SETTING AND DURABILITY OF ASPHALT EMULSIONS

by

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Arizona Transportation and Traffic Institute

to

The Arizona Highway Department
and
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Research Project HPR-1-7(142)

ENGINEERING EXPERIMENT STATION
COLLEGE OF ENGINEERING
THE UNIVERSITY OF ARIZONA
TUCSON, ARIZONA

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SETTING AND DURABILITY OF ASPHALT EMULSIONS

Abstract

The research has been directed towards obtaining information on setting, tenacity, and durability of asphalt emulsions and their residues. Nine emulsions and four of their base asphalts were included in the study. The breakdown of emulsion type is as follows: a) 5-cationics used primarily for chip seals, b) 3-RS-2's used primarily for tacking on flush coating, and c) 1-SS-1H used for slurry seals.

Setting or drying time of the emulsions was determined using a scratch type of test. Tenacity tests gave a measure of tensile force required to pull-out the cover stones on a laboratory constructed chip seal. Aging of the residues and base asphalts were effected by the Shell and also Rolling Thin Film Oven Test.

The results of the study showed that the greatest differences among the emulsions were in viscosity of the emulsion and durability of the residual asphalts.

Part I INTRODUCTION

Objective

In the State of Arizona there has been concern about the quality of asphalt emulsions, especially those used for chip seal applications. Two properties of which little is known are 1) the rate of setting as it affects delays in opening a road to traffic and 2) the strength of the residual asphalt for holding the coverstone in place. These two factores are also affected by design and construction of the chip seal in terms of the variables of quantity, weather conditions, and application procedures.

Present standard specifications of ASTM, AASHO, and the Asphalt Institute do not control setting characteristics and properties of residual asphalt are not controlled to assure durability. Generally, the asphalt in emulsions is of the softest type (in terms of penetration) and it is exposed in service to the highest temperature of a pavement in seal coat construction, which does not seem to be practical.

This research effort has been directed towards defining the present levels of setting and durability characteristics of asphalt emulsions used in Arizona. A literature survey indicated that not much has been done in the area. A reference (1)* reported that during 1969 only one project in the United States was devoted to asphalt emulsions while two projects were devoted to mixtures of asphalt emulsions and six emulsion studies were being conducted in foreign countries. As a consequence, extremely limited guide lines were found for this project.

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* The number in parenthesis corresponds to the reference citation listed at the end of the report.

Procedure

The samples of emulsions and base asphalts used in these studies were taken by the Arizona Highway Department and sources are described in Appendix B. Some of the emulsions were obtained from the distributor at construction sites and some from the colloid mill. Samples of the original base asphalt were obtained from the emulsion plant.

The emulsions and base asphalts are labeled with a number-letter-number sequence. The first number is related to date of receiving; the letter refers to company; and the next number is connected with a refinery.

The base asphalts are numbered to correspond with the emulsion containing the asphalt.

After the samples were obtained, the materials were run through a series of tests as shown in Figure 1. The test procedures are described in Part II of this report.

Part II Test Methods

General

If a test was performed according to a well documented standard, such as an ASTM of AASHO designated test procedure, the actual techniques employed are not described and the number of the standard followed is listed.

A more detailed description is given for all other tests. No distinction, however, is made between those tests performed on the emulsion residues and the base asphalts since the tests used on both are identical.

Brookfield Viscometer Test

A Model HBT Brookfield Viscometer was used to determine the viscosities of the asphalt emulsions at temperatures of 77°, 104°, and 140° F. The tests were run at a speed of 50 rpm for either spindles 1 or 2. These tests were run according to the instruction pamphlet accompanying the Brookfield Viscometer and similar to the ASTM Standard D1824-66, Apparent Viscosity of Plastisols and Organosols at Low Shear Rates by Brookfield Viscometer (2).

At all times, in sampling, storage, etc., care was taken to minimize the evaporation of water from the emulsions.

After running several initial tests, the following criteria were established as necessary for obtaining reproduceability;

1) The spindle had to be placed into the sample prior to attaching to the shaft to assure no air bubbles were trapped under the spindle.

2) The same sample had to be used for measurements at all three test temperatures.

3) When taking readings from a fairly viscous sample, the indicator had to be allowed to stabilize. This took up to 12 revolutions.

4) Very close attention had to be given to the centering of the spindle in the sample.

pH Test

The pH of each of the asphalt emulsions was determined with a Beckman pH meter. The meter used is designated as a Type I potentiometric meter as described in Table III of ASTM Standard E70-68, Determination of pH of Aqueous Solutions with the Glass Electrode (3). This ASTM standard procedure was followed for making the pH determinations.

Particle Charge Test

The emulsions used for aggregate seal coats are either anionic, when the surface of the emulsified particles carries a negative charge; or cationic, when the particle surface carries a positive charge. To determine whether the emulsion is anionic or cationic, a particle charge tester as described in ASTM Standard D244-68, Testing Emulsified Asphalts, (4) was used as well as the test procedure.

Tenacity Test

This test is a modification of one developed by Schweyer and Gartner and described in the paper "A Study of Tenacity of Aggregates in Surface Treatments,"(5).

The basis, objectives, and procedure of the test as performed for these studies are herein described.

Objective

The asphalt emulsions used in this research project are used primarily for aggregate covered seal coats. However, emulsions used for tacking, fog seal, and slurry seals are included in the sampling.

The object of this test was to obtain a measure of the tenacity of a layer of asphalt for holding embedded aggregate. Aggregate chips of controlled size, shape, surface properties and cleanliness were used. The aggregate was placed on the surface of an emulsion in a mock-up roadbed so that the coverstone could be pulled in tension from the roadbed and the tensile strength of the bond between the aggregate and emulsion residue or residue and the roadbed could be determined.

To realize the objective, the tenacity test was developed (a) to provide a test section of optimum size for laboratory work which would be useful in a simple rapid test, yet would be sensitive and indicative of actual service conditions, (b) to measure the bonding differences in asphalt emulsion types; and (c) to observe the effects of temperature (72°, 100°, and 140° F) upon the tenacity of the various emulsion residues.

Equipment and Materials

The emulsions used in this study have been previously identified as Sample No. 1 through Sample No. 9.

The aggregate was selected to meet certain requirements of size, shape, cleanliness, and surface properties. A one-size Salt River aggregate was selected. A sieve analysis of the aggregate showed that 0.7% of the total was retained on the 3/8 inch sieve, 71.8% on the 1/4 inch sieve, and 26.2% on the 1/8 inch sieve. The shape of the aggregate was cubical. The aggregate was washed to remove silt, clay, and other

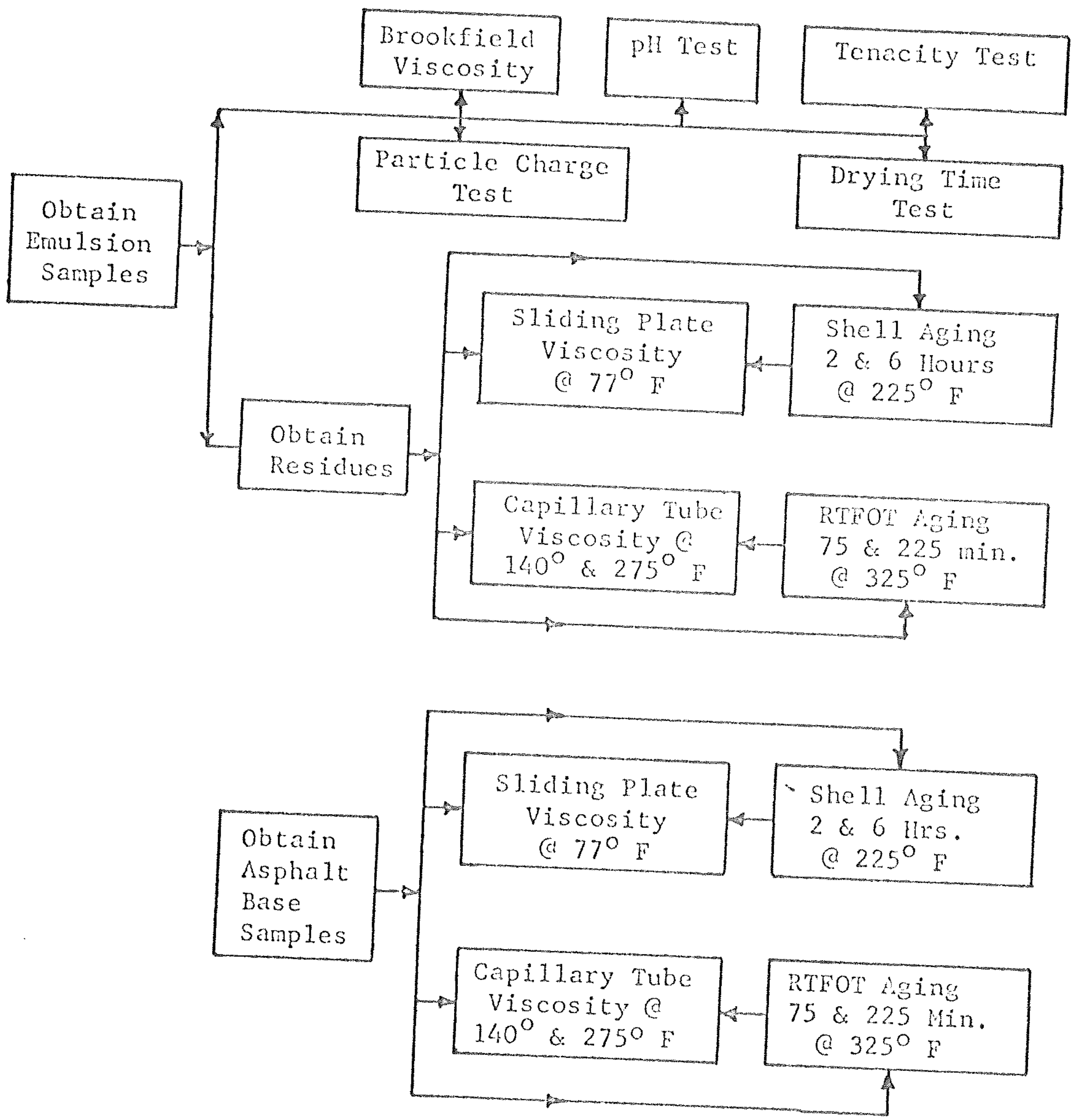

Figure 1 Flow Chart For Testing

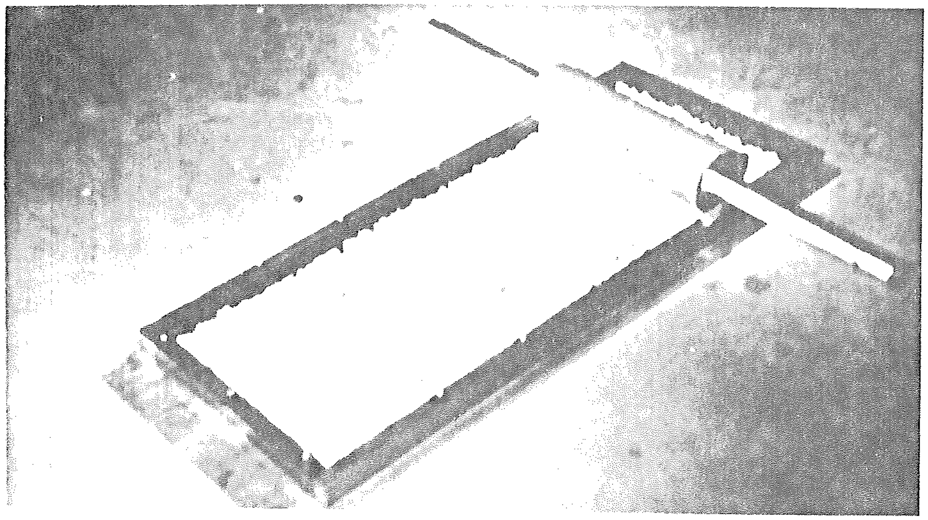

Figure 2 Tenacity Test Chip Seal Roadbed

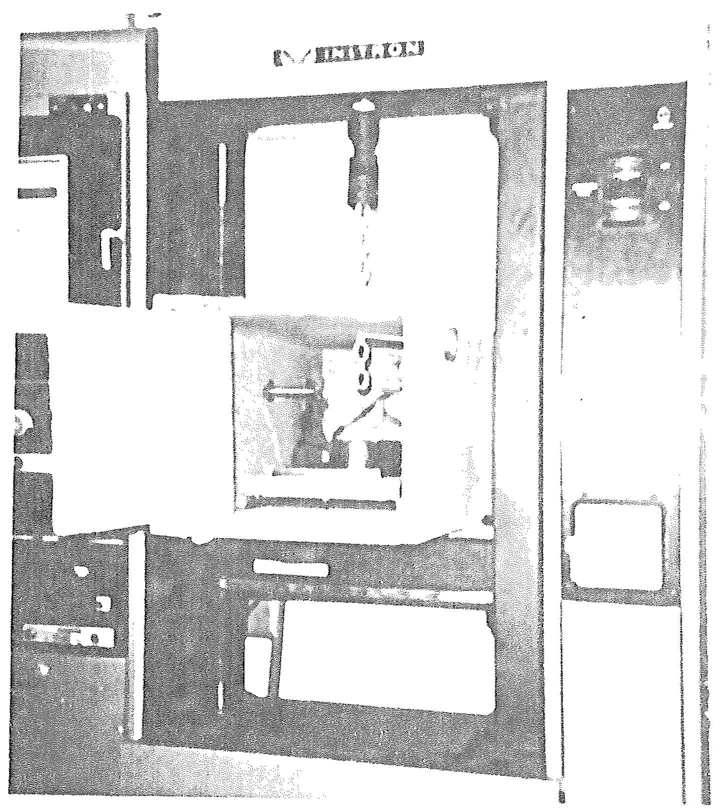

Figure 3 Testing Machine and Temperature Box for Tenacity Test

impurities from the surface.

A piece of 20.0-inch by 8.8-inch aluminum plate was used for the roadbed. Steel shoulders surrounded the roadbed in order to retain the emulsion and maintain a fixed area, Figure 2.

An Instron Universal Testing Machine, Model TT-C with a F-load cell, was used for performing the tenacity tests. Load cell ranges of 200, 500, and 1000 pounds were used for testing at various temperatures. For these tests, a crosshead speed of 10 inches per minute was used. A high speed Leeds and Northrup graphic recorder was used to plot load and displacement.

To provide a constant temperature environment during testing at temperatures of 100° and 140° F, a styrofoam box was built. A heating element, fan, and thermostatic switch were used to control the temperature. This box housed the sample roadbed and was mounted on the Instron testing machine.

Procedure

The asphalt emulsion was warmed to about 120° F and stirred to a smooth texture. The desired amount of emulsion was then applied to the aluminum plate and spread evenly over the surface. A predetermined amount of aggregate was then placed by hand one stone deep across the asphalt and rolled with a hand roller until all aggregate was firmly seated.

Three machined pieces of 4-inch pipe were then placed symmetrically and pressed into the seal coat. These rings were centered over the plate's longitudinal axis. The roadbed sample was then weighed and placed in a forced draft oven at 140° F to cure for 18 hours.

After curing and cooling, the roadbed was weighed, then loose aggregate was removed, and again the roadbed was weighed. A mixture of hydrocal and water was then poured into the steel rings in sufficient amount to penetrate the spaces between aggregate particles and cover all of the aggregate. A hydrocal mixture was used which would harden in about two hours.

When the hydrocal had hardened, a "spider" was attached to each of the three rings. Each ring contained three holes through which the "spider" was attached with three bolts.

The roadbed was then secured to the cross bar of the testing machine and a chain connected to a spider was attached to the reaction head of the testing machine. Each ring was pulled until failure occured.

The roadbeds tested at 100° and 140° F were brought to the proper temperature in an oven. After one hour of heating, the specimen was immediately transferred to the testing box which was mounted on the testing machine and which was also at the correct testing temperature, Figure 3. Thus, no time delay was necessary for bringing the specimens to temperature in the testing box.

All loads were recorded as were the weights before and after curing. In addition, emulsion residue and aggregate spread weights were recalculated.

The amount of emulsion used was such to result in a residue application of 0.20 gallon per square yard. The aggregate was spread at a rate of 20 pounds per square yard.

Drying Time Test

The test apparatus consisted of two basic components: a DC-9300

Gardener Drying Time Recorder, and a black surface Bellani type Livingston atmometer (6), both mounted in a small laboratory oven directly beneath a six-inch, down draft, variable speed fan. The apparatus is illustrated in Figure 4.

The atmometer was supplied with distilled water via a rubber hose which passes through one wall of the oven to a 10 ml. pipet. Evaporation rate was determined by the drop in water level within the pipet for the period of a test run.

The DG-9300 Gardener Drying Time Recorder is described in "Physical Test Bulletin 1964," Gardener Laboratory, Inc., Bethesda, Maryland, as follows:

> "...apparatus for measuring drying time of paint and the like by the character of the mark made by a ball dragged over the drying film. It consists of a synchronous motor, mounted on a tripod, with its shaft oriented vertically; an arm attached to the shaft and a metal rod, terminating in a ball and mounted vertically in the free end of the shaft.
>
> To make a test, set the Recorder on the wet film with the ball resting in the film. Plug the Recorder into a 110 volt 60 cycle AC outlet. The ball describes a circular path, two inches in diameter, in the film. The character of the mark made by the ball is related to the different stages of drying. Determine the time corresponding to any selected position on the mark by comparison with a Template, supplied with the instrument."

The recorder is available with motor speeds varying from one revolution per hour to one revolution in 96 hours. In these tests, a one revolution per hour motor was used.

Rather than use a thin film of emulsion, which would have no physical significance to field applications, aluminum plates were constructed with 3.25-inch diameter cylindrical depressions cut into them approximately 0.053 inch in depth. With the depression filled with emulsion and screeded flush, the film on the plate approximates a field application of 0.30 gallon per square yard.

During a test run, the drying time was taken at the point where the emulsion no longer flowed back into the groove made by the moving teflon ball, usually at this point the aluminum plate became visable in the bottom of the grove, Figure 5.

All of the Drying Time tests were run at room temperature with the apparatus set up as shown in Figure 4. Due to the heating effect of the fan motor, the inner glass oven door was left open a few inches in order to maintain a fairly constant temperature. Temperatures, however, still varied slightly throughout a series of tests.

A series of tests was run for each emulsion, and consisted of the determination of drying time at several different evaporation rates. Evaporation rate was changed by varying the speed of the overhead fan. The rheostat used for this purpose had dial readings from 0 to 150, the lower settings indicating lower motor speeds. Five or six tests were run on each emulsion, each test with a different fan setting, thereby obtaining several different evaporation rates each with a corresponding drying time.

Each individual test was run as follows:

(a) The emulsion was mixed thoroughly by hand, carefully, so as not to induce excessive air bubbles which would cause erroneous results.

(b) A small amount of emulsion was then poured into the depression in the aluminum plate and screeded with a glass rod so as to give a uniform thickness of emulsion remaining in the depression.

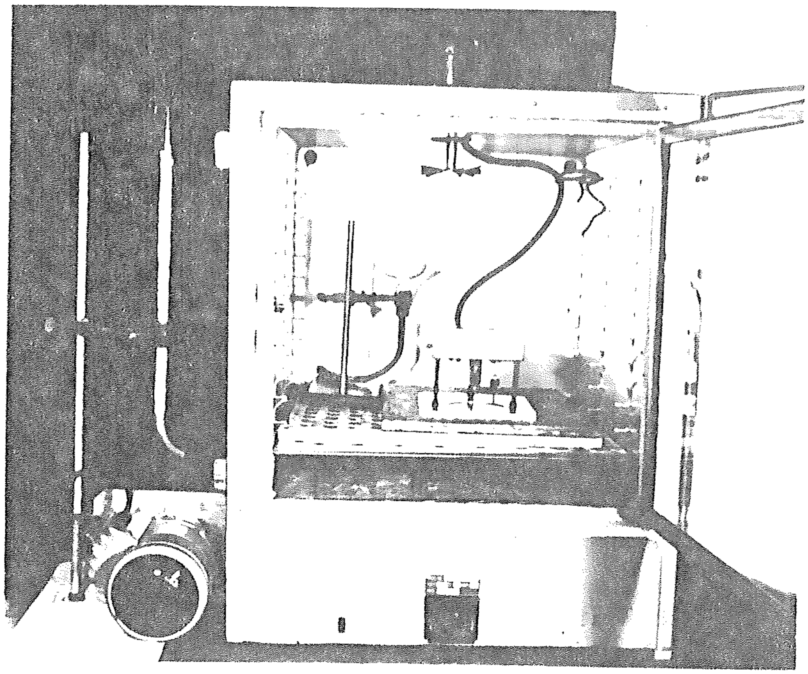

Figure 4 Drying Time Test Equipment

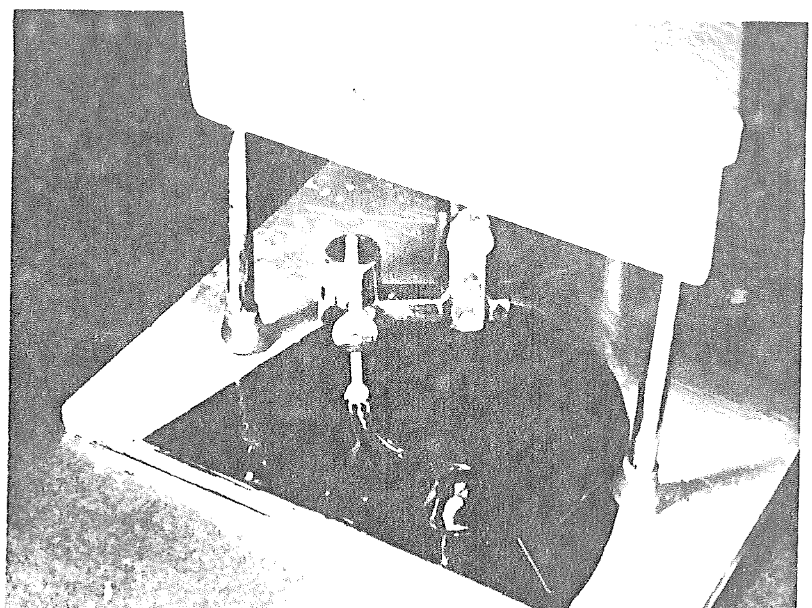

Figure 5 Drying Time Test Completed

(c) The plate was then placed on the level board in the oven, the Gardener Recorder placed on top of it, and the rotating shaft of the recorder centered over the pool of emulsion. The 12-gram weight was then placed on the scribing arm.

(d) The starting position of the teflon ball was recorded by a pencil mark on the metal plate and the Recorder switched on. At the same time, the position of the water level in the pipet feeding the atmometer was recorded on the data sheet, along with starting temperature, fan setting, and the time.

(e) The recorder was then allowed to run until such a time that the emulsion no longer flowed back and filled the gap left by the ball, in most cases the plate being visible at the bottom of the groove.

(f) When that condition became apparent, the machine was shut off; time, temperature, and pipet water level recorded; and the drying time determined, by use of the template described previously, and recorded.

A test, as described above, was run for each emulsion under the different evaporation conditions as mentioned above.

Residue Determination

To determine the residue of each emulsion ASTM Standard D244-68, Testing Emulsified Asphalts, (4), was used. The procedures described for 'Residue by Evaporation' Procedure B were followed. Procedure B is to be followed when tests on the residue are required.

Sliding Plate Viscosity

These measurements were made with a device manufactured by Hallikainen Instruments following the basic design of Shell Oil Company. The procedure utilized was essentially that described by the manufacturer and by ASTM under the heading of "Proposed Method of Test for Viscosity of High Consistency Materials With Modified Sliding-Plate Microviscometers", appearing on page 885-895 of Reference 4. The main difference was in the thickness of asphalt film used in the test.

Shell Aging

In the 1969 ASTM Book 11, (4), pages 863-867, there is described the Proposed Method of Test for Aging Index of Bituminous Materials.

This method describes the procedure for the measurement of the increase in viscosity which occurs when a semi-solid bituminous material is heated in a thin film under conditions specified. That is, a film of bituminous material 5μ in thickness is heated in air for 2 hours at 225° F. The viscosity of the original material and of the sample after heating are measured at 77° F using a sliding plate micro-film viscometer. The aging index is the ratio of the viscosity at 77° F after heating to its original viscosity at 77° F.

This technique was used for aging at 2 hours and at 6 hours. These studies, however, utilized a 15 μ film thickness instead of a 5μ.

Capillary Tube Viscosity

This test was performed in accordance with the ASTM Standard D2171-66, Test for Absolute Viscosity of Asphalts (4).

This method covers procedures for the determination of absolute viscosity of asphalt by a vacuum capillary viscometer at 140° F. It is applicable to materials having viscosities in the range of 42 to 200,000 poises.

A Cannon-Manning Vacuum Viscometer was used for these tests. This viscometer is a capillary type made of borosilicate glass and is one of the two types specified.

The ASTM standard indicates that the method is suitable for use at temperatures other than 140° F. The ASTM precision is based only on 140° F tests.

Tests for this research work were performed at 140° F and 275° F.

Rolling Thin Film Aging

This test was performed in accordance with Test Method No. Calif. 346-D, April 1970, (7). The test method is titled "Method of Test for Determining the Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin Film Oven Test)." The effects of this treatment are established from measurements of physical properties of an asphalt before and after the test.

The emulsion residues and base asphalts were aged for 75 minutes and also 225 minutes at 325° F in accordance with the test method. Within 2 hours after aging, the capillary tube viscosity was determined for each sample at 140° F.

An aging index of each asphalt cement was then determined by obtaining the ratio of the viscosity of the aged material to the original viscosity.

Part III TEST RESULTS AND DISCUSSION

General

The data accumulated from performing the tests described in Part II are listed in Appendix A. General discussions of the data, along with comparative graphs, are presented in this part of the report. However, additional discussion of the data in the form of a comparative analysis is offered in Part IV.

Particle Charge and pH of Emulsions

The particle charge and pH of each emulsion are listed in Table I of Appendix A. Examination of the data shows that emulsions 1, 3, 4, 5, and 7 had a positive charge while Nos. 2, 6, 8, and 9 had a negative charge. The positive charged cationic emulsions were acidic having pH values of less then 5.5 and pH of the anionic emulsions (negative charge) ranged from 7.6 to 11.3. It is noted that the K or C classification is justified for the cationic emulsions and also that emulsion 8, a slow-setting mixing type, was close to being neutral.

Emulsion Residue

The amount of residue in each emulsion was determined in order to calculate the spread rates for constant residual asphalt spread in the tenacity test. Also, the values for residue amount were desired for comparison with specification requirements.

In general the requirements on amount of residue specified by the Arizona Highway Department (8) were met except for the RS-2 emulsions Nos. 6 and 9, these had residues of 62.4 and 61.4 percent respectively and the specifications cite a minimum value of 63 percent. It is also apparent that the cationic emulsio generally had the larger value of residual asphalt.

Brookfield Viscosity of Emulsions

The Brookfield viscosity of each emulsion was determined at temperatures of 77°, 104°, and 140° F. Table I contains the values of these measurements. The plot of Figure 6 shows relationships between Brookfield viscosity and temperature. It is noted from the curves that the effects of temperature on the fluidity of the emulsions are similar for most of the samples. The outstandingly different response to temperature is represented by emulsion No. 6. Also of interest is the generalized grouping of curves on the basis of particle charge as indicated on the graph.

No attempt has been made to compare Brookfield viscosity to specification values in units of Saybolt-Furol-seconds since there appears to be no simple and generally accepted relationship between these two.

Tenacity Tests

Table 2 in Appendix A itemizes the stone coverage, emulsion and residue spread rates, and failure loads at different temperatures for the Tenacity Test. A plot of the failure load (tenacity) vs. temperature is presented in Figure 7. The general decrease in tenacity with increase in test temperatures was as expected; however, the relative positions of the curves are not necessarily related to their location in the plot of emulsion viscosity vs. temperature, (Figure 6). Two factors will affect position comparison: first, the viscosity influencing the tenacity is that of the residue and secondly, the relatively fast rate of loading. However, again we see the grouping of curves based on particle charge. Also, it is noticed that sample No. 6 is quite different from the rest.

Drying Time Tests

The effects of evaporation rate on drying time are listed in Table 3 of Appendix A and are shown graphically in Figure 8. The evaporation rate was changed by the rate of air flow over the specimens rather than by temperature variation; even so, the test temperature for the different emulsions varied from 83° to 90° F; however, the test temperature was held within ± 1° F for each sample.

The curves of Figure 8 show a large variation in drying time for the emulsions. It is seen that for the same evaporation rate one emulsion can dry up to six times faster than another. The position of a curve appears to be influenced by initial viscosity, viscosity of residual and amount of residual asphalt. We assume that the small variation in test temperature had no significant effect on drying time.

Although the evaporation rates have not been correlated with field conditions, it would seem that drying time would bear a direct relationship to the delay in opening a new chip seal to traffic.

Absolute Viscosity of Emulsion Residues and Base Asphalts

Absolute viscosities of the emulsion residues and base asphalts at 77°, 140°, and 275° F are listed in Table 4. Inspection of the data shows that the residues had higher viscosity values than the original asphalt; the differences were higher at the lower temperature of 77° F.

It is noted that the 140° F viscosity of the asphalts is much higher than normally specified for residues of emulsions; the range of values

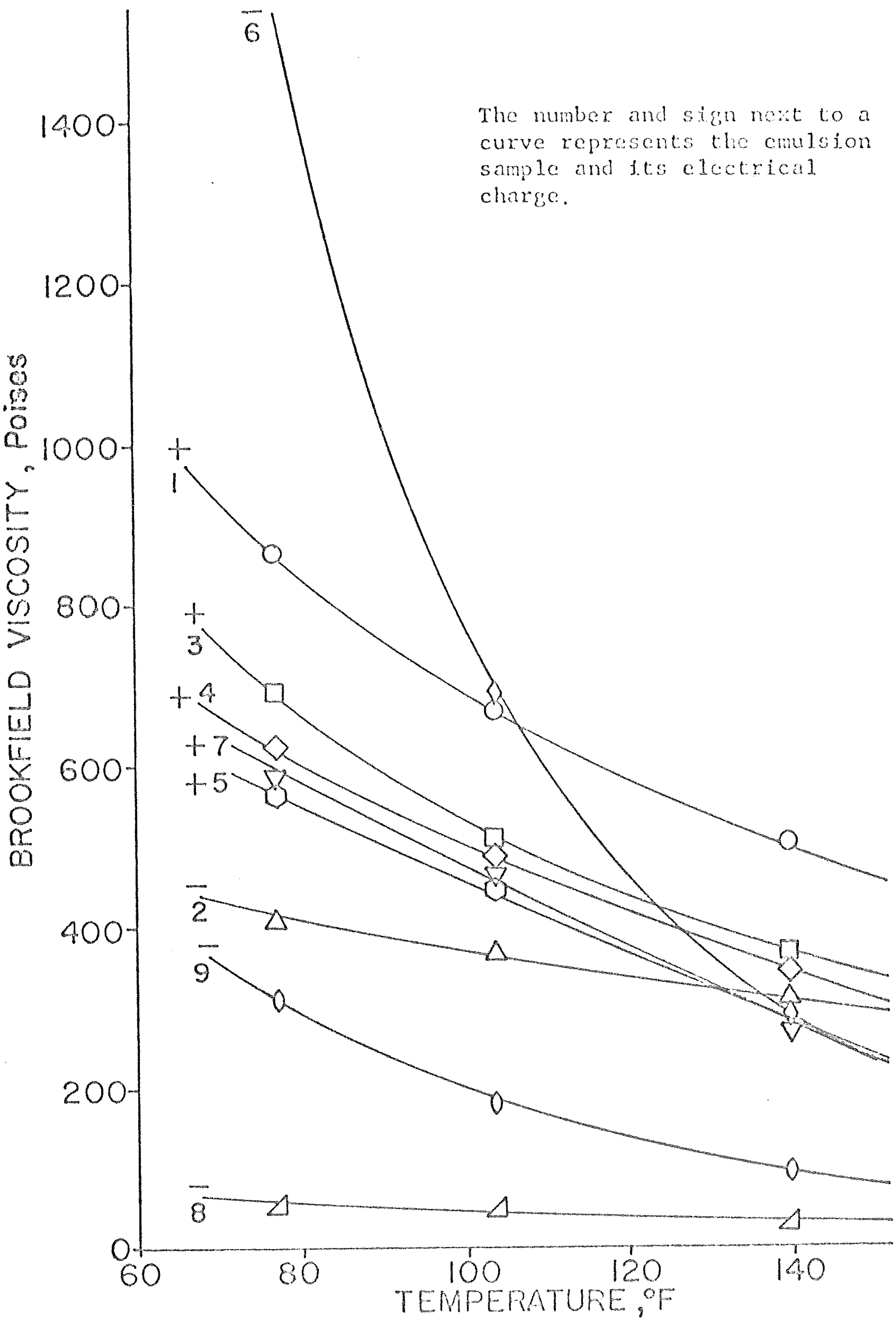

Figure 6 Viscosity-Temperature Relationship for Asphalt Emulsions

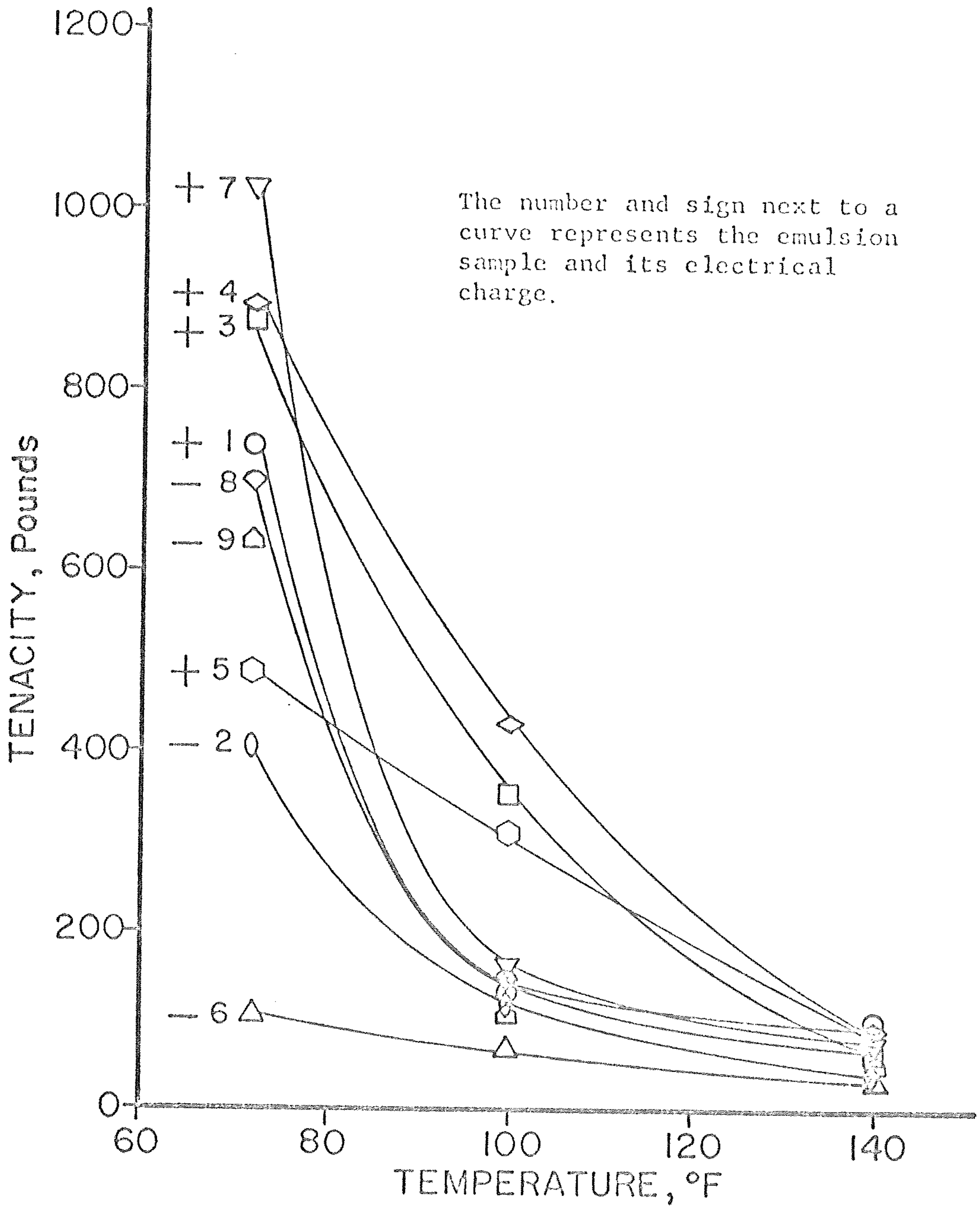

Figure 7 Effect of Temperature on Tenacity of Emulsion Residue for Holding a Coverstone

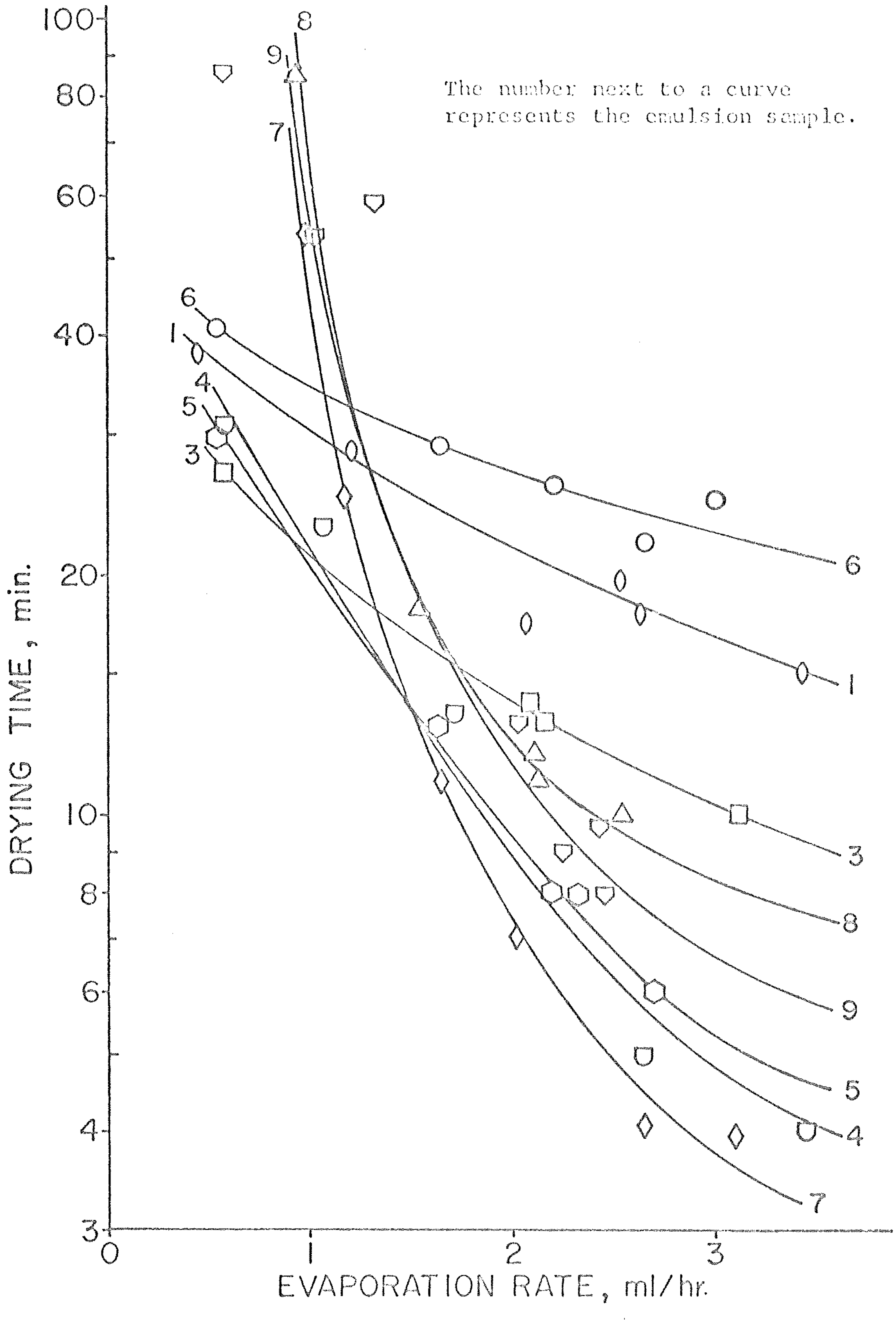

Figure 8 The Effects of Evaporation Rate on Drying Time for Asphalt Emulsions

is from 1210 to 3780 poises. The data plotted in Figure 9 have been selected to show extreme values of viscosity and temperature suceptibility.

Relative Viscosities of Emulsion Residues and Base Asphalts

The effects of heat and air in increasing viscosity of an asphalt is expressed as a multiplying factor called relative viscosity. The effects of the two methods used and the periods of aging time are listed in Table 5 of Appendix A. It appears that the two methods of determining resistance to oxidation, rate the asphalts in essentially the same order, see Table 6.

The bottom half of Tables 5 and 6 show that the asphalt with greatest resistance to oxidation was base No. 8, and then followed by 2, 3, and lastly No. 1. The rating of the emulsion residues containing these base asphalts is almost the same, the order being Nos. 8, 2, 1, and lastly 3.

Figure 10 shows a plot of relative viscosity vs. aging time for two base asphalts. The relative viscosities obtained by capillary tube and sliding plate procedures are also shown. It is noted that relative viscosity values obtained by the capillary tube procedure are higher than by the sliding plate; however, it is not intended to imply that the former aging is more severe since viscosity tests and temperatures are different.

The most important finding of these measurements are the high values of relative viscosity compared to those being specified or recommended. The State of Texas specifications (9) on requirements for relative viscosity set a maximum value of 6.0 using the Shell procedure for asphalts having 140° F viscosities comparable to those of this study.

The Asphalt Institute and Pennsylvania recommend relative viscosity value of 5 and 4.5 when determined by the capillary tube method and aged by the AASHO Thin Film Oven Test (9). Skog (10) has shown that the effects of aging by the AASHO Thin Film Oven Test are quite comparable to the Rolling Thin Film Test.

It is seen that not one of the base asphalts met any of the proposed requirements of durability as presented by other agencies.

A study of the aging data shows that most of the asphalts have an increasing rate of aging with increase of aging time. We assume that this trend would be eventually reversed at high aging time so that a limiting value of relative viscosity will be reached.

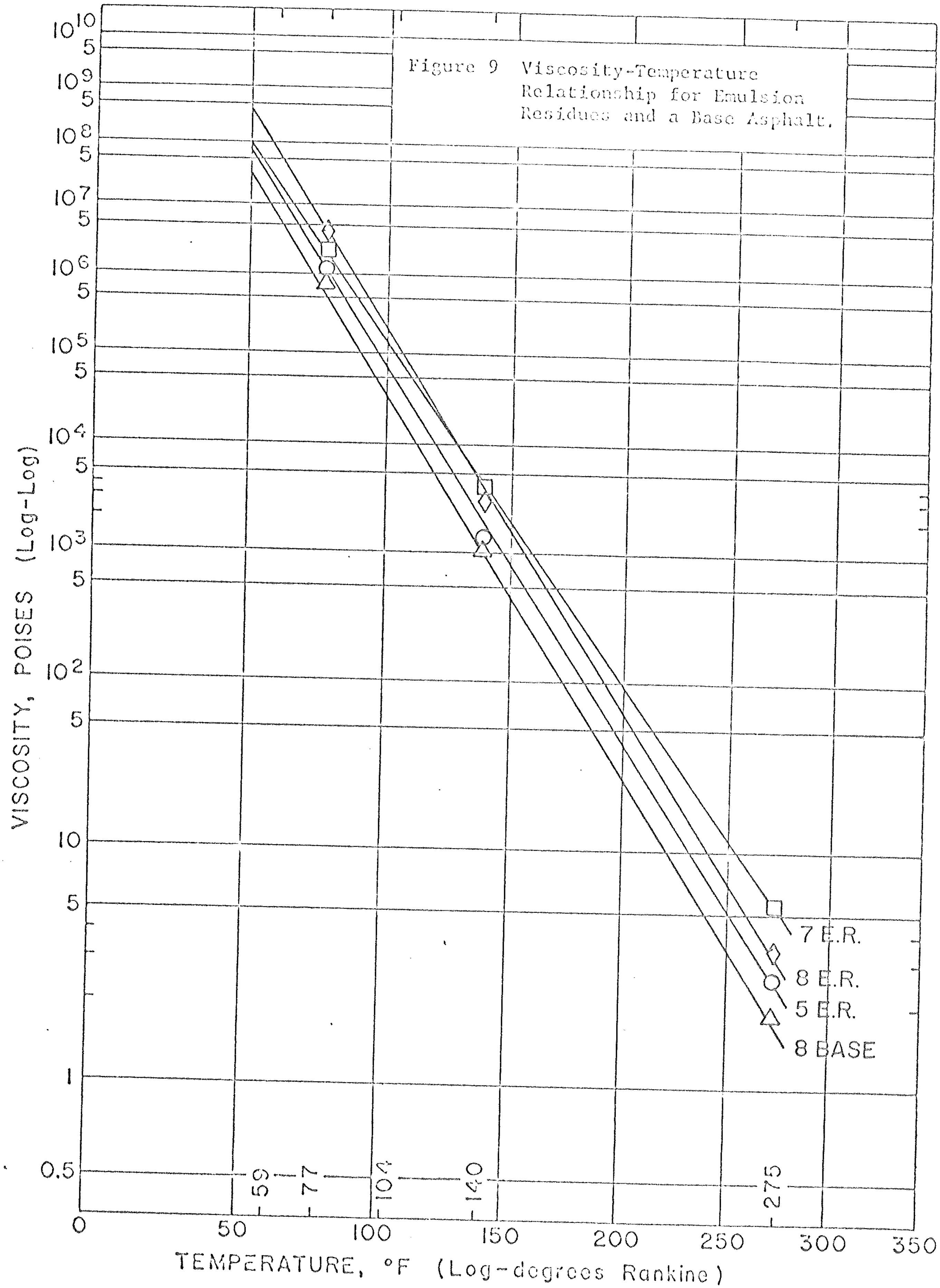
Figure 9 Viscosity-Temperature Relationship for Emulsion Residues and a Base Asphalt.
VISCOSITY, POISES (Log-Log)
TEMPERATURE, °F (Log-degrees Rankine)
7 E.R.
8 E.R.
5 E.R.
8 BASE
59
77
104
140
275

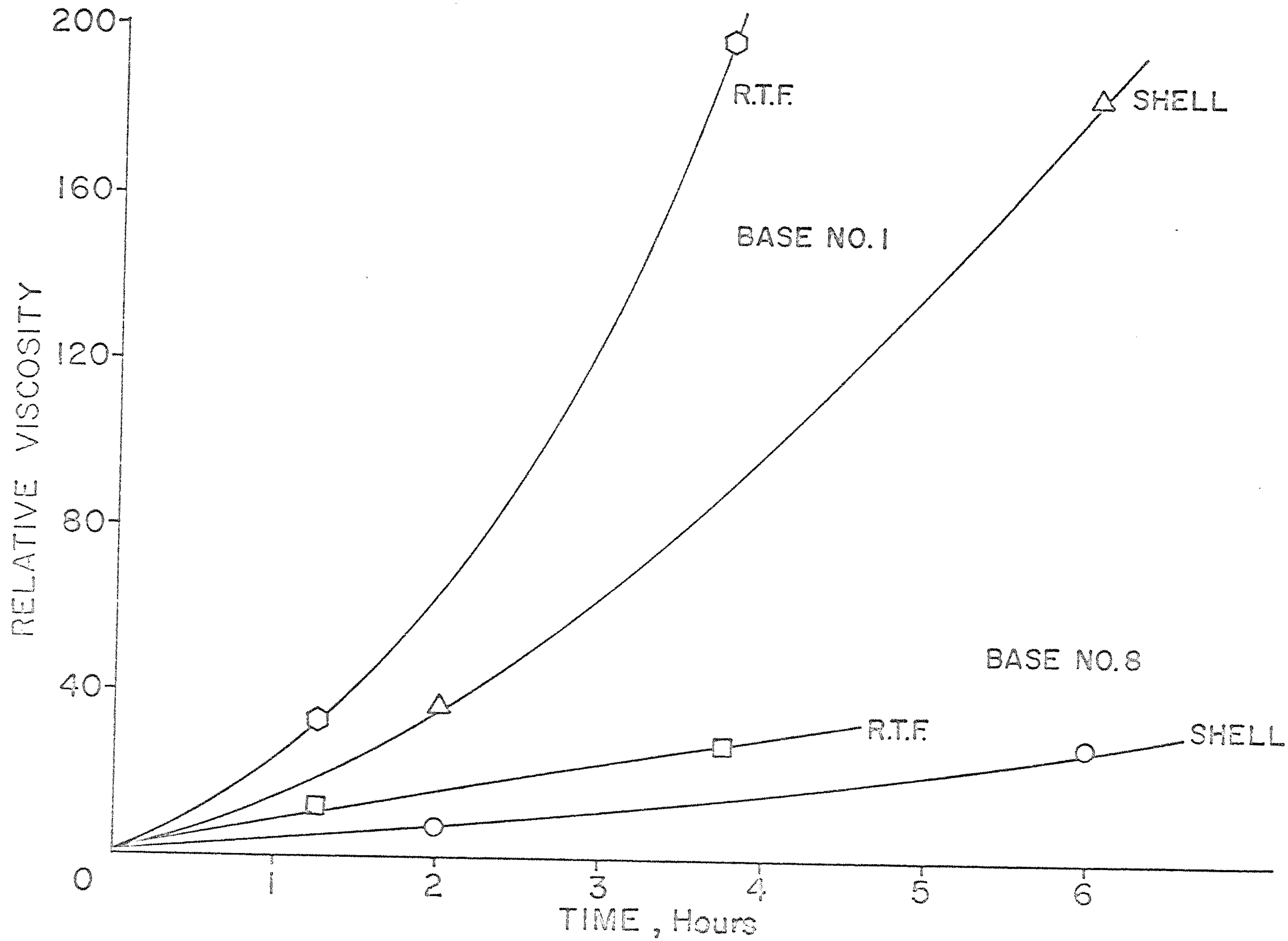

Figure 10 . Effects of Aging Time and Method on Viscosity of Asphalts

Part IV COMPARATIVE ANALYSIS OF RESULTS

General Characteristics of Asphalt Emulsions

As expected, the amount of residue is greater for the cationic than for the anionic emulsions; however, the emulsions from company A generally contained more binder than did those from the other sources.

The low viscosity of emulsion 8 may be attributed to the low amount of residue. It is probable that since this type of emulsion is used for slurry seal works and the principal contractor of slurry seals in Arizona uses a machine requiring low viscosity emulsion, that this characteristic was "taylor made" to suit a special pump.

The high 77° F viscosity of emulsion 6, can not be explained but can be expected to cause more pumping and spraying problems during cool weather than the other emulsions.

The corresponding viscosities of emulsion pairs 4 - 5, and 2 - 9 seem to be due to their common source.

Emulsion Residues

The differences in tenacity value of the emulsion residues are not as great at 140° F as they are at the other test temperatures; the high to low tenacity ratios being 2.6, 6.0, and 10.2 for 140°, 100°, and 72° F respectively. The relative values of tenacity at 72° F seem to be accounted for primarily on the basis of aging characteristics rather than on residue viscosity. The reader is reminded that specimens were cured at 140° F for 18 hours prior to testing and during this period were subject to oxidation. It is seen that tenacity values for residues 3, 4, and 7 are the highest as are their relative viscosity value; ranking 8th, 9th, and 7th respectively. Absolute viscosities at 77° F were of comparatively low value for emulsion 3 and 4 but of a high value for No. 7. The ranking of emulsion residue Nos. 6 and 8 are based on both viscosity and aging considerations. Again as for the Brookfield viscosity values, emulsion No. 6 shows as being quite different from the others.

As noted before, the higher tenacity values were associated with the cationic emulsions which generally adhere to silicious aggregates, as used in the test, better than do the anionic ones.

The curves of Figure 11 are plots of log viscosity vs. tenacity. From consideration of viscosity and oxidation susceptibility of the asphalt is seems that emulsions Nos. 5 and 8 would be the best ones for a chip seal with respect to service requirements. However, the viscosity of emulsion 8 is too low from the viewpoint of construction requirements.

Drying Time

Since temperature was essentially constant during the test period, it would seem that emulsion characteristics contributing primarily to drying time would be amount of residue and viscosity of the residue. It is noted that emulsions Nos. 8 and 6 have the lowest and highest Brookfield viscosities at 77° F, but their drying times are similar at the higher evaporation rates.

At the lower evaporation rate emulsions 7, 8, and 9 have the longest drying times which seems to correspond directly with the lowest amounts of residue and indirectly with the highest values of viscosity for all the emulsions.

At the highest evaporation rate emulsions 1, 3, and 6 have the

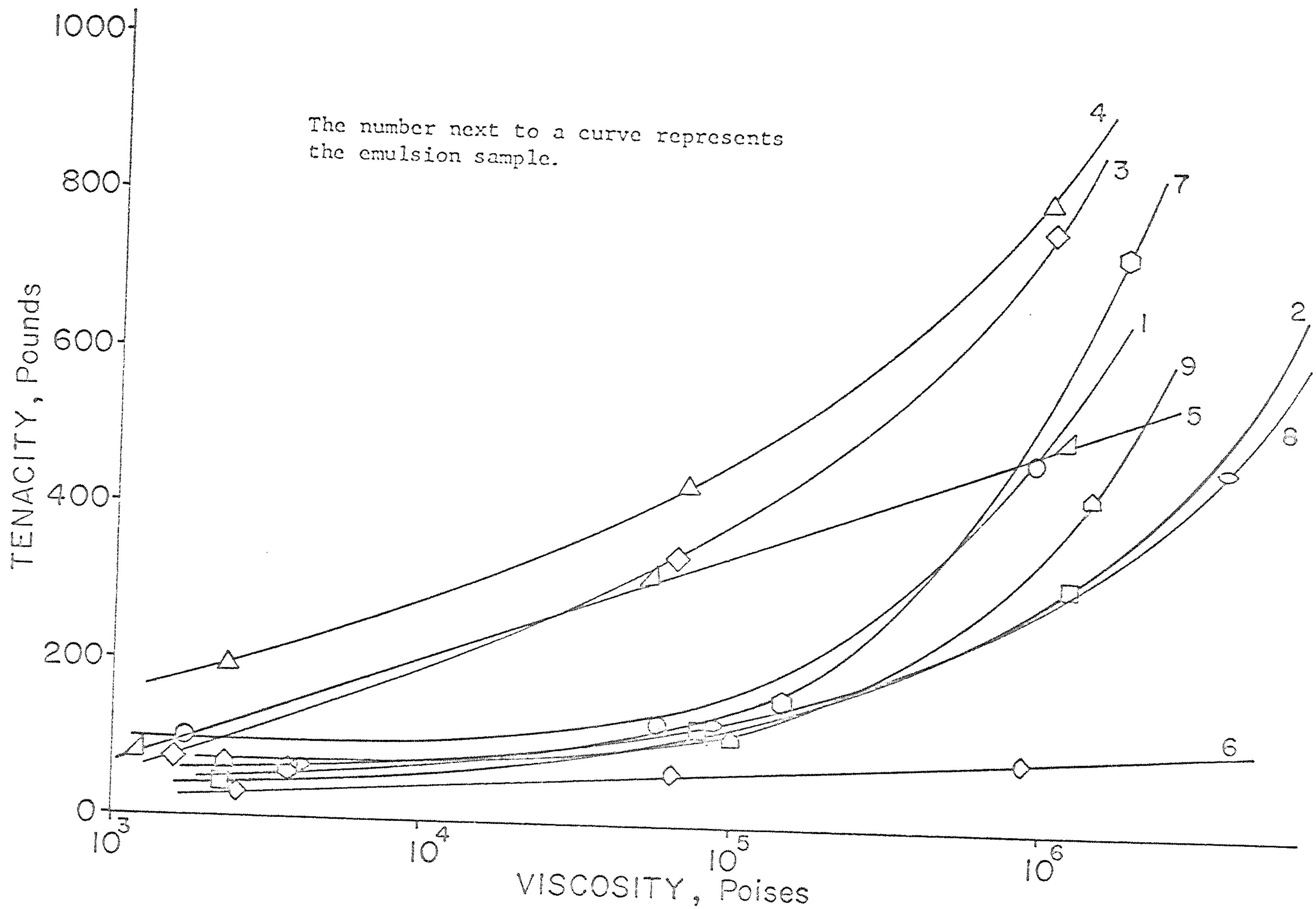

Figure 11 Relationship Between Viscosity of Residues and Tenacity

longest drying times which, in this case, seems to correspond directly with the lowest residue viscosities.

Part V SUMMARY AND CONCLUSIONS

The following items present a summary of findings and conclusions reached within the limits of and restricted to this study.

1. Brookfield viscosities indicated that the cationic emulsions with high residue contents had the higher values. The Brookfield viscometer was adequate for comparing effects of temperatures on fluidity of emulsions.

2. The values of pH and particle charge were in correspondence to the acidity or alkalinity of the emulsion.

3. The tenacity of the emulsion residues for holding a Salt River coverstone, seemed to be related primarily to "aging" susceptibility of the residual asphalt rather than on "original" residue viscosity.

4. Drying time of the emulsions was dependent on evaporation rate; however, at low evaporation rates the emulsions with the least amounts of residue were slowest in drying and at high evaporation rates the emulsions with the softest residues had the greatest drying times.

5. The absolute viscosity of the emulsion residues were higher than that of the orginal base asphalt; thus indicating that in producing the emulsion, the base asphalt was hardened. The 77° F viscosity of the emulsion residues ranged from 0.92×10^6 to 3.92×10^6 poises and that for the original base asphalt ranged from 0.42×10^6 to 0.99×10^6 poises; at 140° F those ranges were 1210 to 3780 poises and 1240 to 1700 poises respectively. The ranges of viscosity appear adequate

for pavement surface conditions in Arizona.

6. The aging characteristics of the original and residual asphalt varied over a large range. For the Shell procedure of aging, relative viscosity values varied from 6.1 to 36.2; the one state setting limits on this characteristic requires a maximum of 6.0 for comparable asphalt cements. For the Rolling Thin Film aging procedure, relative viscosity values ranged from 15.8 to 38.1; proposed and required values for this method are less than 5 and a maximum of 4.5. Not one of the asphalt cements met proposed and specified durability requirements.

7. In consideration of setting, tenacity, and durability characteristics it appears that emulsion Nos. 8 and 5 are the best for service conditions; however, the low viscosity of emulsion No. 8 (a mixing type) would make application for a chip seal extremely difficult.

ACKNOWLEDGEMENT

The cooperation and assistance received from the Arizona Highway Department in obtaining the materials tested are greatly appreciated.

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APPENDIX A

Research Data

TABLE 1 Characterisitcs of Asphalt Emulsions

Sample Number	Type	Viscosity*, poise 77° F	104° F	140° F	Particle Charge	pH	Residue, Percent
$1\text{-}B_1$	RS-3KH	867	670	501	+	3.5	67.8
$2\text{-}B_2$	RS-2	411	370	317	-	11.3	64.0
$3\text{-}A_1$	RS-3KH	691	511	369	+	3.2	72.4
$4\text{-}A_2$	CRS-2H	623	497	352	+	5.3	67.6
$5\text{-}A_2$	CRS-2H	570	444	282	+	2.5	70.2
$6\text{-}A_1$	RS-2	1621	676	288	-	11.2	62.4
$7\text{-}A_3$	RS-3KH	589	467	275	+	4.5	63.5
$8\text{-}C_1$	SS-1H	56	45	36	-	7.6	59.6
$9\text{-}B_2$	RS-2	314	180	94	-	10.0	61.4

* Viscosity by Brookfield Viscometer

TABLE 2 Data and Test Results of Tenacity Tests

Sample Number		Cover Stone (lbs./yd.^{2})	Emulsion Spread (gal/yd.^{2})	Residue Spread (gal/yd.^{2})	Failure Load, Lbs. 72° F	100° F	140° F
					a	b	c
1.	a	20.6	0.297	0.210	760	149	98
	b	20.7	0.294	0.184	730	123	106
	c	20.6	0.297	0.192	720	135	99
	avg.	20.6	0.296	0.195	737	124	102
2.	a	20.7	0.294	0.179	435	112	45
	b	20.4	0.313	0.208	380	138	51
	c	19.5	0.313	0.194	405	120	58
	avg.	20.2	0.307	0.194	407	123	51
3.	a	20.5	0.275	0.184	860	195	74
	b	21.0	0.272	0.184	895	380	63
	c	19.7	0.313	0.197	---	470	86
	avg.	20.1	0.273	0.188	878	348	74
4.	a	19.8	0.300	0.197	900	420	93
	b	22.0	0.297	0.208	900	395	86
	c	20.4	0.294	0.208	874	475	108
	avg.	20.4	0.297	0.204	891	430	96
5.	a	20.1	0.292	0.168	377	390	102
	b	20.4	0.284	0.186	480	340	70
	c	20.4	0.284	0.197	485	305	80
	avg.	20.3	0.287	0.184	481	345	84

TABLE 2 Data and Test Results of Tenacity Tests (continued)

Sample Number	Cover Stone (lbs./yd.^{2})	Emulsion Spread (gal./yd.^{2})	Residue Spread (gal./yd.^{2})	Failure Load, Lbs. 72°F	100°F	140°F
				a	b	c
6. a	20.2	0.297	0.216	69	61	38
b	20.6	0.321	0.194	117	78	32
c	20.4	0.324	0.216	118	73	46
avg.	20.4	0.314	0.198	101	71	39
7. a	20.4	0.316	0.218	---	157	59
b	19.0	0.305	0.214	1050	158	65
c	20.4	0.316	0.210	990	157	83
avg.	19.9	0.312	0.214	1020	157	69
8. a	19.5	0.334	0.202	840	183	70
b	19.7	0.340	0.210	570	123	67
c	20.7	0.337	0.202	670	135	88
avg.	19.8	0.337	0.205	693	147	75
9. a	20.6	0.327	0.208	630	115	74
b	19.3	0.330	0.210	575	95	76
c	20.1	0.337	0.234	690	142	60
avg.	20.2	0.331	0.217	632	118	70

TABLE 3 Effects of Evaporation Rate (E.R.) on Drying Time (D.T.) of Asphalt Emulsions

Fan Speed	Sample Number 1		2		3		4		5		6		7		8		9	
	E.R.	D.T	E.R.	D.T	E.R	D.T.	E.R.	D.T.	E.R	D.T.	E.R.	D.T.	E.R.	D.T	E.R.	D.T.	E.R.	D.T.
1	0.45	38			0.56	27	0.51	31	0.51	30	0.49	41	1.15	25	0.90	85	0.52	86
2									1.60	13	1.60	29	2.00	7	1.50	18	1.30	60
3	1.20	28					1.10	23									1.04	54
4	2.04	17			3,10	10	1.50	11	2.30	8	2.20	26	1.60	11	2.10	11	2.05	14
5																	2.40	10
6	2.50	20			2.14	13	2.60	5	2.20	8	2.60	22	2.60	4	2.10	12	2.40	8
7	2.60	18															2.20	9
8	3.40	15			2.10	14	3.40	4	2.70	6							2.60	6
9													3.10	4	2.5	10		
10											3.00	25						
Test Temperature	83° F				85° F		85° F		87° F		90° F		90° F		87° F		83° F	

TABLE 4 Absolute Viscosities of Emulsion Residues and Base Asphalts

Sample Number		Viscosity, poise — Temperature, °F 77*	140**	275**
Emulsion Residues	1	0.92×10^6	1.76×10^3	3.65
	2	1.21×10^6	2.30×10^3	4.14
	3	1.02×10^6	1.58×10^3	3.32
	4	1.00×10^6	2.36×10^3	4.42
	5	1.19×10^6	1.21×10^3	2.66
	6	0.90×10^6	2.56×10^3	4.35
	7	1.82×10^6	3.72×10^3	5.22
	8	3.92×10^6	3.78×10^3	3.40
	9	1.42×10^6	2.34×10^3	3.93
Base Asphalts	1	0.42×10^6	1.27×10^3	3.27
	2	0.99×10^6	1.70×10^3	3.32
	3	0.86×10^6	1.37×10^3	2.78
	8	0.69×10^6	1.24×10^3	1.92

* Viscosity by sliding plate viscometer at a shear rate of 5×10^{-2} sec^{-1}.

** Viscosity by capillary tube.

TABLE 5 Relative Viscosities of Emulsion Residues and Base Asphalts by Two Methods of Aging

	Sample Number	Shell Procedure* Aging Period, Hrs. 2	6	Rolling Thin Film** Aging Period, Minutes 75	225
Emulsion Residues	1	8.0	39.6	24.6	80.1
	2	6.5	35.5	20.4	60.4
	3	13.7	58.0	30.3	124.1
	4	21.2	128.0	38.1	178.0
	5	6.1	13.7	16.9	67.6
	6	8.4	77.8	20.9	82.4
	7	11.8	36.3	26.2	187.4
	8	6.1	33.2	15.8	38.6
	9	7.0	26.8	18.2	54.7
Base Asphalts	1	36.2	181.0	32.6	197.6
	2	7.9	35.4	20.2	83.5
	3	14.0	55.0	34.5	145.3
	8	7.8	29.0	14.3	27.4

* Viscosity measurement made at 77° F

** Viscosity measurement made at 140° F

TABLE 6 Ranking* by Relative Viscosity of Emulsion Residues and Base Asphalts

Sample Number		Shell Procedure Aging Period, Hrs. 2	6	Rolling Thin Film Aging Period, Min. 75	225	Composite
Emulsion Residues	1	5	6	6	5	5
	2	3	4	4	3	4
	3	8	7	8	7	8
	4	9	9	9	8	9
	5	1	1	2	4	2
	6	6	8	5	6	6
	7	7	5	7	9	7
	8	1	3	1	1	1
	9	4	2	3	2	3
Base Asphalts	1	4	4	3	4	4
	2	1	2	2	2	2
	3	3	3	4	3	3
	8	2	1	1	1	1

* The lower numbers represent the least increase in viscosity due to aging.

APPENDIX B

Research Data

Asphalt Emulsion Samples

The following listing gives the source of the emulsion samples, the date received, the emulsion type, the manufacturer, and the laboratory identification (samples) number.

Sample No.	Date Received	General Information
1-B_1	8-18-69	Sampler: Arizona Highway Department Type: RS-3KH Manufacturer:
2-B_2	8-18-69	Sampler: Arizona Highway Department Type: RS-2 Manufacturer:
3-A_1	8-26-69	Sampler: Supplier Type: RS-3KH Manufacturer:
4-A_2	9-23-69	Sampler: Arizona Highway Department Type: CRS-2H (Special #2 Asphalt) Manufacturer:
5-A_2	9-23-69	Sampler: Arizona Highway Department Type: CRS-2H (Special #1 Asphalt) Manufacturer:
6-A_1	10-30-69	Sampler: Arizona Highway Department Type: RS-2 Manufacturer:
7-A_3	11-28-69	Sampler: Arizona Highway Department Type: RS-3KH Manufacturer:
8-C_1	11-28-69	Sampler: Arizona Highway Department Type: SS-1H Manufacturer:
9-B_2	11-28-69	Sampler: Arizona Highway Department Type: RS-2 Manufacturer:

Asphalt Cement Samples

Four asphalt cement samples were obtained. The sample number of each corresponds to the emulsion sample number. That is, asphalt cement sample number 1 is the base asphalt used in making emulsion sample number 1.

The data listed are similar to that shown for the emulsions.

Sample No.	Date Received	General Information
$1\text{-}B_1$	8-18-69	Sampler: Arizona Highway Department Type: 85/100 Penetration Source:
$2\text{-}B_2$	8-18-69	Sampler: Arizona Highway Department Type: 85/100 Penetration Source:
$3\text{-}A_1$	8-26-69	Sampler: Supplier Type: 85/100 Penetration Source:
$8\text{-}C_1$	11-28-69	Sampler: Arizona Highway Department Type: 60/70 Penetration Source: