viscosity vs. log absolute temperature can be used to predict the temperature associated with a specific viscosity value. To determine how these particular asphalts would fit the viscosity gradings proposed for asphalt cements, the 140°F viscosities were estimated by this graphical method.

A proposed method of implementing the use of viscosity-temperature relationships to achieve more nearly optimum conditions for mixing and placing asphalt concrete is included at the end of this report.

BACKGROUND

Several interrelated factors are of concern to the designers of asphalt mixtures. The asphalt must be heated to obtain a fluidity suitable for thoroughly coating the aggregate particles with a correct film thickness. Excessive fluidity might result in the asphalt draining off of the aggregate during transporting and placing the mixture. Too little fluidity makes mixing more difficult; requiring more time and more power and in some cases resulting in nonuniform coating of aggregate or in too thick films of asphalt. The hardening of the asphalt that accompanies mixing, as measured by the loss in penetration, increases with mixing temperature. A study by Bright and Reynolds[1] found the percent retained penetration decreases about 2 percent for each 10°F increase in mixing temperature up to a temperature of 340°F. At still higher temperatures they found the hardening was accelerated. Since the asphalt hardening is related in a general way to the fatigue life of the pavement, lower mixing temperatures are desirable from this standpoint.

Temperatures that are too low to permit thorough coating of aggregate particles with asphalt films of suitable thickness can also result in pavements providing unsatisfactory service because of raveling or bleeding.

The best viscosity to permit proper mixing and still limit the amount of hardening is not universally agreed upon and undoubtedly somewhat different optimum values would exist for different aggregates and different conditions of placement. It seems, however, a kinematic viscosity of approximately 240 centistokes provides the optimum fluidity for mixing and placing dense graded asphalt concrete. Since a rather small change in temperature results in a large change in viscosity, a range of viscosities from about 155 to 310 centistokes is frequently considered appropriate for control. These limits were suggested in 1943 by Nevitt and Donaldson[2] (75 to 150 Saybolt Furol seconds) and they have received widespread acceptance. In recent years, the improved efficiency of mixing equipment has made it practical to mix higher viscosity asphalts and thereby reduce the hardening that accompanies higher temperatures. In 1959, Nevitt stated a viscosity of 300 Saybolt Furol seconds (approximately 620 centistokes) was a practicable minimum with modern equipment[3]; however, this value requires further verification for widespread acceptance.

Use of a higher viscosity limit is advocated as a means of preventing excessive hardening from overheating. If the mixing equipment is capable of proper particle coating with higher viscosities and, further, if the stiff mix can be compacted to a desirable density, the higher viscosities would provide added durability to the pavement by reducing the initial hardening. Except during very favorable ambient temperatures, compaction to a desirable density becomes difficult and often is not attained with the higher viscosity mixes. Failure to achieve proper density is more damaging to pavement durability than moderately higher mixing temperatures.

These factors do not alter the desirability of using viscosity rather than temperature to control mixing conditions, but they do broaden the range in which the optimum mixing viscosity might occur under given conditions. The temperature range associated with a change in kinematic viscosity from 155 centistokes to 310 centistokes is different for different asphalts, but it is usually between 25 and 35°F. Operating temperatures can probably be controlled within a more narrow range than this, but a temperature control within plus or minus 10°F is considered good according to Collier[4]. A range of temperatures of plus or minus 10 degrees from a presumed optimum temperature corresponding to a kinematic viscosity of 240 centistokes would cause a range of viscosities from about 185 to 295 centistokes. This illustrates that within the practical limits of construction control, a fairly broad range of asphalt viscosities must be expected.

SCOPE OF INVESTIGATION

To determine the temperature-viscosity relationships of those asphalts used in state highway construction in Oregon, samples were obtained from construction project shipments and directly from eight different suppliers. In all, approximately 275 samples were tested for kinematic viscosity. Three producers: Shell Oil Company, Chevron Asphalt Company, and Douglas Oil Company furnished almost all of the asphalt used on the construction projects underway during the period the sampling was done. Most of the samples were from these three suppliers. Samples were also obtained from other suppliers marketing in Oregon, namely: Sinclair Refining Company, Golden Bear Oil Company, Husky Oil Company, Union Oil Company, and Richfield Oil Corporation. The sampling and testing of these asphalts were done during 1962 and 1963 so the results are not necessarily indicative of the temperature-viscosity relationships of the current production of these companies. The general range of values, however, is represented by the samples tested. Fifty samples from 1969 production were checked for viscosity at 275°F and all the values fell within the band of values reported herein.

Sampling covered the three penetration grades likely to be used in hot-mix pavements: 60-70, 85-100, and 120-150. Tests were conducted by capillary viscometer to determine the kinematic viscosity at three different temperatures for each sample. The temperatures were selected to provide viscosities in the range of mixing. For the 60-70 penetration and the 85-100 penetration materials the temperatures were 250°F, 275°F, and 300°F. The 120-150 penetration asphalt was tested at 225°F, 250°F, and 275°F. Some samples in the various grades were tested at additional temperatures to supplement the information.

RESULTS OF TESTS

The testing of each sample involved several determinations of viscosity at each temperature to minimize the experimental error. Usually, a group of 5 readings on a given sample fell within a range of about 3 percent, but greater ranges occurred on some samples. The work was carefully controlled to assure suitable accuracy.

Results of tests on the samples obtained from construction project shipments show appreciable variations sometime exist in a given penetration grade from a given supplier. This might result from variations in blending in the refinery, from variations in refining, or from distribution of materials from different crude sources. The number of samples from Douglas, Chevron, and Shell obtained on Oregon projects varied from 13 to 38 for a given grade and supplier. Variations as great as 40 percent were found in the viscosities within these groups. Between groups, variations as high as 80 percent were noted. It takes relatively small temperature changes to cause these differences, however. Table 1 lists the kinematic viscosities at different temperatures for the samples obtained from the construction project shipments.

The high and low values from Table 1 are plotted versus absolute temperature in Figures 1, 2, and 3 to express bands for each grade and each supplier. The 85-100 penetration materials from the three suppliers were the most similar. The 60-70 and the 120-150 penetration materials had a wider divergence between suppliers. For the 85-100 and 120-150 samples, the high side of the Shell band is almost identical to the low side of the Douglas band. The Chevron band overlaps the other two.

For the 85-100 penetration materials, a 12°F range of temperature covers the total range of asphalts from these three suppliers at a viscosity of 240 centistokes (approximate optimum mixing viscosity). A 15°F range in temperature covers the outer limits of the 60-70 penetration asphalt and a 16°F range covers all three of the 120-150 penetration asphalts at this viscosity. Considering the practical limits of mixing temperature control, these particular materials have similar characteristics. Taking temperatures at the middle of the band for each supplier, there is only about a five degree range from low to high at the 240 centistoke viscosity. For these materials, little would be gained by specifying a different temperature for each supplier's product. At 240 centistokes, the median temperature for the 60-70 asphalt is 286°F, for the 85-100 asphalt it is 278°F, and for the 120-150 asphalt it is 273°F. By determining the temperature viscosity relationships of each shipment of asphalt, somewhat closer temperature recommendations could be made. Since accurate viscosity values are not easily determined in the field, the supplier would have to furnish the information in order to have it soon enough in many cases. Proposals for viscosity grading of asphalt cements include the value at 275°F. This value could be used with a nomograph to read the temperature corresponding to the desired viscosity.

In addition to the numerous samples obtained from construction project shipments, all of which were supplied by Chevron Asphalt Co., Douglas Oil Co., and Shell Oil Co., individual samples in each penetration grade were obtained directly from each firm marketing asphalt in Oregon. The firms supplying these samples and the source of the crudes were:

Chevron Asphalt Co.	Specially produced for this project from San Ardo, California crude
Douglas Oil Co.	Portland plant, crude from San Joaquin Valley, California
Douglas Oil Co.	Santa Maria, California crude
Golden Bear Oil Co.	Vedder type crude, Mt. Poso Area, Kern County, California
Husky Oil Co.	Crude source is Elk Basin, Fourbear, and Oregon Basin, Wyoming
Richfield Oil Corp.	Los Angeles Basin crude
Shell Oil Co.	Blended residues from various crude sources
Sinclair Refining Co.	Mixed Wyoming crude produced from Wertz, Lost Soldier, Crooks Gap, Happy Springs, Sand Draw, and miscellaneous minor fields in the same area
Union Oil Co.	Los Angeles Basin crude Approximately 15 different crude fields involved.

The materials were tested at three or four temperatures in the general range used for mixing and placing asphalt concrete. To determine how these particular samples would fit the proposed viscosity gradings, the test values were plotted and the kinematic viscosity at 140°F was estimated from the chart. The viscosities determined by test and those at 140°F estimated by plotting are shown in Table 2. Included in this Table are the percent deviations of the 275°F values from the mean for the same temperature and same penetration grade. There is a rather wide spread in the viscosities of these materials. In particular, the Douglas Oil Co. asphalt from Santa Maria crude is much less sensitive to temperature changes than the others. Two of the materials, Golden Bear and Sinclair products, have viscosities appreciably lower than the average at the test temperatures. For the estimated viscosities at 140°F, only the Sinclair asphalt has a value significantly lower than the others. Curves showing the range of temperature-viscosity values for the three penetration grades are included. Figure 4 shows the variation within the different 120-150 asphalts tested, Figure 5 is for the 85-100 material, and Figure 6 covers the 60-70 grade. The figures show the two limiting materials from Table 2; the other seven samples fall within these bands. The curves were extended to the 140°F temperature; however, these values are merely estimated. At a viscosity of 240 centistokes the temperature range is 36°F for the 120-150 grade, 32°F for the 85-100 grade, and 34°F for the 60-70 grade.

DISCUSSION OF RESULTS

Among the asphalts tested in this project, wide variations in high temperature viscosities were found between the asphalts of several producers. Also, significant variations exist between different shipments from a given producer. Through combinations of refining and blending techniques, asphalts are produced that meet pertinent specifications. Since the grading is based on consistency at 77°F, there is presently no classification of the materials at elevated temperatures. Asphalts produced from different crude oil sources are frequently dissimilar as the tests indicate. Since most individual producers market materials blended from different crude sources, the variations between different shipments are not surprising.

The temperature-viscosity characteristics of the asphalts tested vary to a great enough extent to make it desirable to know the viscosity at one or more temperatures near the mixing temperature. If those concerned with mixing and placing the asphalt concrete knew the viscosity of each shipment of asphalt cement at, say, 275°F, a chart could be devised to estimate the temperature associated with any desirable viscosity in this general temperature range. One such chart is shown by Halstead[8]. Although the viscosity is important to mixing, factors of greater concern are the hardening of the asphalt associated with excessive temperatures at the upper limit and the inability to obtain adequate compaction of mixes that are too viscous at the other extreme. Parker[6] shows various mix properties versus compaction temperature and although there are no abrupt changes, a compaction temperature of less than 225°F caused a significant increase in void content for samples compacted by the Marshall method. A study by Walters[7] illustrates the difficulty of achieving adequate densities when paving cools quickly during placement and compaction. These studies do not provide the viscosities associated with the test temperatures. Santucci and Schmidt[9] show the viscosity at breakdown rolling versus core density. For normal, understressed mixes the density drops off significantly at higher viscosities. A study by Area, Shah, and Adam[10] provides some information on compaction temperatures although primarily their work shows the advantage of high pressure (85 psi) pneumatic rollers in reducing traffic caused densification and rutting. Minor[11] states dense graded mixes should be compacted at temperatures above 200°F. He shows a viscosity of about 4000 centistokes at that temperature. Using pneumatic breakdown of thick lift pavements, Minor obtained excellent densities by completing the compaction above 225°F with a corresponding viscosity of about 1750 centistokes. It is apparent that obtaining suitable densities to provide stable, long-life pavements requires careful control of the viscosity during lay-down and rolling as well as proper compaction equipment.

CONCLUSIONS

Knowledge of the temperature-viscosity characteristics of each shipment of asphalt cement would be helpful to those involved in mixing and placing the asphalt concrete. The mixing viscosity must be adjusted to permit proper compaction viscosities, taking into consideration air temperature, length of haul, thickness of lift, and compaction equipment. Higher mixing viscosities have the advantage of being less damaging to the asphalt; however, this must be balanced against the reduced pavement life resulting from weathering of a porous, inadequately compacted mix. It is likely that a near-optimum compromise between these characteristics is achieved by trial on projects managed by experienced personnel, but a number of substandard loads may be in place before the best mixing temperature is determined. Prior knowledge of temperature-viscosity characteristics could be correlated to reduce or eliminate the experimentation. The proposed system of grading asphalts by viscosity at 140°F would also include limits for the viscosity at 275°F. By having the viscosity at 275°F listed on the refinery test report accompanying the shipment, the value would be available at the paving plant. One variable that would still have to be handled on the basis of experience or trial is the difference in hardening that occurs during mixing for the different asphalts. For some asphalts this variation would be significant for its effect on compactibility; however, in most cases it would not be highly so.

Although it is recognized that operating temperatures of mixing plants cannot be controlled precisely and the amount of cooling during hauling and placing is difficult to predict, knowledge of temperature-viscosity relationships would provide a guide for the optimum temperatures for each asphalt concrete mix.

IMPLEMENTATION OF RESULTS

Implementation of the use of viscosity to gain optimum conditions would require that the value at 275°F be provided by the supplier at the time of delivery or that a very rapid field test be developed for the purpose. The requirement that the information be included on the refinery test report is suggested. Knowing the viscosity at 275°F, a simple chart can be used to predict the temperature associated with a given desired viscosity in the range of mixing and placing. The best temperature for plant operation for that particular asphalt cement can thus be provided to the operator in advance. Figure 7 was prepared from the various asphalts tested during this study to illustrate the use of a curve to obtain the optimum mixing temperature for any asphalt cement if the viscosity at 275°F is known. This curve assumes the optimum viscosity for mixing is 240 centistokes. If another value was found to be preferable, a similar curve could be prepared for the selected viscosity.

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Table 1

Kinematic Viscosities of Asphalts from

Construction Project Shipments

Supplier	Penetration Grade	Temp °F	No. of Samples	Kinematic Viscosities, C.S. Average	High	Low	Spread	% Spread
Chevron Asphalt	60-70	300	26	152	169	136	33	22
Douglas Oil	"	"	13	193	204	162	42	22
Shell Oil	"	"	19	166	180	157	23	14
Chevron Asphalt	85-100	300	28	131	146	116	30	23
Douglas Oil	"	"	16	148	157	131	26	18
Shell Oil	"	"	28	127	135	120	15	12
Chevron Asphalt	60-70	275	26	289	344	256	88	30
Douglas Oil	"	"	13	369	380	320	60	16
Shell Oil	"	"	19	315	325	311	14	4
Chevron Asphalt	85-100	275	28	244	257	216	41	17
Douglas Oil	"	"	16	282	323	261	62	22
Shell Oil	"	"	28	233	246	220	26	11
Chevron Asphalt	120-150	275	25	208	239	189	50	24
Douglas Oil	"	"	38	233	283	208	75	32
Shell Oil	"	"	26	203	208	191	17	8
Chevron Asphalt	60-70	250	26	606	721	537	184	30
Douglas Oil	"	"	13	800	833	703	130	16
Shell Oil	"	"	19	691	729	662	67	10
Chevron Asphalt	85-100	250	28	520	588	471	117	22
Douglas Oil	"	"	16	594	629	540	89	15
Shell Oil	"	"	28	495	543	467	76	15
Chevron Asphalt	120-150	250	25	454	524	408	116	25
Douglas Oil	"	"	38	505	638	432	206	41
Shell Oil	"	"	26	411	437	383	54	13
Chevron Asphalt	120-150	225	25	1002	1184	899	285	28
Douglas Oil	"	"	38	1223	1563	1066	497	41
Shell Oil	"	"	26	918	1059	687	372	40

Table 2

Kinematic Viscosities for Different Grades

of Asphalt Cement, Centistokes

Supplier	Temperature, F					% Deviation of 275 F value from mean
	300	275	250	210	140 Estimated	
120-150 penetration						
Chevron	114	196	405	1711	80,000	-11
Douglas - Portland	113	201	415	1668	65,000	- 9
Douglas - Santa Maria	211	355	755	3237	110,000	+61
Golden Bear	89	156	335	1385	70,000	-29
Husky	141	249	495	1959	69,000	+13
Richfield	112	188	398	1581	62,000	-15
Shell	159	268	585	2479	110,000	+22
Sinclair	89	153	305	1106	30,000	-30
Union	126	215	440	1781	70,000	- 2
		(220.1)				
85-100 penetration						
Chevron	135	252	529		130,000	-10
Douglas - Portland	138	260	551		140,000	- 7
Douglas - Santa Maria	216	412	873		160,000	+48
Golden Bear	97	196	407		140,000	-30
Husky	174	340	698		140,000	+22
Richfield	128	245	520		130,000	-12
Shell	182	350	741		180,000	+25
Sinclair	102	184	370		52,000	-34
Union	144	271	567		120,000	- 3
		(278.9)				
60-70 penetration						
Chevron	161	300	634		130,000	-17
Douglas - Portland	201	375	810		175,000	+ 4
Douglas - Santa Maria	286	539	1183		220,000	+50
Golden Bear	125	236	506		120,000	-34
Husky	253	479	1030		190,000	+33
Richfield	167	312	662		135,000	-13
Shell	231	435	936		175,000	+21
Sinclair	129	235	478		70,000	-35
Union	175	326	678		120,000	- 9
		(359.7)				

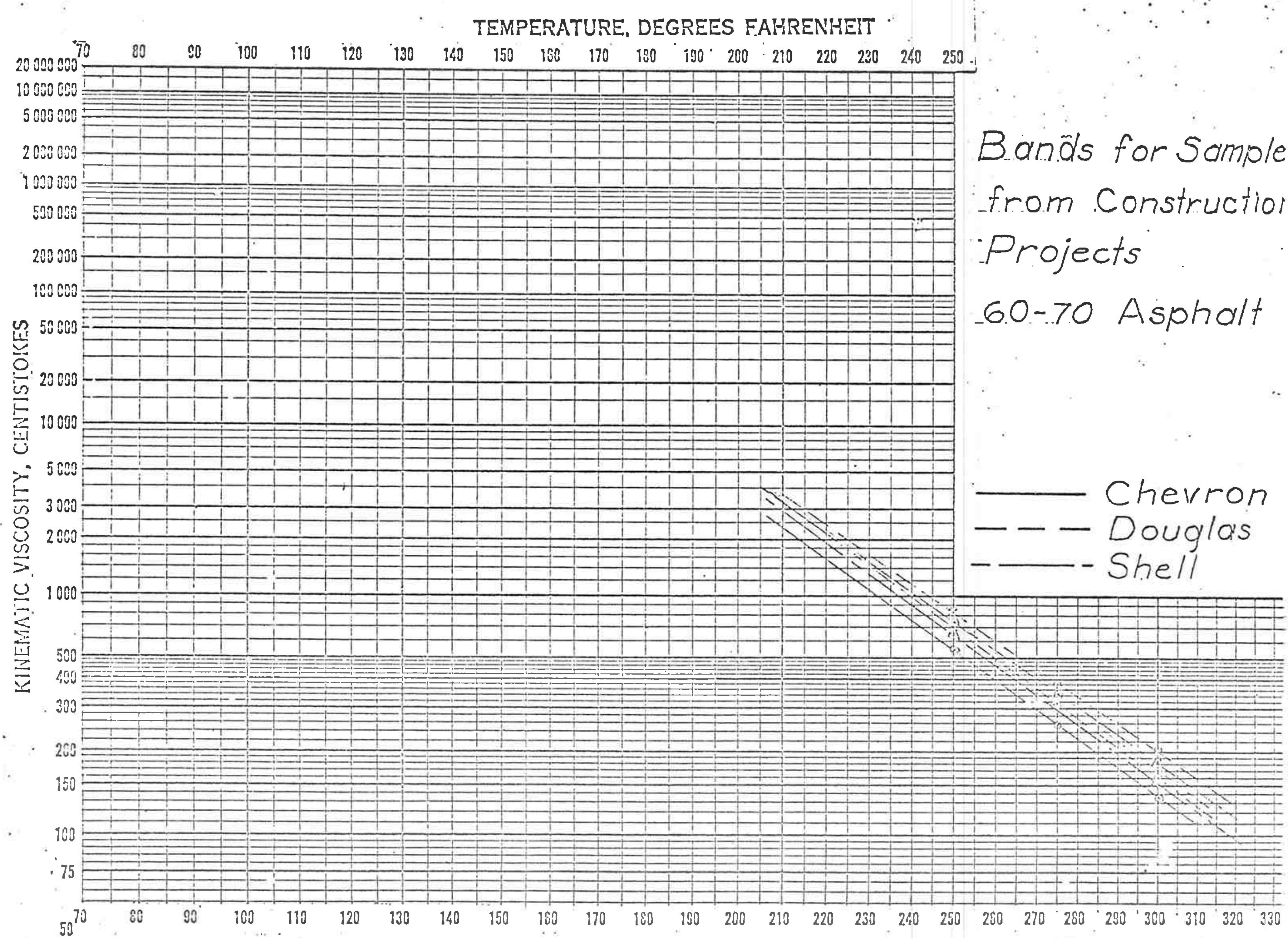

Figure 1. Temperature - viscosity curves for 60-70 asphalt from construction projects.

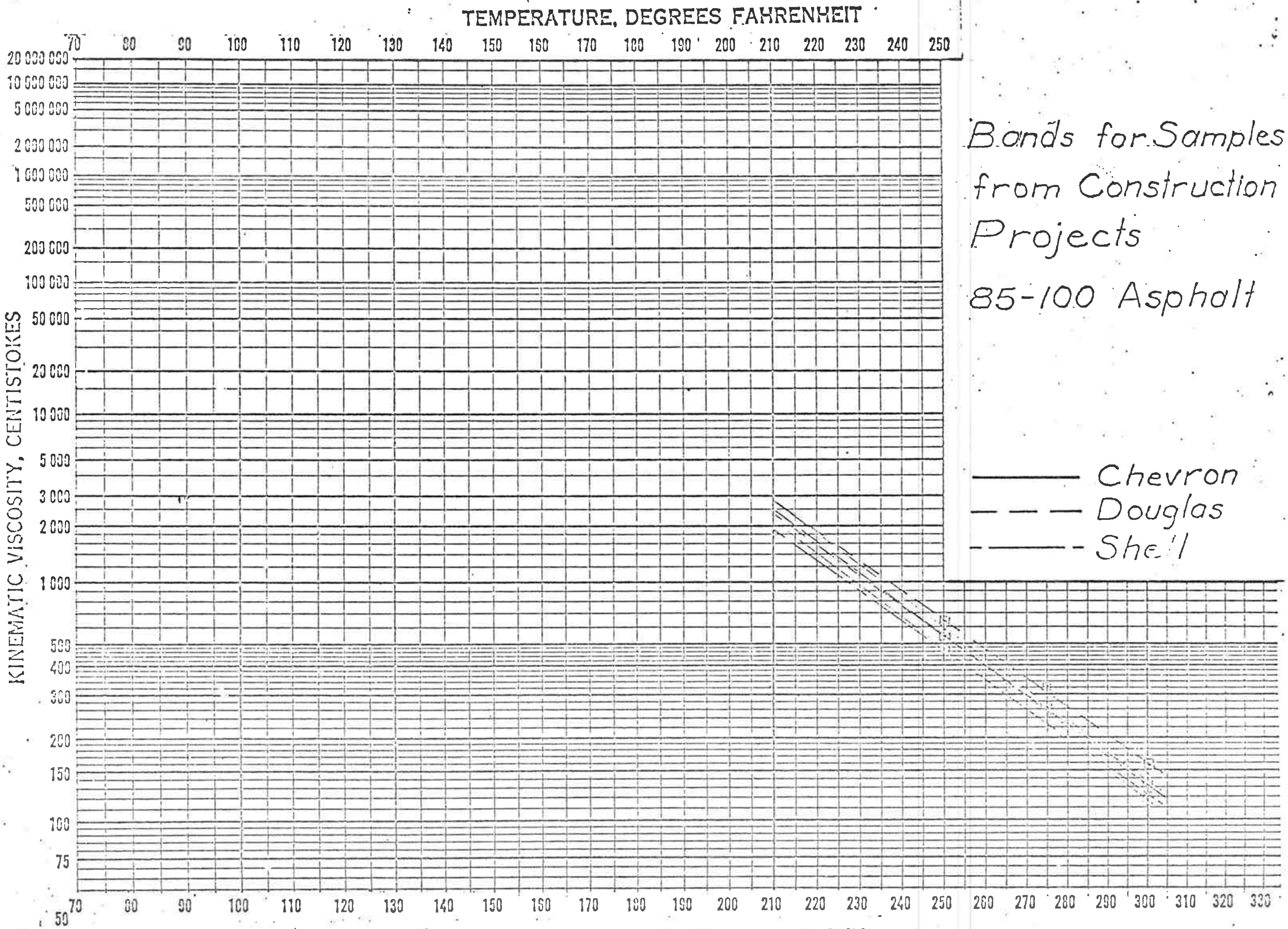

Figure 2. Temperature - viscosity curves for 85-100 asphalt from construction projects.

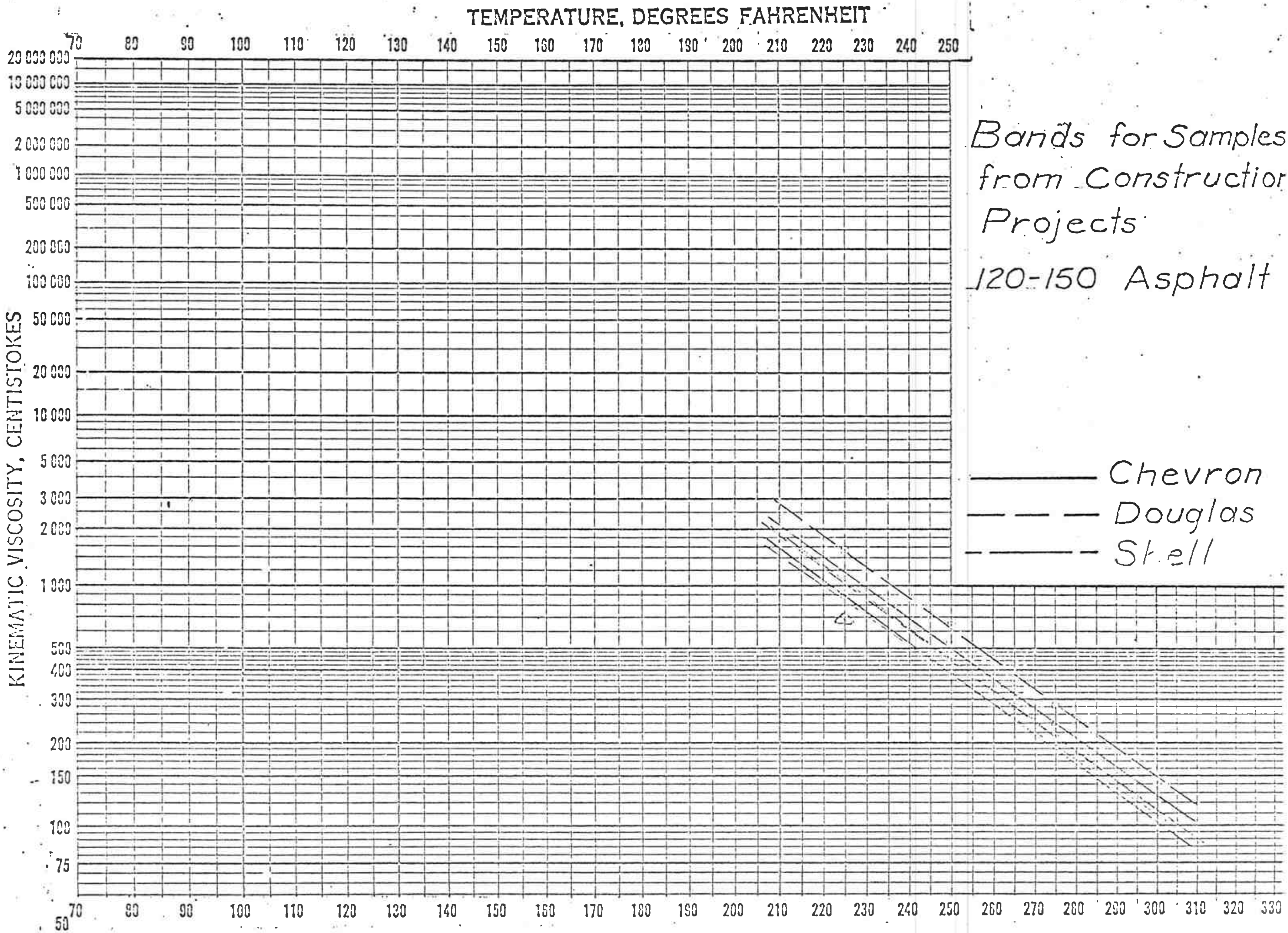

Figure 3. Temperature - viscosity curves for 120-150 asphalt from construction projects.

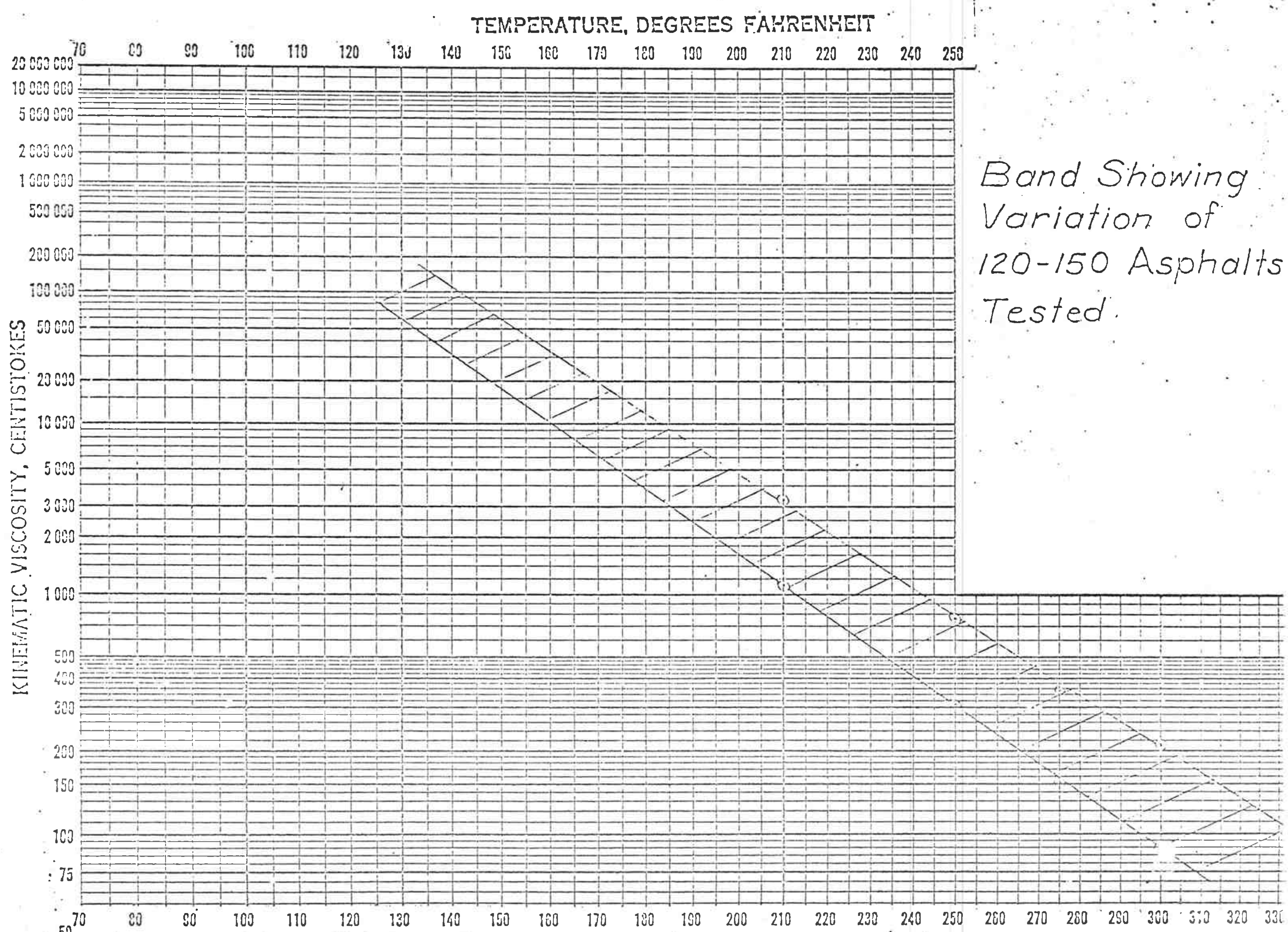

Figure 4. Temperature - viscosity variation of 120-150 asphalts tested.

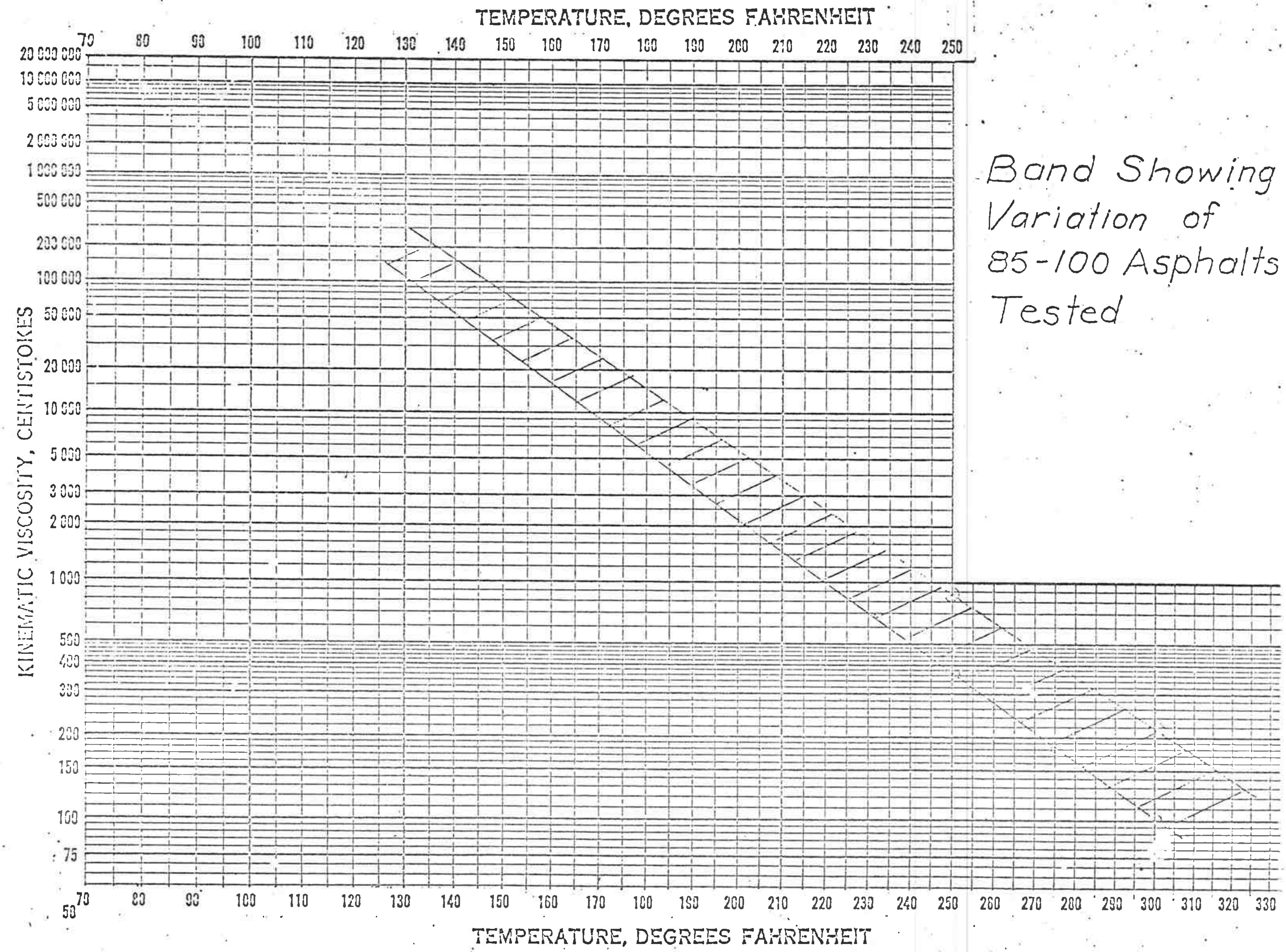

Figure 5. Temperature - viscosity variation of 85-100 asphalts tested.

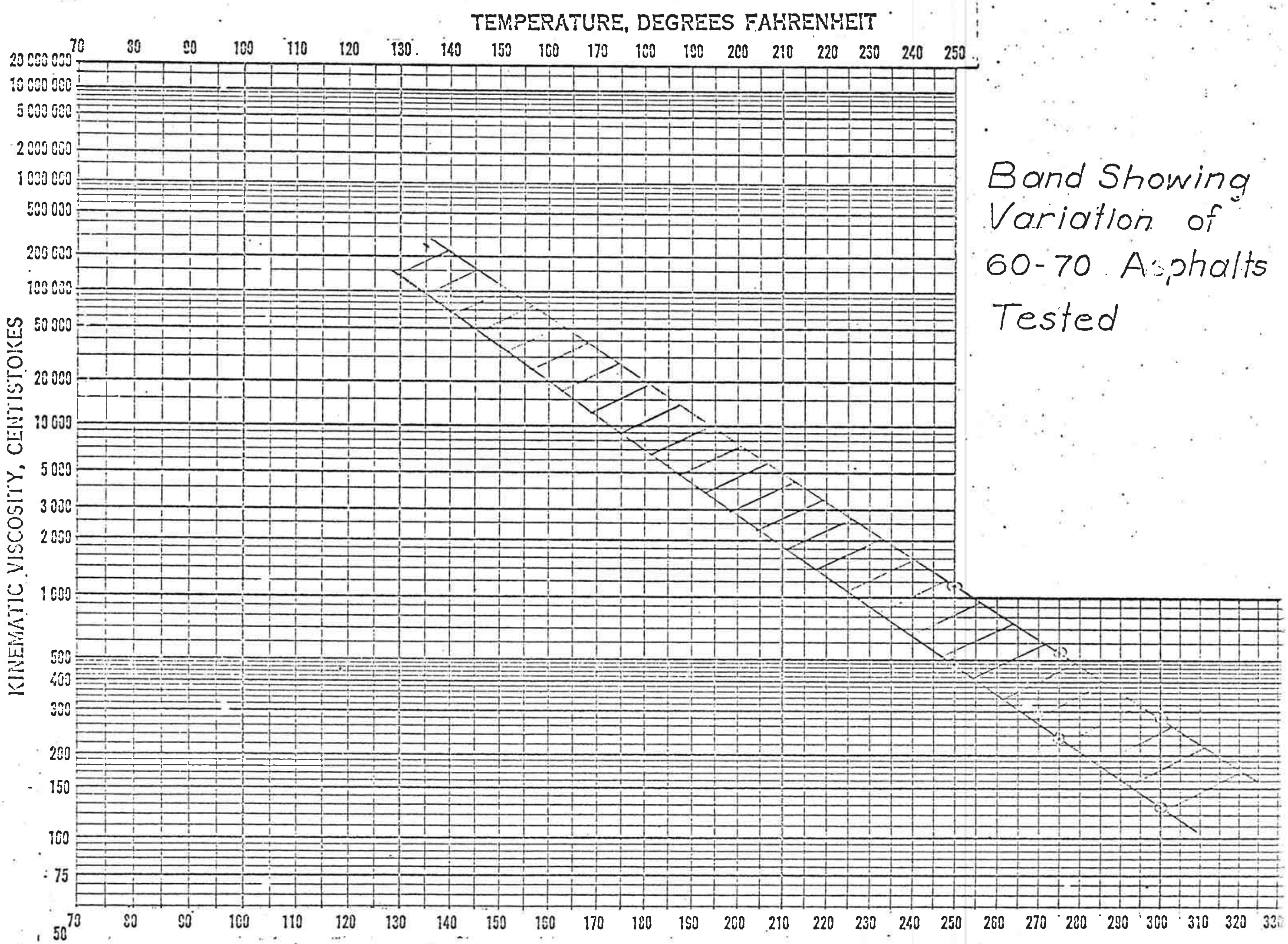

Figure 6. Temperature - viscosity variation of 60-70 asphalts tested.

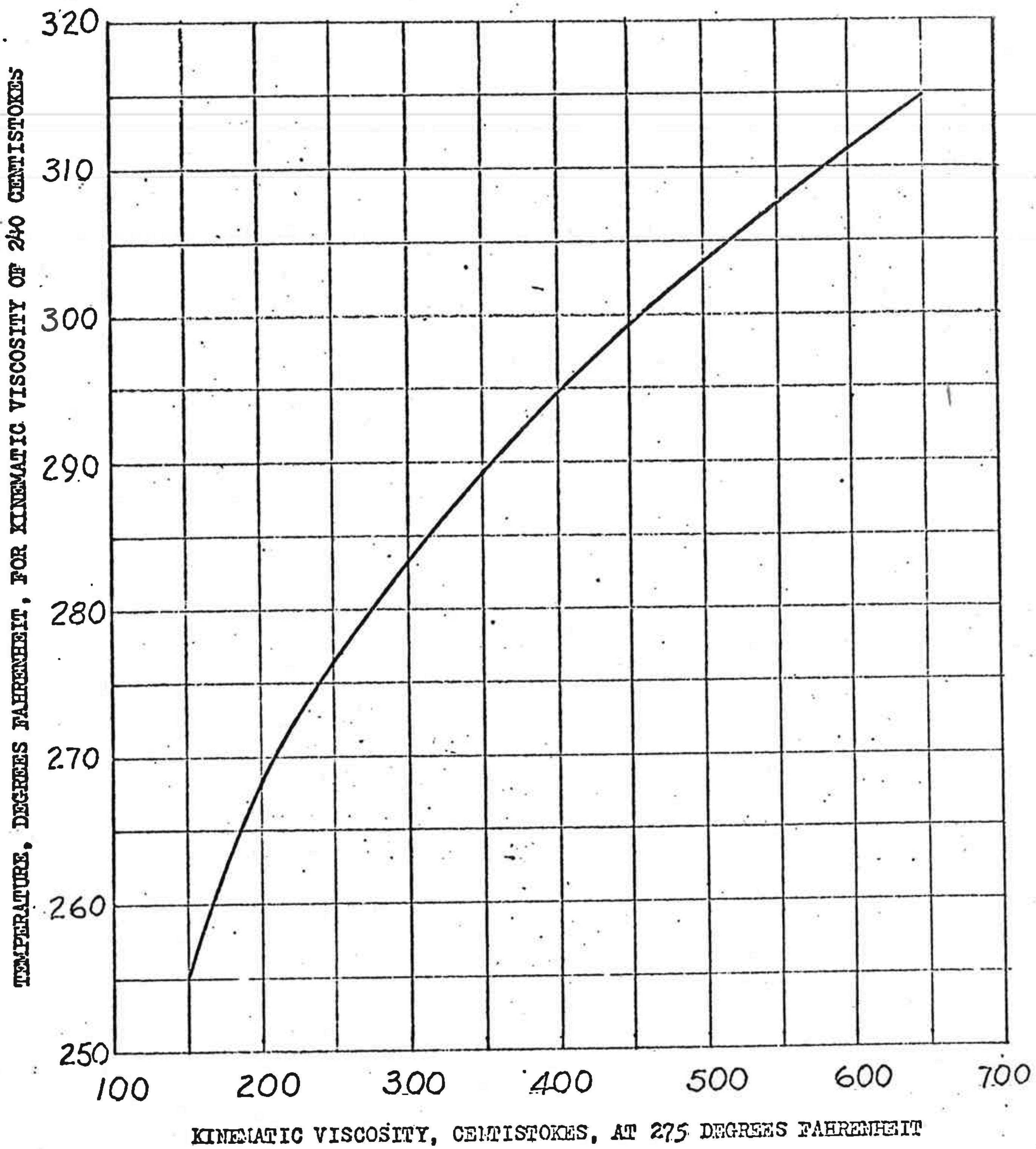

Figure 7. Curve for finding proper mixing temperature from kinematic viscosity at 275 degrees Fahrenheit.