RELATIONSHIP OF PAVING ASPHALT TEMPERATURE SUSCEPTIBILITY AS MEASURED BY PVN TO PAVING ASPHALT SPECIFICATIONS, ASPHALT PAVING MIXTURE DESIGN AND ASPHALT PAVEMENT PERFORMANCE

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INTRODUCTION

As a measure of paving asphalt temperature susceptibility, PVN is an abbreviation for “pen-vis number”, which in turn is a shortened version of ‘penetration at 25 C (77 F)-viscosity at 135 C (275 F) number”, since as will be explained later, PVN is evaluated from the penetration at 25 C (77 F) and corresponding viscosity at 135 C (275 F) of paving asphalts from asphalt based “wax free” crude oils, insofar as any asphalt is entirely free from wax.

In 1947, light waxy crude oils that provided asphalt of high temperature susceptibility were discovered in Western Canada in large volume. Shortly afterward, the Canadian Federal Government decreed that all petroleum products marketed west of the Ontario-Quebec border had to be made from these crude oils.

Up to that time most of the asphalt used in Ontario came from Venezualan crude oils that were refined in Montreal in the Province of Quebec. They had low temperature susceptibility and a high viscosity at 135 C (275 F) (Group A in Figure 14). Paving mixtures made with these asphalts were so stable that the rollers could be operated right up to the spreader. On the other hand, paving asphalts from these Western Canadian light waxy crude oils were of high temperature susceptibility and had very low viscosity at 135 C (275 F) (Group C in Figure 14). Paving mixture immediately behind the spreader lacked the stability to which contractors had become accustomed. Rolling had to be delayed to allow the paving mixtures to cool and develop sufficient stability to support the weight of the roller. As one Materials Engineer said facetiously, the roller man operated the spreader in the morning and then got on the roller to roll in the afternoon what he had spread in the morning.

The contractor complaints over delayed rolling were so serious that in 1960 the Ontario Department of Highways constructed three six-mile Test Roads about 40 miles apart on existing highways in South Western Ontario, Figure 1. In each 6-mile Test Road there were three 2-mile pavement test sections. A different paving asphalt was used in each of the three 2-mile test sections, 2-miles were paved with 85/100 penetration asphalt of low temperature susceptibility (Group A), 2-miles were paved with 85/100 penetration of approximately medium temperature susceptibility (Group B), while 85/100 penetration asphalt of high temperature susceptibility (Group C), was used for the other 2-mile pavement section. The same three asphalts were replicated in the three Test Roads. The results from these Test Roads will be referred to later.

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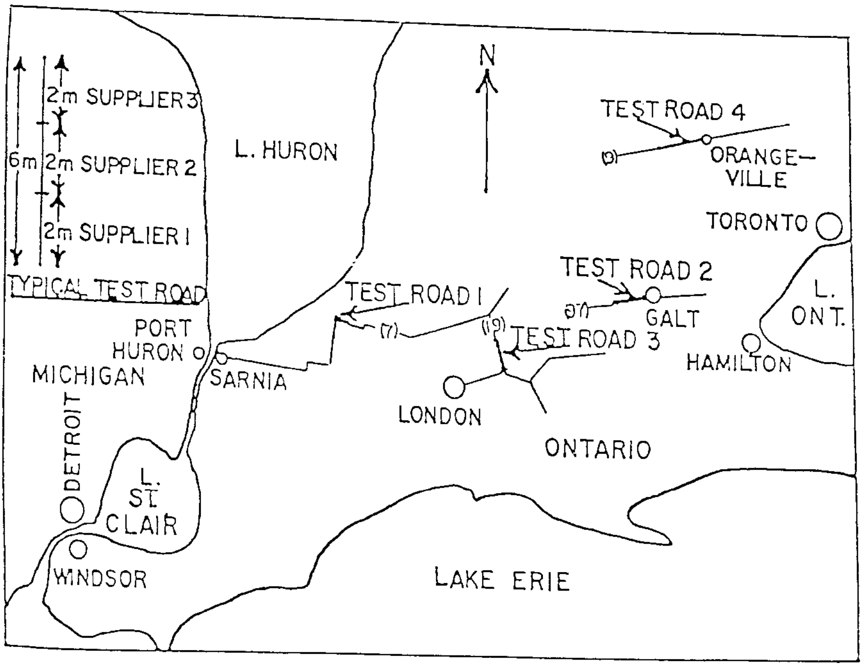

Figures 1: Locations of Four Ontario Test Roads.

Two or three years later, without waiting for results from its test roads, the Ontario Department of Highways adopted a paving asphalt specification requiring that 85/100 penetration asphalt must have a minimum viscosity of 140 seconds Saybolt Furol at 135 C (275 F), later changed to 280 centistokes at 135 C (275 F). For the 150/200 penetration grade, the minimum viscosity at 135 C (275 F) was 200 centistokes. They rejected all asphalts of high temperature susceptibility and about half of those of medium temperature susceptibility.

Ontario's use of asphalts of three different temperature susceptibilities in its three Test Roads, and its adoption of minimum viscosities at 135 C (275 F) for its new specification for paving asphalts, led the writer *(2,3,4* ***and 5)*** to wonder if temperature susceptibility for paving asphalts could be based on penetration at 25 C (77 F) and viscosity in centistokes at 135 C (275 F). This paper will attempt to show that PVN is the most useful measure of paving asphalt temperature susceptibility that has been proposed so far.

Since the pen-vis number (PVN) concept for expressing paving asphalt temperature susceptibility was originated by the writer about twenty years ago, it has been slowly developed from isolated bits and pieces of information, some of them my own, but some from the publication of others. In many respects, it has been like putting a jig-saw puzzle together, except that with a jig-saw puzzle, from the beginning, one has a picture of the final grouping of pieces to follow as a guide. When working with PVN, I have not had this picture of the final assemblage to follow. Only within the past few months have I been able to fit all the isolated bits of information together into a well organized whole, which is the subject of this paper.

As I, and I believe many others see it, the major asphalt paving problems today are centered very largely around the following six headings:

(A) A more useful paving asphalt specification.
(B) Avoidance of low temperature transverse pavement cracking in winter.
(C) Providing adequate pavement stability for summer traffic.
(D) Elimination of pavement rutting.
(E) Developing a much more rational method for pavement recycling.
(F) Providing surface treatments with superior service performance.

In addition, the paper will show how each of the above six objectives can be further improved by the incorporation of small percentages of suitable polymers into the paving asphalt.

The paper shows that when everything else is equal, aggregate etc., a major part of the solution for each of these six items involves providing asphalts with higher viscosity at 135 C (275 F) for any given penetration at 25 C (77 F). That is, the paving asphalt must often have a lower temperature susceptibility. This is one of the basic purposes of pen-vis number (PVN), which as has been stated, is evaluated from the penetration of a paving asphalt at 25 C (77 F) and the corresponding viscosity at 135 C (275 F). In terms of their PVN values, Figure 14, which normally range from 0.0 to -1.5, all paving asphalts can be separated into one or the other of three groups, Group A, low temperature susceptibility (PVN from 0.0 to -0.5), Group B, medium temperature susceptibility, (PVN from -0.5 to -l.0), and Group C, high temperature susceptibility, (PVN from -1.0 to -1.5). Therefore, particularly for pavements for higher traffic volumes, PVN points the way toward asphalts of lower temperature susceptibility to solve the six problems previously referred to.

Figure 2 illustrates that two-thirds of the U.S.A. North of the Mason-Dixon Line has a frost penetration in winter ranging from 18 in. in the south to 72 in. in Northern Minnesota. Still greater depths of frost penetration occur in Canada and Alaska. Because of the repeated contraction and expansion stresses caused by changing temperatures in winter, this can result in severe low temperature transverse pavement cracking, in which no engineer could take any pride, in expensive maintenance for crack filling and other repairs, and in the unseen costs of shortened pavement service lives. Unstable pavements under summer traffic are subject to rutting and to other forms of pavement distortion because of the lack of adequate pavement stability. Pavement recycling is increasing, but current methods of design seem to be ill-considered and inadequate. They appear to be geared for short range success but at the expense of the same pavement deterioration in the long run that led to their recycling in the first place. A more rational method with much improved long range service life is proposed. More serviceable surface treatments can also be constructed.

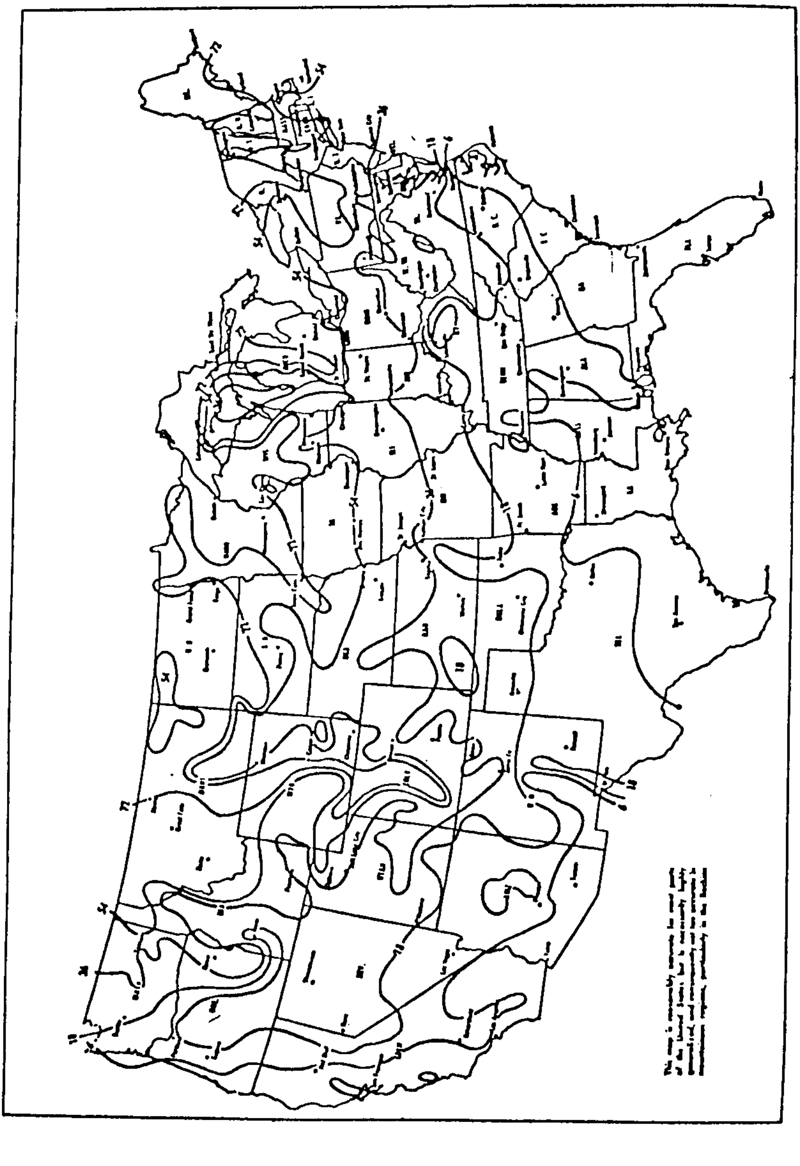

Figure 2: Maximum Depth of Frost Penetration, Inches.

PAVING ASPHALT TEMPERATURE SUSCEPTIBILITY AND PVN

The temperature susceptibility of a paving asphalt is the change in the consistency (viscosity or penetration of the asphalt) for a given change in its temperature. As shown by Figure 3, taken from ASTM D 2493, a straight line graph results when the log log viscosity of an asphalt is plotted versus the log of its absolute temperature. The slope of this line provides the temperature susceptibility of the asphalt.

Figure 4 is taken from a small portion of Figure 3, and illustrates the temperature susceptibility of three asphalts, all of which have the same consistency at 25 C (77 F). Because it has the steepest slope, Asphalt 3 in Figure 4 is said to have high temperature susceptibility, since for the three asphalts illustrated in Figure 4, its consistency changes the most for a given change in temperature. Since its slope changes the least for a given change in temperature, Asphalt 1 in Figure 4 is said to have low temperature susceptibility. Because the slope of Asphalt 2 is in-between the slopes of the other two asphalts in Figure 4, Asphalt 2 is said to have intermediate or medium temperature susceptibility.

Figure 5 illustrates the five principal methods that have been proposed as measures of paving asphalt temperature susceptibility. The first, penetration ratio, is based upon penetrations at 4 C and 25 C (39 F and 77 F). It has had local application but does not appear to have been adopted on a national scale.

The second, viscosity temperature susceptibility, (VTS), has been promoted by The Asphalt Institute as a criterion for paving asphalt temperature susceptibility. As shown on Figure 5, VTS is based on the difference in log log viscosity at each of two temperatures, usually 135 C (275 F) and 60 C (140 F), divided by the difference in the logs of the same two absolute temperatures. This equation reduces temperature susceptibility to a very small number, since for example, the value of log log 1000 is only 0.4771 and for 500 is only 0.4312, with the difference between them being only 0.0459. With such small numbers, the supporters of VTS, who refuse to admit that temperature susceptibility is an important property of paving asphalts, can argue that paving asphalt temperature susceptibility either does not exist, or that it is not significant, or that it is merely the result of experimental error. This is illustrated by the following data for two asphalts that were obtained by The Asphalt Institute:

Penetration at 25 C (77 F)	119	103
Viscosity at 60 C (140 F) (poises)	808	2222
Viscosity at 135 C (275 F) (Cst)	223	540
VTS	3.67	3.34
Difference in VTS = 3.67 - 3.34 = 0.33		
PVN	-0.94	+0.28
Difference in PVN = +0.28 -(0.94) = 1.22		

Note: the PVN values have been added for comparison.

In his AAPT paper of 1970, Lefebvre (*4*) provided Figure 6, which shows the ratio between viscosity in poises at 60 C (140 F) and viscosity in centistokes at 135 C (275 F). Figure 6 indicates that this ratio varies with both

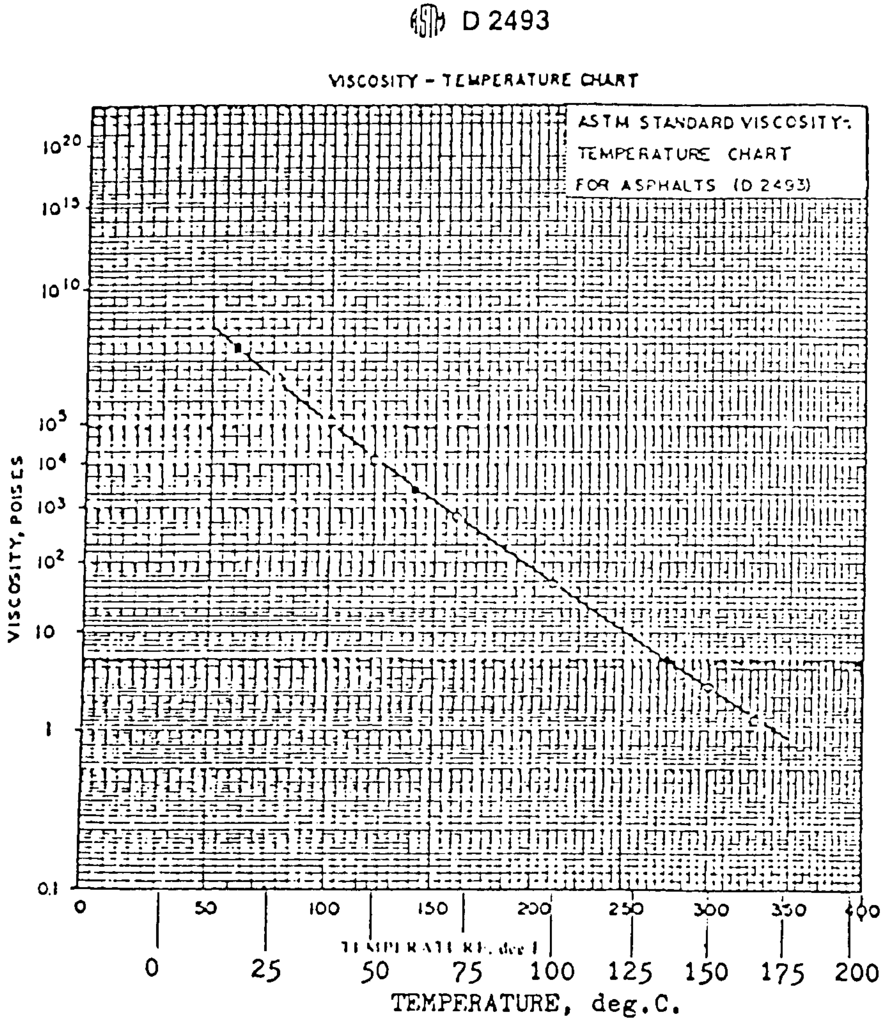

Figure 3: Facsimile of Viscosity-Temperature Chart on Which a Typical Experimental Curve Has Been Plotted.

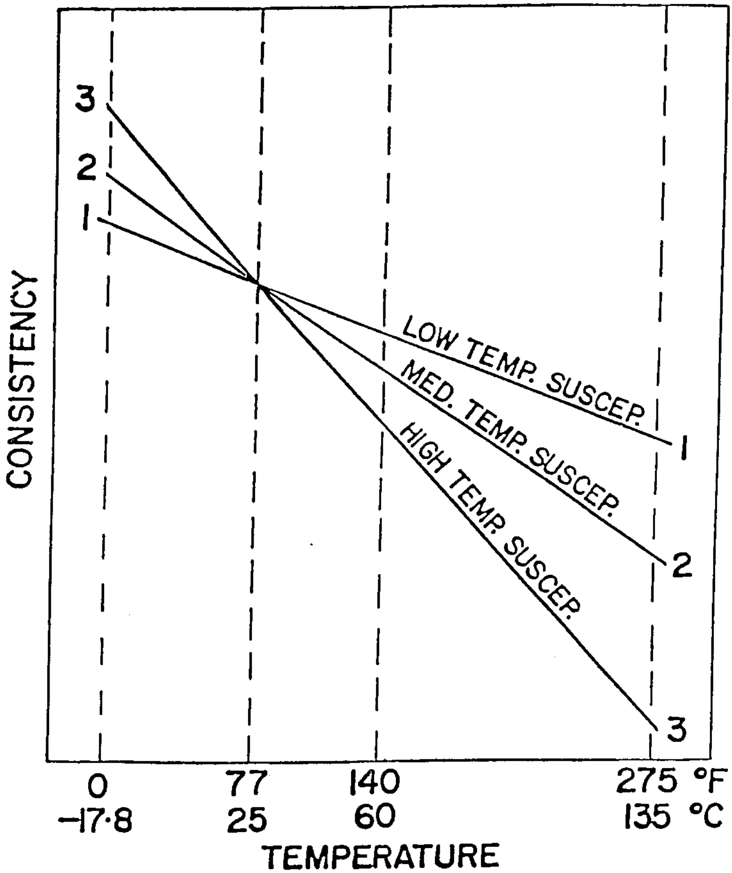

FIg. 4 SKETCH ILLUSTRATING DIFFERENT TEMPERATURE SUSCEPTIBILITIES OF PAVING ASPHALTS

Figure 4: Sketch Illustrating Different Temperature Susceptibilities of Paving Asphalts.

TEMPERATURE SUSCEPTIBILITIES

1. PENETRATION RATIO

$$= \frac{\text{PEN AT } 25\,°C \;\; 100g \;\; 5s}{\text{PEN AT } 4\,°C \;\; 200g \;\; 60s}$$

2. VISCOSITY TEMPERATURE SUSCEPTIBILITY (VTS)

$$VTS = \frac{\text{LOG LOG VISCOSITY at } T_2 - \text{LOG LOG VISCOSITY at } T_1}{\text{LOG } T_1 - \text{LOG } T_2}$$

3. PENETRATION INDEX (PI)

PFEIFFER AND VAN DOORMAAL

$$B = \frac{\text{LOG}(800) - \text{LOG (PEN at } 25°\text{ C)}}{T\,(R\&B)\,°C - 25\,°C}$$

$$PI = \frac{20 - 500\,B}{50\,B - 1}$$

4. PENETRATION INDEX (PI)

HEUKELOM

PEN AT 4, 10, 25 °C EXTRAPOLATED TO PEN = 800 (100g 5s)

PI BY PIVOT ON SHELL BTD CHART

5. PEN – VIS NUMBER (PVN)

PEN AT 25 °C (77 °F)

VISCOSITY AT 135 °C (275 °F)

Figure 5: Indicating Five Methods for Expressing Paving Asphalt Temperature Susceptibility.

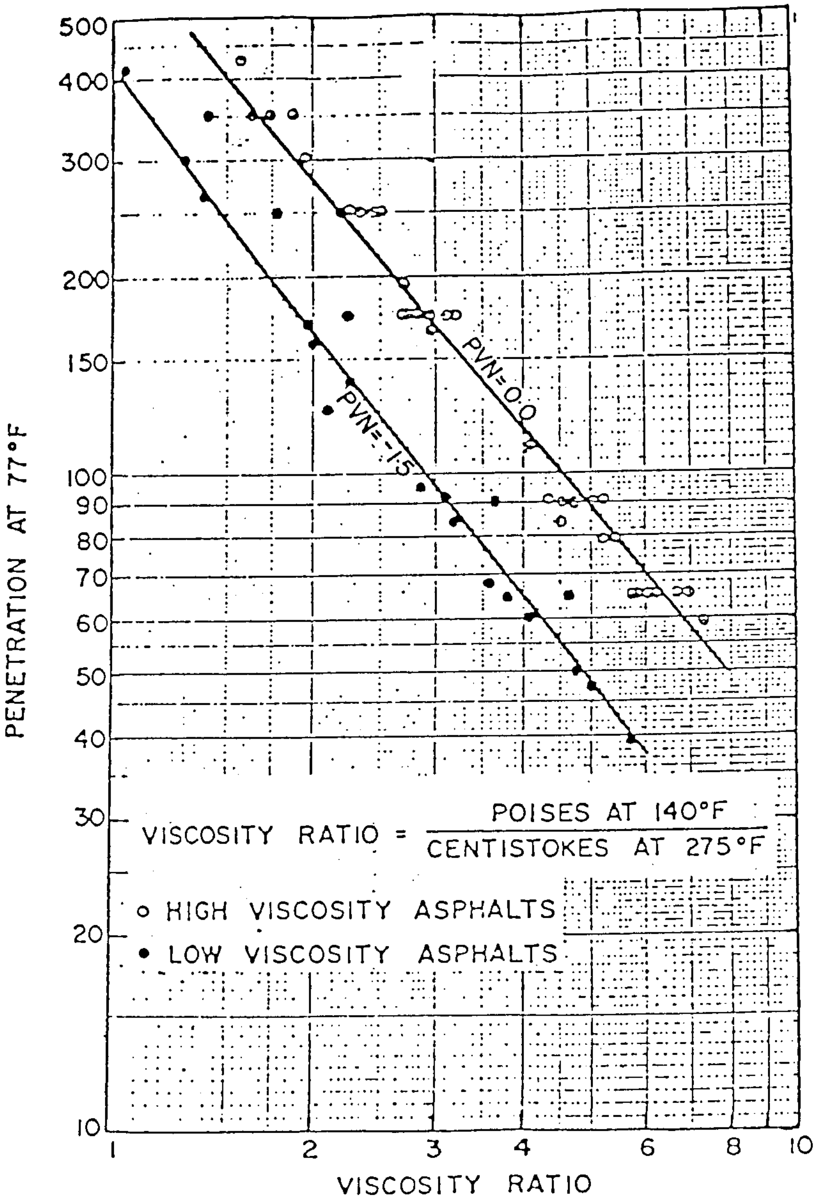

Figure 6: Relationship between Viscosity Ratio and Penetration at 77 F.

penetration at 25 C (77 F) and with PVN (although it was not called PVN at that time), and that its value ranges from about one to eight.

As a basis for paving asphalt specifications, the asphalt suppliers encouraged both ASTM and AASHTO to change the method for grading paving asphalts from penetration at 25 C (77 F) to grading them by viscosity in poises at 60 C (140 F), with the resulting five grades, AC 2.5, AC 5, AC 20, AC 20, and AC 40, Figure 7, to which a sixth grade AC 30 was added later.

Figure 8 shows how these five viscosity grades at 60 C (140 F) appear when they are plotted on a chart in terms of PVN values. Both Figures 6 and 8 demonstrate that the relationship between viscosity in poises at 60 C (140 F) and viscosity in centistokes at 135 C (275 F) is not simple.

Pfeiffer and Van Doormaal of the Royal Dutch Shell Laboratories at Amsterdam, Holland, in a paper published in 1936 (*6*), adopted a very different approach for the measurement of paving asphalt temperature susceptibility, which they named penetration index, or PI. As an axis for reference they based their zero PI on a Mexican asphalt of 200 penetration at 25 C (77 F) that was derived from a “wax free” asphalt based crude oil. To measure the temperature susceptibilities of various paving asphalts, they prepared a nomograph, Figure 9, for which the penetration at 25 C (77 F) and the ring and ball softening point of a paving asphalt were required, as indicated by Equation 3 on Figure 5. To use this nomograph, a straight line was drawn from the point representing the penetration test value on the ordinate on the right, which lists values for the penetration test at whatever temperature in °C it was measured, usually 25 C (77 F), to a corresponding point on the ordinate on the left, which marks the difference in temperature in °C between the ring and ball softening point and the temperature at which the penetration test was made. The value indicated by the point where this line intersects the oblique line representing penetration index, or PI, indicates the PI of the paving asphalt.

As shown by Equation 3 in Figure 5, values for the penetration of a paving asphalt at 25 C (77 F) and for its ring and ball softening point temperature are required for Pfeiffer’s and Van Doormaal’s temperature susceptibility measurement in terms of PI. However, because of small quantities of wax retained in paving asphalts made from Western Canada’s light waxy crude oils, the softening point temperatures were much too high. They exceeded the softening point temperatures of paving asphalts otherwise the same but free from wax. This made Pfeiffer’s and Van Doormaal’s equation useless for expressing the temperature susceptibilities of paving asphalts from these waxy crude oils.

Heukelom (7) attempted to overcome the effect of wax in these paving asphalts by making penetration tests at 4 C, 10 C and 25 C, and extending the least squares line through these values to obtain the temperature corresponding to a penetration of 800, since for many asphalts this corresponded approximately to the ring and ball softening point temperature. Heukelom substituted this temperature for the ring and ball softening point temperature in Pfeiffer and Van Doormaal’s equation to obtain a corrected value for PI, or the PI could alternatively be taken from Shell’s Bitumen Test Data Chart (*7*). However, as will be shown shortly, Heukelom appears to have over-corrected for wax content. Consequently, for asphalts from these light waxy crude oils,

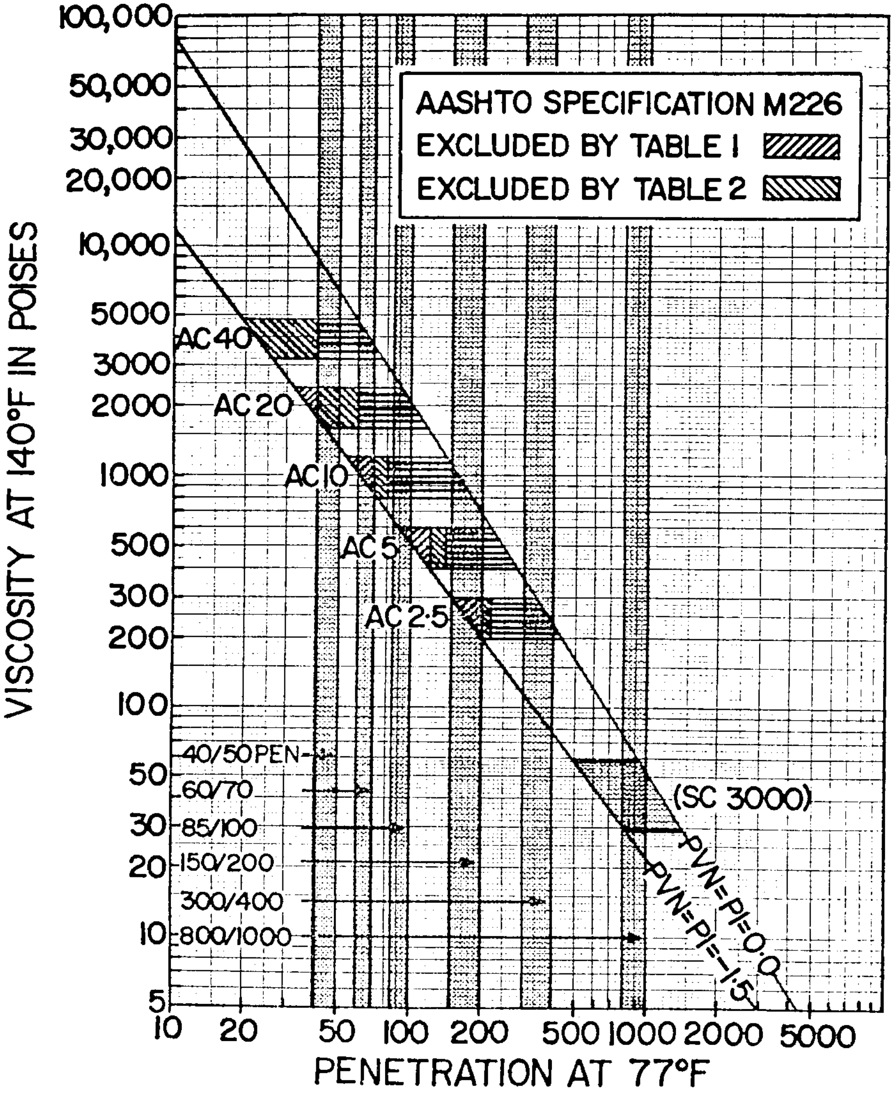

Figure 7: Relationships between Viscosity at 140° F in Poises, Penetration at 77° F, and Temperature Susceptibility.

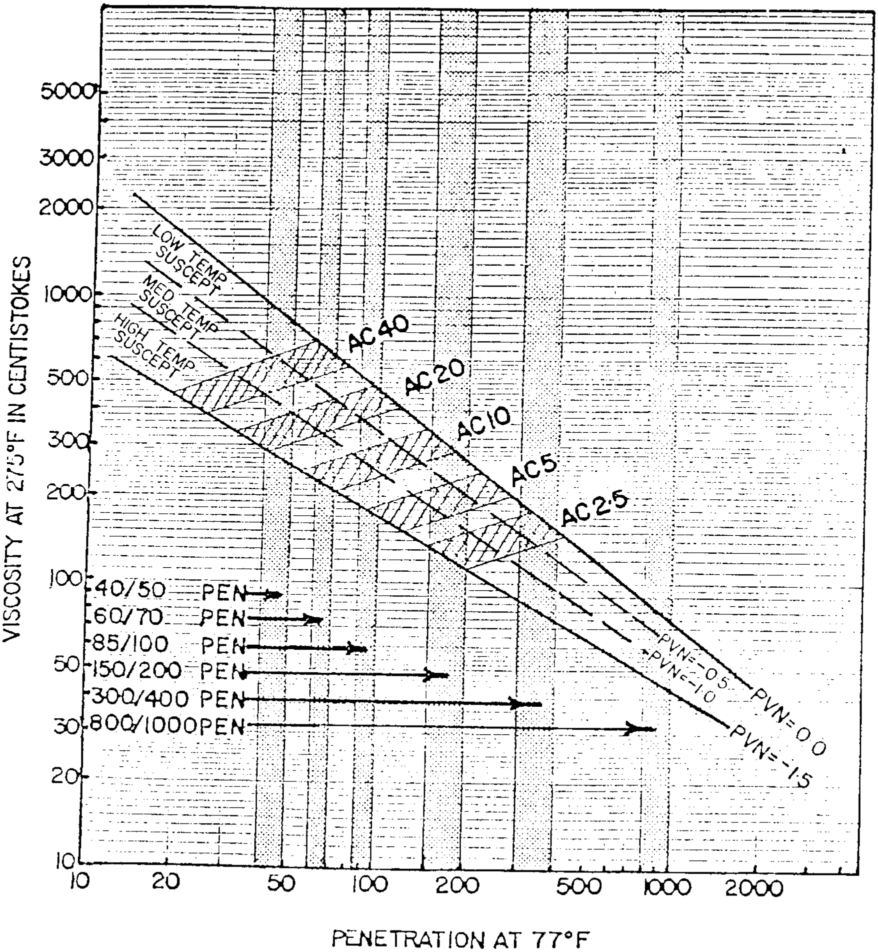

Figure 8: Viscosity grades at 140°F (60°C) plotted on a PVN chart.

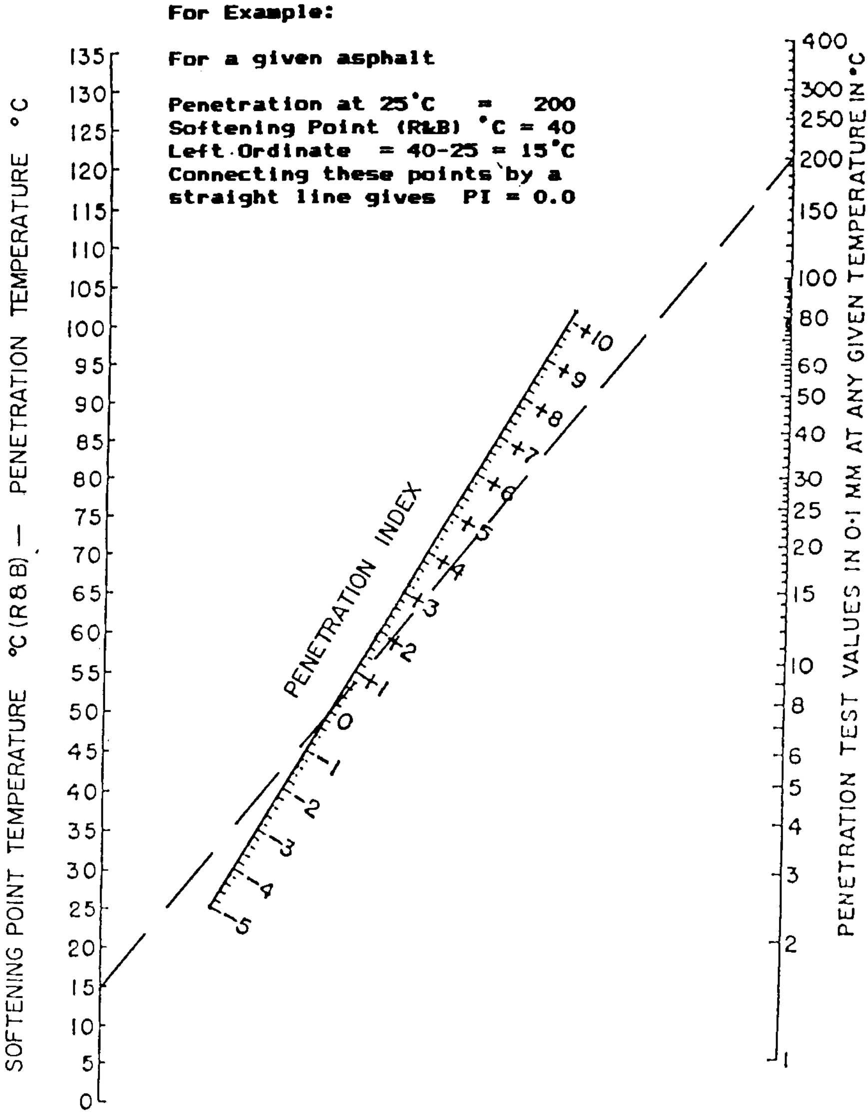

Figure 9: Pfeiffer's and Van Doormaal's Nomograph for Paving Asphalt Temperature Susceptibility.

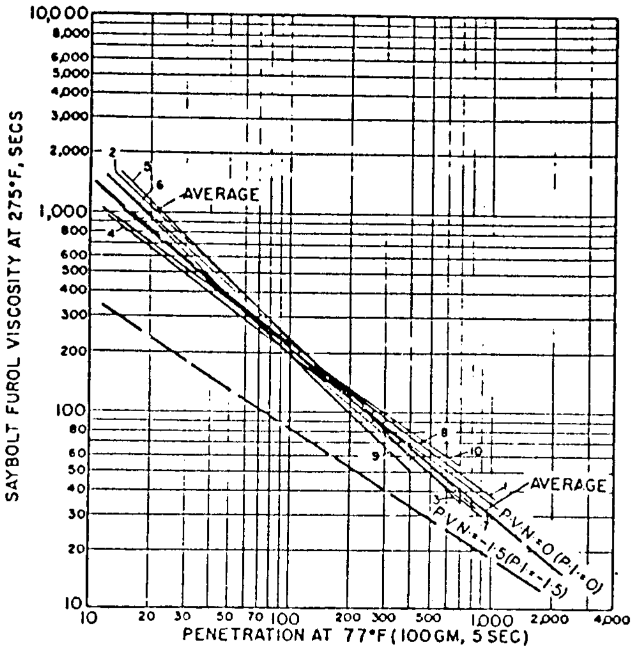

Figure 10: Relationship between Penetration at 77 F. and Viscosity at 275 F. for Pen-Vis Numbers of 0.0 and -1.5.

Pfeiffer and Van Doormaal's method gives PI values that are too high, while Heukelom's method seems to provide PI values that are too low.

It was mentioned in the Introduction, that Ontario's use of 85/100 penetration asphalts of three different temperature susceptibilities in its three Test Roads, and its adoption of minimum viscosities at 135 C (275 F) for its new specifications for paving asphalts about 1962 or 1963, led me to wonder if temperature susceptibilities for paving asphalts could be based on penetration at 25 C (77 F) and viscosity in centistokes at 135 C (275 F). Since Pfeiffer and Van Doormaal had coined the term "penetration index" or PI for temperature susceptibility in their paper published in 1936 (*6*), in my first references to temperature susceptibility, PVN was referred to as a "modified PI". By 1972, it was realized that a different term was required, and since then it has been referred to as "pen-vis number" or PVN (*8*).

One prefers if possible, when introducing a new concept, to build on what has gone on before. In 1936, Pfeiffer and Van Doormaal (*6*) provided axes of reference for their measure of paving asphalt temperature susceptibility or PI. As previously pointed out, for zero PI they selected a Mexican asphalt of 200 penetration at 25 C (77 F) from a "wax free" asphalt based crude oil. Consequently, I tried their zero PI as the zero for PVN and found that it appeared to fit, Figures 10, 11 and 12. It also happened that a PVN of -1.5 for paving

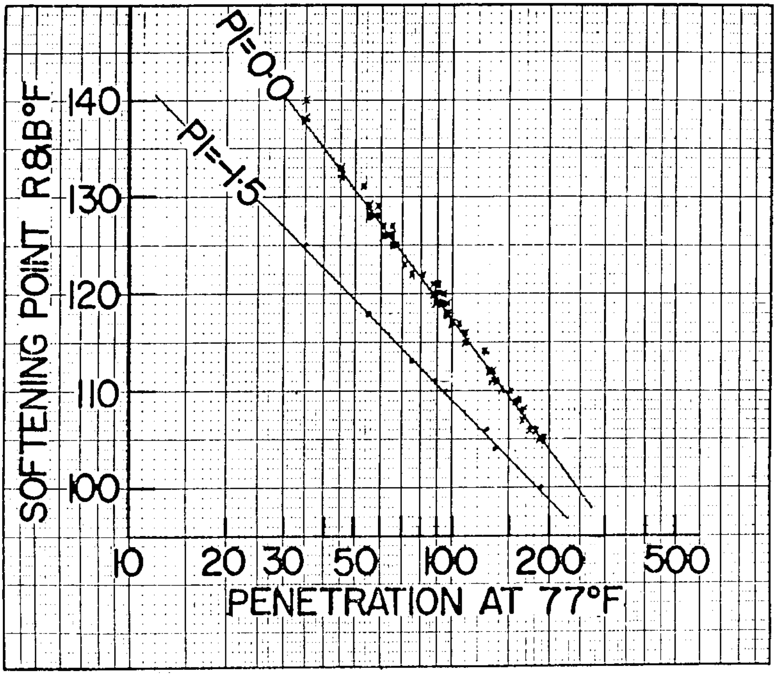

Figure 11: Illustrating Relationships between Penetration at 77°F, Softening Point °F (Ring and Ball), and Penetration Index (PI) Values of 0.0 and -1.5 for Paving Asphalts Manufactured by Steam or Vacuum Reduction.

asphalts from appropriate "wax free" asphalt based crude oils, matched Pfeiffer and Van Doormaal's PI of -1.5 for the same asphalts Figures 10, 11 and 12.

In the Appendix to my 1972 AAPT paper (8), I show a rough plot of viscosity SSF at 275 F (135 C) versus penetration at 77 F (25 C) for 10 asphalts with a Pfeiffer and Van Doormaal PI of 0.0, Figure 10, which also shows a similar plot for Pfeiffer and Van Doormaal penetration index, PI of -1.5. The lines representing PI = 0.0 and PI = -1.5 in Figure 10 were drawn as best lines through the data. The data illustrated in Figure 10 came from an internal report by Esso Research and Engineering, showing values for penetration at 77 F (25 C), softening point by ring and ball, viscosity SSF at 275 F (135 C) and other data for residues that were recovered by steam or vacuum distillation with penetrations at 77 F (25 C) from each crude oil, ranging from about 200 to 35. All the asphalts for which data are given in Figure 10, came from "wax free" asphalt based crude oils. Consequently, asphalts ranging in penetration at 25 C (77 F) from about 200 to about 35, that were obtained from each crude oil by steam or vacuum distillation are also shown in Figure 10 to have the same PVN value, either PVN = 0.0 or PVN = -1.5.

Later, the writer made a more thorough investigation of penetration at 25 C (77 F), viscosity at 135 C (275 F) and other inspection data that were obtained

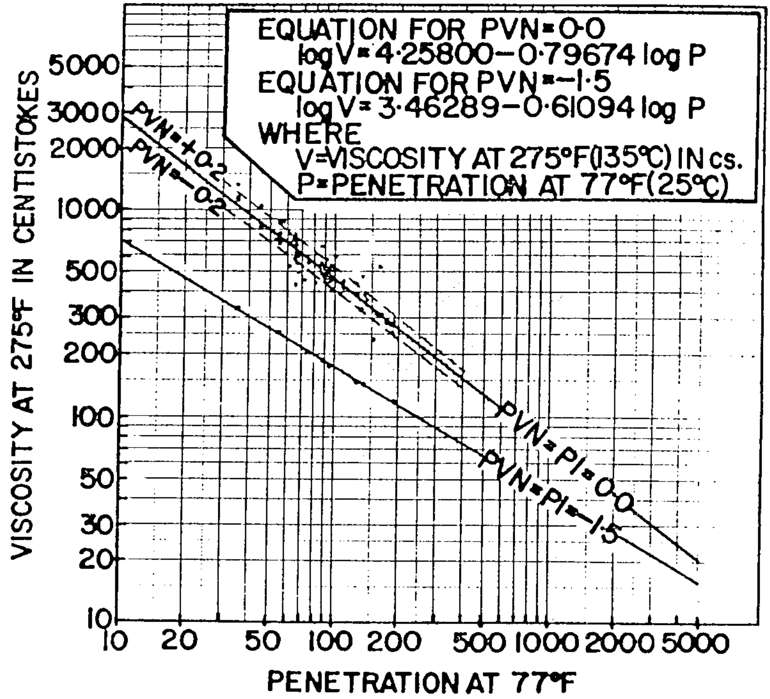

Figure 12: Illustrating Development of Pen-Vis Numbers from Relationships between Viscosity at 275°F in Centistokes, Penetration at 77°F, and Penetration Indices.

by the U.S. Bureau of Public Roads on 310 samples of paving asphalts from U.S.A. and Canada, and published in Public Roads magazine in 1959 and 1960 (*9, 10*). Most of these asphalt samples were manufactured by steam or vacuum distillation. On the basis of their ring and ball softening points and their penetrations at 25 C (77 F), Pfeiffer and Van Doormaal PI values were calculated for each of these 310 asphalt samples. Of asphalts produced by steam or vacuum reduction, there were 82 paving asphalts with PI values of 0.0 ± 0.2 and eight asphalts with PI ratings of -1.5 ± 0.2. In Figure 11, the ring and ball softening points for each of the 82 asphalts with a PI of 0.0 ± 0.2 and for asphalts with a PI of -1.5 ± 0.2 as ordinate, have been plotted versus their corresponding penetrations at 25 C (77 F), and least squares lines labelled PI = 0.0 and PI = -1.5 have been drawn through the data. The agreement for PI values of 0.0 and -1.5 is very good.

The viscosity in centistokes at 135 C (275 F) as ordinate versus the corresponding penetration at 25 C (77 F) as abscissa for each of the same 82 paving asphalts in Figure 11 with a PI value of 0.0 ± 0.2 have been plotted on Figure 12, and the least squares line through these data is labelled PVN = PI = 0.0. Similarly, the viscosities in centistokes at 135 C (275 F) versus the corresponding penetrations at 25 C (77 F) for the eight paving asphalts with a

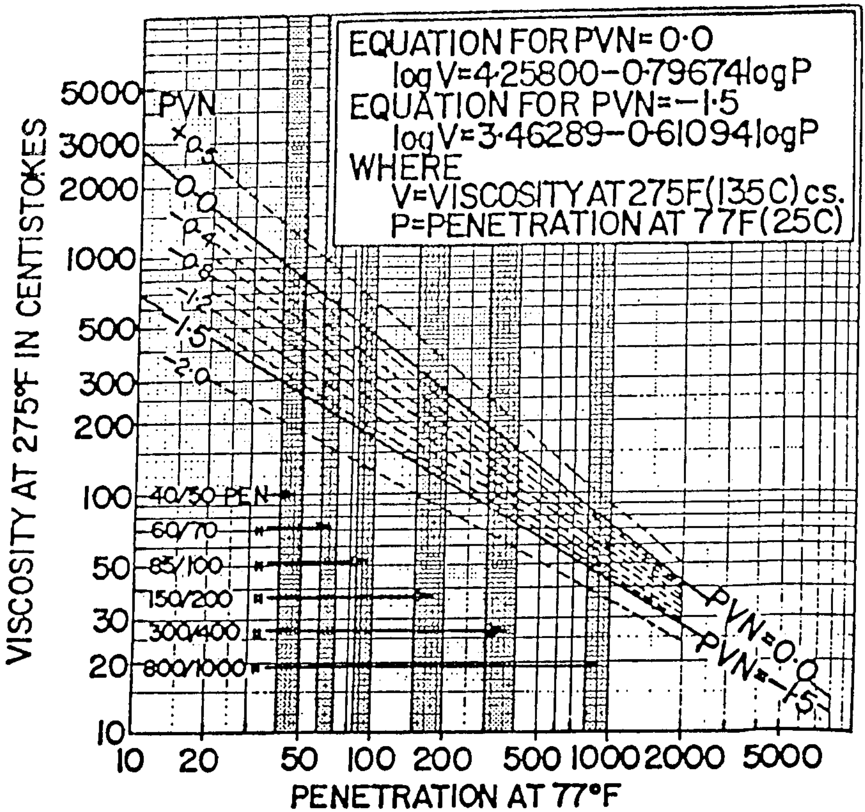

Figure 13: A Chart for the Determination of Approximate Values for Pen-Vis Numbers for Asphalt Cements.

PI of -1.5 + 0.2 in Figure 11, have also been plotted on Figure 12 and the least squares line through these data has been labelled PVN = PI = -1.5. There is very little scatter of data about the least squares line representing PVN = -1.5 in Figure 12. Consequently, at least for the 90 asphalts manufactured by steam or vacuum distillation referred to in Figures 11 and 12, values for PVN = 0.0 or -1.5 are numerically equal or very nearly so to their corresponding values for PI = 0.0 and -1.5 respectively. It was pointed out earlier, that specification paving asphalts made from waxy crude oils by steam or vacuum reduction have false ring and ball softening points because they contain wax, which in turn provide misleadingly high PI values. These misleading PI values can be avoided by using the corresponding PVN values which are based on "wax free" asphalts.

It should be emphasized again, that all the data illustrated in Figure 10, 11 and 12 are for paving asphalts from asphalt based crude oils that were "wax-free".

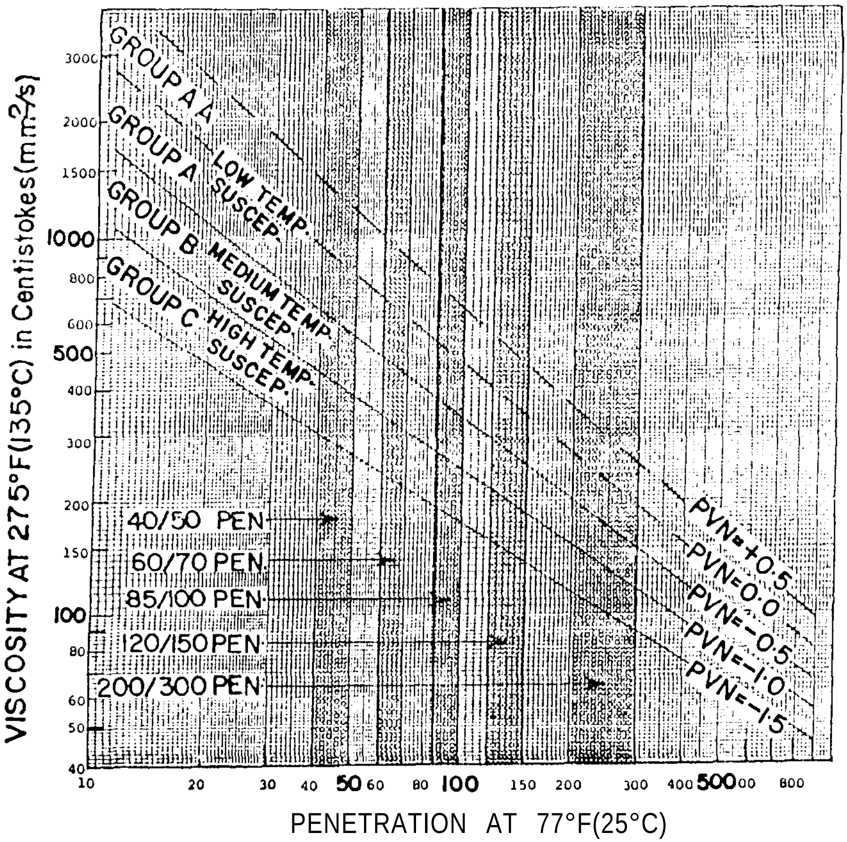

Figure 14: Illustrating a Specification Based on Penetrations at 77°F (25°C), Viscosities at 275°F (135°C), and Temperature Susceptibilities of Paving Asphalts.

The data in Figure 12 are generalized in Figure 13 for paving asphalts with PVN values ranging from +0.5 to -2.0, which cover practically all paving asphalts being marketed in North America.

It is a simple matter to go from the general PVN chart of Figure 13, to the paving asphalt specification chart of Figure 14, in which paving asphalts are separated into Groups A, B and C, in terms of their temperature susceptibilities. Group A, with a minimum PVN of -0.5 includes paving asphalts of low temperature susceptibility, Group B with a PVN range of -0.5 to -1.0, includes paving asphalts of medium temperature susceptibility, while Group C with a maximum PVN of -1.0 includes paving asphalts of high temperature susceptibility.

There is as much need or justification for separating paving asphalts into three groups of temperature susceptibility, as there is for three groups of cutback asphalts, rapid curing or RC, medium curing or MC, and slow curing or

SC grades, or for three groups of asphalt emulsions, rapid setting RS, medium setting or MS, and slow setting or SS emulsions. As illustrated by Figures 4 and 14, Group A paving asphalts of low temperature susceptibility and Group C paving asphalts of high temperature susceptibility, are at the opposite extremes of the paving asphalt temperature susceptibility scale. They result, for example, in the great differences in low temperature transverse pavement cracking shown in Figure 22 for pavements containing these two extreme groups of paving asphalts, where, at the pavement age of 10 years, there were 15 times as many Type 1 low temperature transverse pavement cracks per lane mile in the pavement containing Group C asphalt, as in the test pavement made with Group A asphalt. Consequently, there is a real practical need for Group B asphalts of intermediate temperature susceptibility with PVN values from -0.5 to -1.0. This will be referred to again later in the paper. Figure 14 should be part of every paving asphalt specification. Two versions of an appropriate specification are given in Appendix B.

It should be noted that no extra testing is required to obtain the PVN value of any paving asphalt. Simply determine the penetration at 25 C (77 F) of the asphalt and its viscosity in centistokes at 135 C (275 F). These values are normally determined as a part of the routine inspection data on any asphalt sample. Plot these values as the coordinates of a point on Figure 13. From the nearest oblique line representing PVN values, the PVN of the paving asphalt can be read by interpolation. This value of PVN is probably accurate enough for most purposes. If a truly accurate value of PVN is required, it can be obtained from Appendix A, which lists the equations required for this purpose and provides a sample calculation.

As previously mentioned, in 1959 and 1960, in Public Roads Magazine (*9,10*), the U.S. Bureau of Public Roads published data that had been obtained on 310 samples of paving asphalts from the U.S.A. and Canada. Their data for penetration at 25 C (77 F) and viscosity at 135 C (275 F) have been plotted on the pattern of Figure 14 to give Figure 15, which shows that the temperature susceptibilities of these asphalt samples ranged from a PVN of +0.5, representing low temperature susceptibility, to a PVN of -1.5, representing high temperature susceptibility.

In Figure 16, the data of Figure 15 have been plotted in terms of PVN versus Pfeiffer's and Van Doormaal's PI as given by penetration at 25 C (77 F) and softening point in C, Equation 3 in Figure 5. For Figure 17, the data in Figure 16 have been plotted as the average of the PVN values versus the average of the PI values for Groups A, B and C. To utilize all of the data, the values for PVN = 0.0 $\pm$ 0.25 were taken to represent asphalt with a PVN of 0.0, the values for PVN = -0.5 $\pm$ 0.25 were taken to represent asphalts with a PVN of -0.5. Similarly, asphalt with values for PVN = -1.0 $\pm$ 0.25 represented paving asphalts with a PVN of -1.0, and asphalts with values for PVN = -1.5 $\pm$ 0.25 represented asphalts with a PVN of -1.5. In each case, the corresponding value for Pfeiffer and Van Doormaal's PI was also calculated.

It will be noted from Figure 17 that the averages for asphalt of low temperature susceptibility with a PVN of 0.0 and also with a PI of 0.0 practically

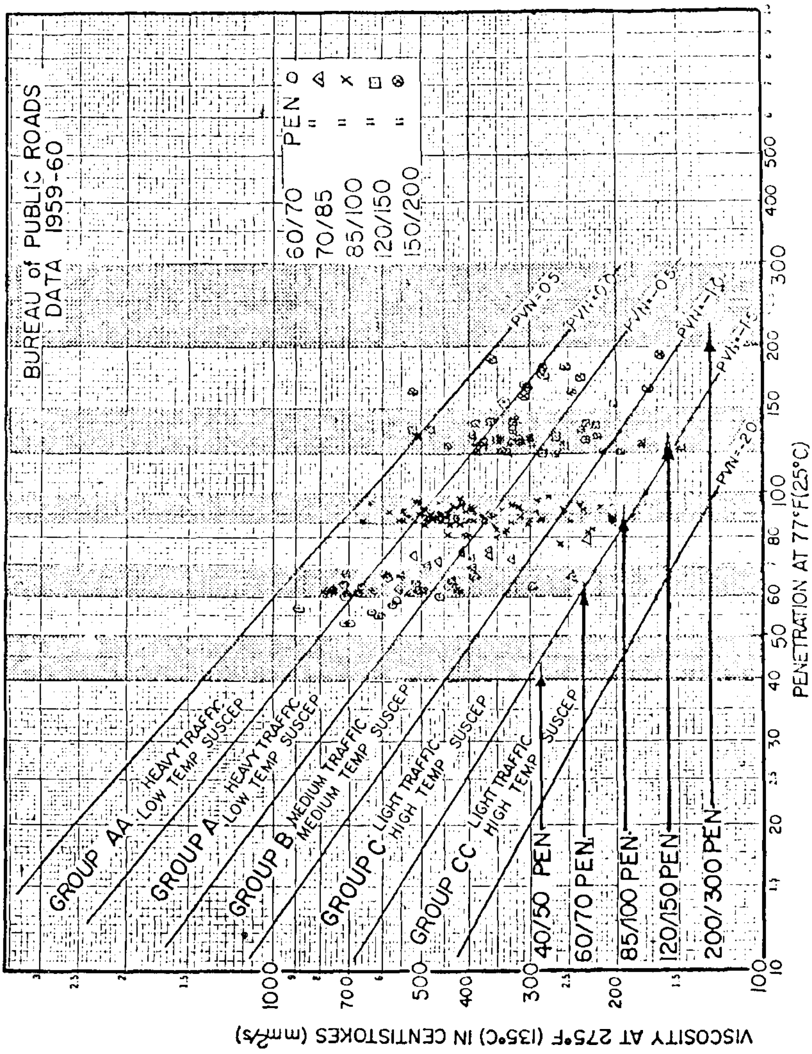

Figure 15: Paving Asphalt Temperature Susceptibility Groups A, B, and C from US Bureau of Public Roads Paving Asphalt Sample Survey Published in 1959 and 1960.

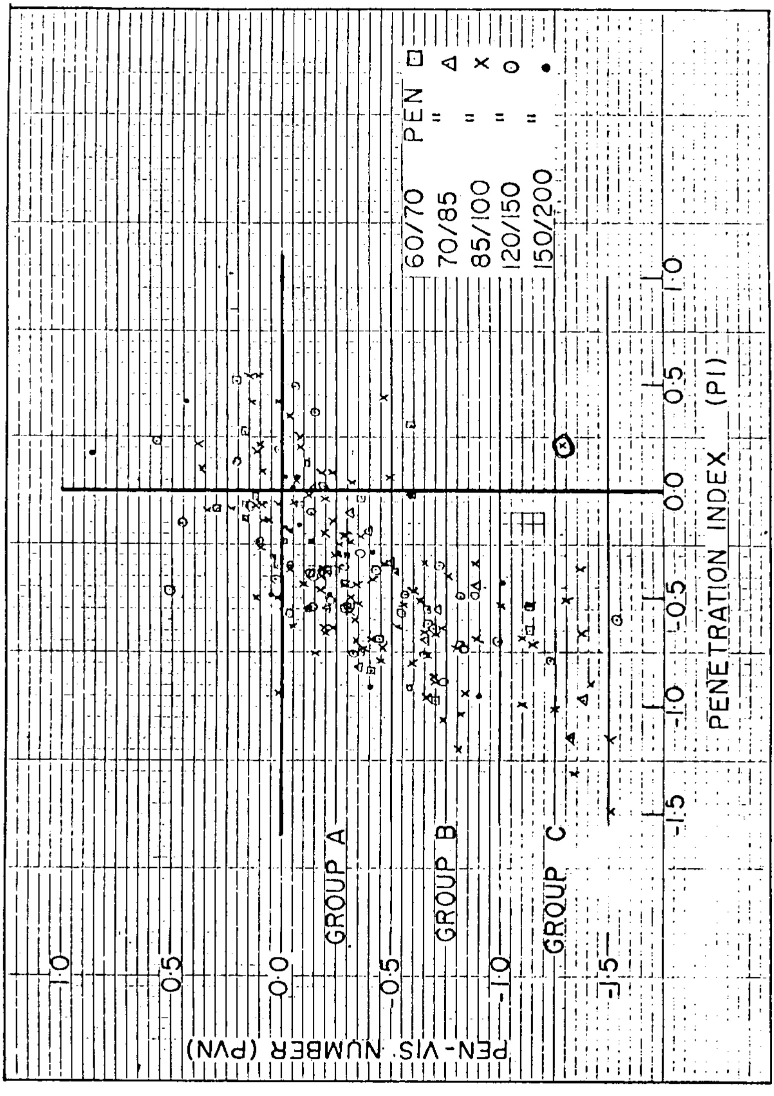

Figure 16: Plot of PVN Values versus Pfeiffer's and Van Doormaal's PI Values for the Bureau of Public Roads Data for Temperature Susceptibility Groups A, B, and C.

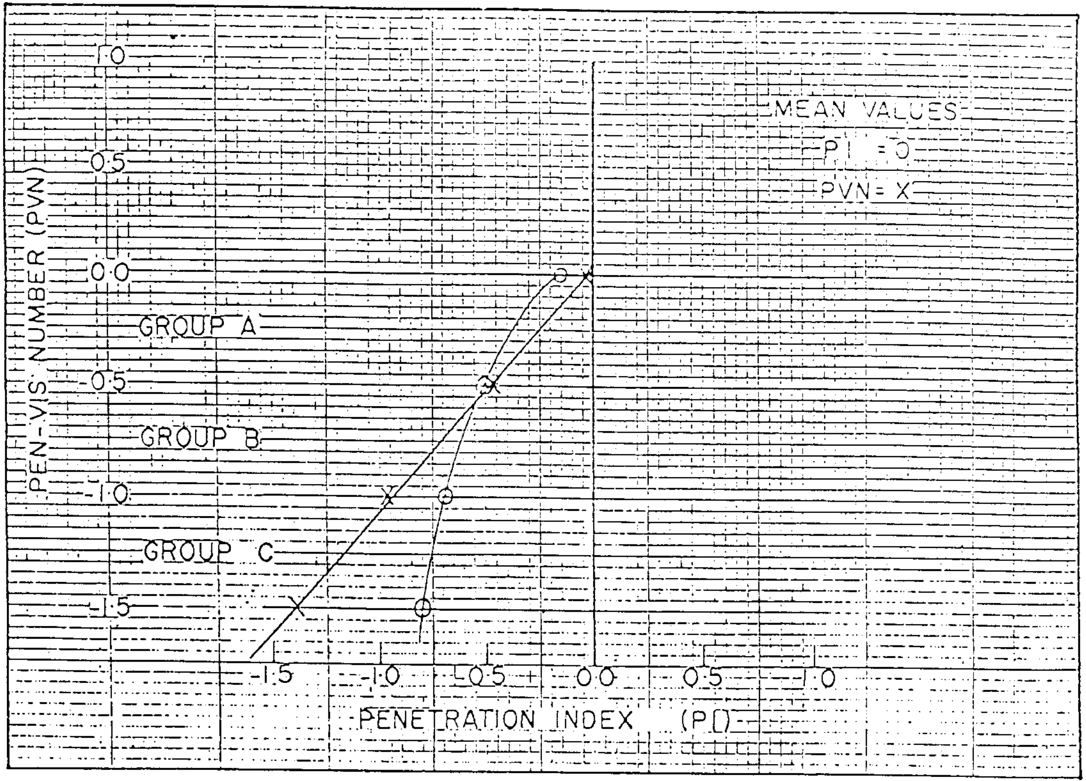

Figure 17: About 200 Samples of Paving Asphalts Obtained by the U.S. Bureau of Public Roads Divided into Temperature Susceptibility Groups A, B, and C, and the Mean Values for PVN versus PI Determined for Each Group.

coincide. This could be expected because asphalts with PVN or PI values of 0.0 are “wax free” from asphalt based “wax free” crude oils. Because of the effect of wax on asphalt softening point, the average values for PI for asphalts with higher and higher wax contents diverge farther and farther from their corresponding PVN values. That is, with increasing wax content, the PI values become higher and higher than the PVN values that represent “wax free” asphalts.

This is why Pfeiffer and Van Doormaal’s PI values for these waxy asphalts are always misleading. They are misleading by the amount of the difference shown in Figure 17 between the corresponding average PI and PVN values. *As will be shown later, because the represent the “wax free” condition, the PVN values are the correct values to use when assessing pavement performance.*

Figure 18 is a plot of data published by The Asphalt Institute in 1979 (II) in terms of penetration at 25 C (77 F) and viscosity at 135 C (275 F), for 68 samples of paving asphalt being marketed in the U.S.A. and Canada. These data have been plotted on the pattern of Figure 14 to give Figure 18. It will be noted that in comparison with Figure 15, because of the OPEC oil crisis in 1973 there has been a downward shift in the data toward higher temperature susceptibility. The data of Figure 18 have been plotted on Figure 19 as PVN versus corresponding PI values as determined by Heukelom by the method of item 4 in Figure 4.

For Figure 19, as for Figure 16, the data of Figure 18 have been given in terms of PVN versus Heukelom’s corresponding PI values. Unfortunately, the Asphalt Institute study did not include softening point values. Consequently, a direct comparison between Pfeiffer’s and Van Doormaal’s and Heukelom’s PI values cannot be made.

As for Figure 17, in Figure 20 the average PVN value for each of the groups of data in Figure 19 have been plotted versus the corresponding average PI (Heukelom) value. That is, an average value for PVN = 0.0 includes all data within the group of PVN = 0.0 ± 0.25, etc.

Heukelom was supposed to be correcting Pfeiffer and Van Doormaal’s values for wax contents in these paving asphalts. However, Figure 20 demonstrates that Heukelom over-corrected for wax content. For example, for PVN 0.0 for “wax-free” asphalt of low temperature susceptibility, PVN and Pfeiffer and Van Doormaal’s values are in close agreement, both being very nearly zero, For this “wax-free” condition, PVN = 0.0, Heukelom’s PI value should also have been close to zero, and should have agreed with Pfeiffer and Van Doormaal’s PI = 0.0. Instead, Heukelom’s PI value has been over-corrected and shows a PI value = -1.0 approximately. Similar very wide divergences occur for corresponding PVN values of -0.5, -1.0 and -1.5. Consequently, for asphalts from waxy crude oils, modulus of stiffness values corresponding to Heukelom’s PI values will be much too low, just as modulus of stiffness values corresponding to Pfeiffer and Van Doormaal’s PI values of -1.0 and -1.5 are much too high.

It is of interest that the PVN values for the Bureau of Public Roads and for The Asphalt Institute’s data practically coincide for the entire PVN range of PVN from 0.0 to -1.5. Consequently, the writer believes that these are the cor-

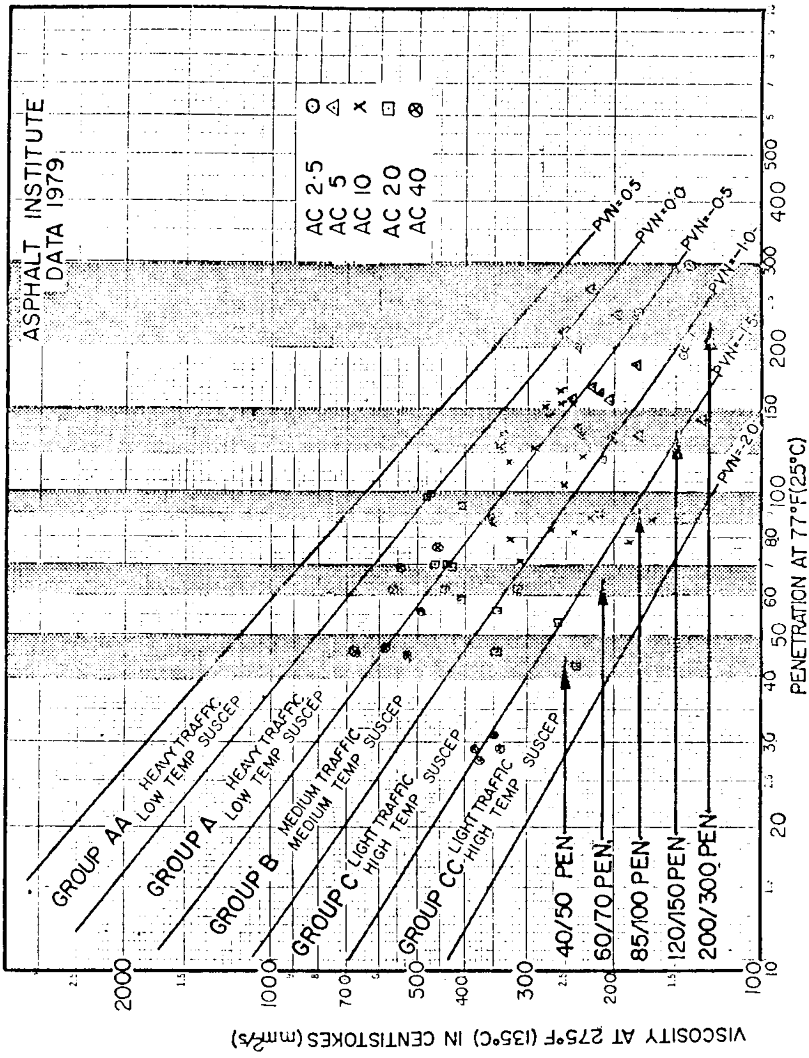

Figure 18: Paving Asphalt Temperature Susceptibility Groups A, B and C, from The Asphalt Institute's 1979 Survey.

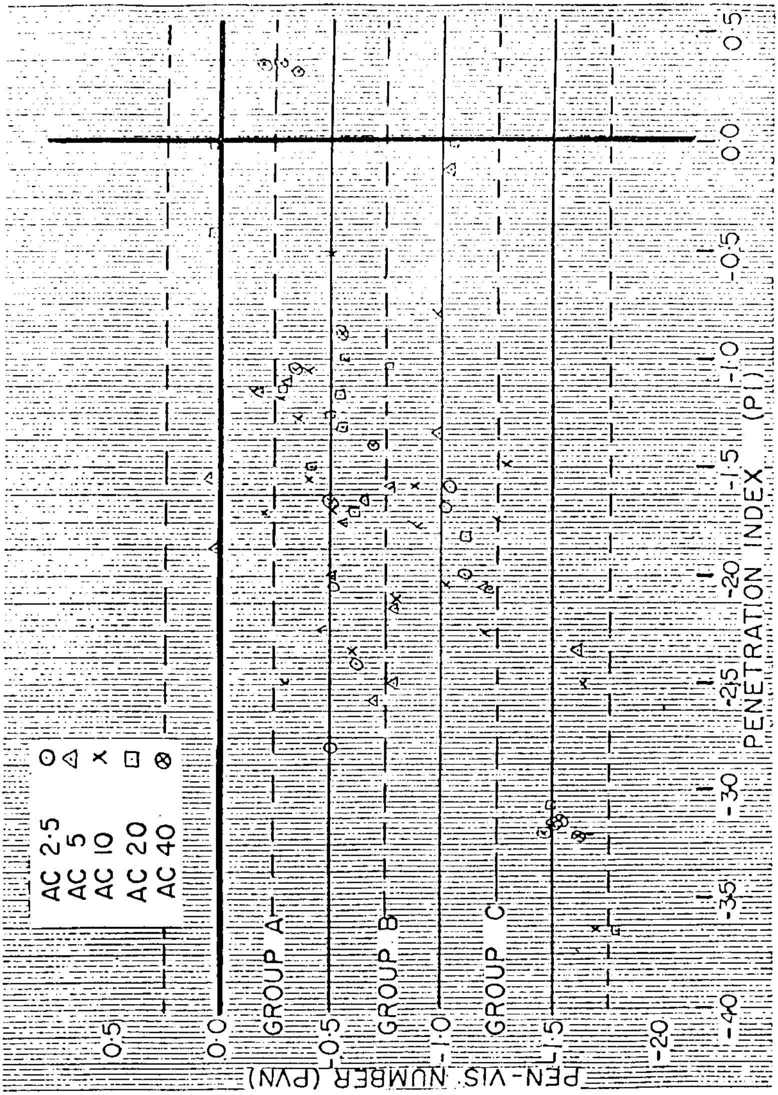

Figure 19: Plot of PVN versus Heukelom's PI Values for the Asphalt Institute's Data.

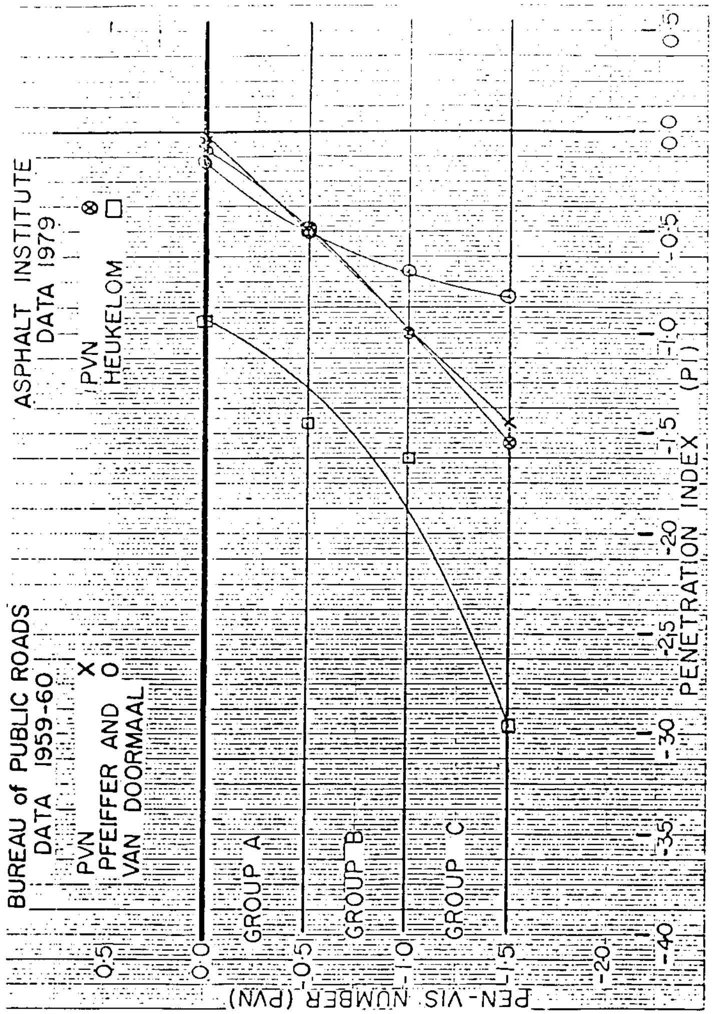

Figure 20: Plot of Average Values of Temperature Susceptibility in Terms of PVN versus Heukelom's PI Values for Group A, B and C for the Asphalt Institute's Data and Compared with Similar Values in Figure 17.

rect temperature susceptibility values to use with Van der Poel's nomographs (*12,13*) for paving mixture design.

Incidentally, Figure 15, Bureau of Public Roads data, and Figure 18, Asphalt Institute data, both demonstrate that paving asphalt grades in the U.S.A. are well distributed over Grade A, low temperature susceptibility, PVN greater than -0.5, Group B, medium temperature susceptibility, PVN -0.5 to -1.0 and Group C, high temperature susceptibility, PVN = -1.0 and lower.

THIN-FILM OVEN TEST RESIDUE

The Thin-film Oven Test Residue of a paving asphalt has the same PVN value as the original asphalt.

This is supported by data obtained by Meidinger and Kasianchuk of the British Columbia Department of Highways (*14*), by Anderson, Dukatz and Petersen (*15*), by Anderson, Dukatz and Rosenberg (*16*), by Kandhal and Koehler (17), and by our own laboratory, McLeod (18). All of these studies indicate that the PVN of a Thin-film Oven Test Residue is the same or very nearly the same as the PVN of the original asphalt.

LOW TEMPERATURE TRANSVERSE PAVEMENT CRACKING AND PVN

Reference was made earlier to the three 6-mile Test Roads constructed in South Western Ontario in 1960, in each of which three 2-mile test pavements were constructed using three 85/100 penetration asphalts of low, medium and high temperature susceptibilities, Figure 5. By 1968, low temperature transverse pavement cracking was becoming a serious problem on Canadian highways. At that time, the writer realized that these three Test Roads, although 8 years old, would provide an excellent outdoor laboratory for the study of low temperature transverse pavement cracking. For each of the next thirteen years, my associate, Charles Perkins, for the first two years and myself for the final 11 years with tally sheet in hand, walked on the adjacent gravel shoulders of each of these test roads, tallying each of the low temperature transverse pavement cracks that had developed, Figure 21. The cracks that completely crossed the full width of a traffic lane, Type 1, turned out to be the most significant in relation to the properties of the asphalts in the pavements.

The results of this crack survey are illustrated in Figure 22, in which numbers of Type 1 low temperature transverse pavement cracks per lane mile as abscissa, are plotted versus the PVN values of -0.23, -0.41 and -1.35 of the three 85/100 penetration asphalts as ordinate, on an annual basis. It can be seen, that particularly in these pavement's early lives, up to from 10 to 15 years, that pavements made with paving asphalt of low temperature susceptibility, PVN = -0.23, had the lowest number of Type 1 transverse cracks per lane mile, and that the numbers of these cracks increased as the temperature susceptibilities of the asphalts increased from PVN = -0.23, to -0.41 to -1.35.

It is apparent from Figure 22, that 85/100 penetration asphalt was too hard a grade of asphalt to have been used to eliminate or at least greatly reduce low temperature transverse pavement cracking. The objective of any treatment for

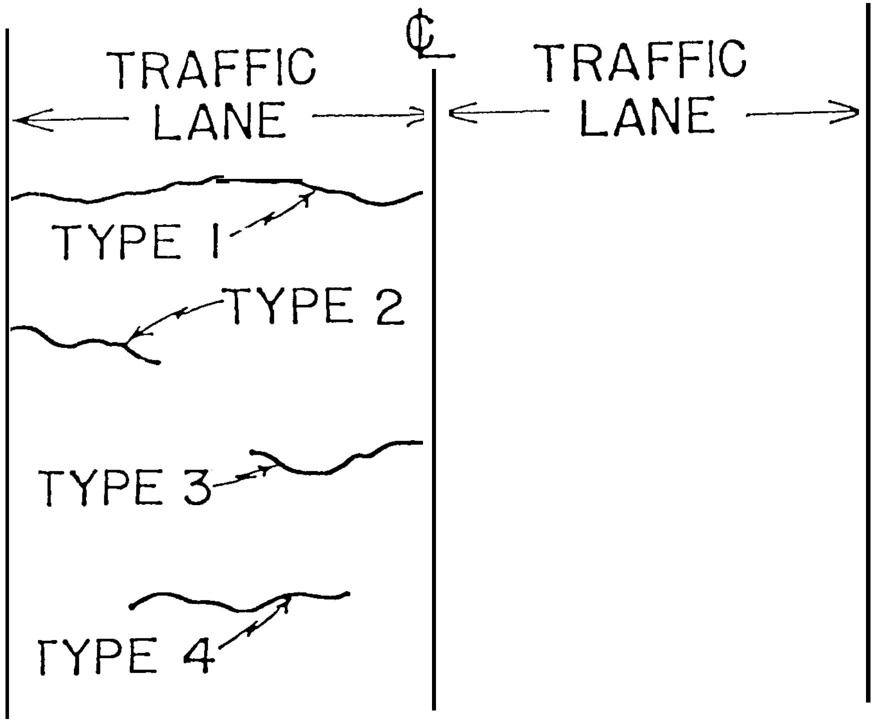

Figure 21: Types of Transverse Pavement Cracks.

low temperature transverse pavement cracking should be no thermal cracks during the service life of the pavement. This will be considered later in the paper.

Table 1 provides inspection data for the three 85/100 penetration asphalts of different temperature susceptibilities that were used in the three Ontario Test Roads as measures of temperature susceptibility. It is obvious from Table 1 that the values for Pfeiffer and Van Doormaal's PI and for PVN point in completely opposite directions. For example, Supplier l's asphalt has a PI value of -1.00, but a PVN value of only -0.23. However, Figure 22 shows that the values for PVN point in the right direction insofar as thermal cracking is concerned. The PI values in Table 1 are in error because of the influence of wax in the asphalt, particularly in the asphalt furnished by Supplier 3, which provides values for both softening point and PI that are much too high.

In 1961, Ontario constructed Test Road 4, Figure 1, to include two pavement sections, each several miles long. In this project the asphalt was of high temperature susceptibility in both cases, PVN = -1.35. For one pavement section 150/200 penetration was used, and for the other, 85/100 penetration. Figures 23, 24 and 25 show the appearance of these two test pavements after 4 years of service, after which they were overlaid. The pavement made with

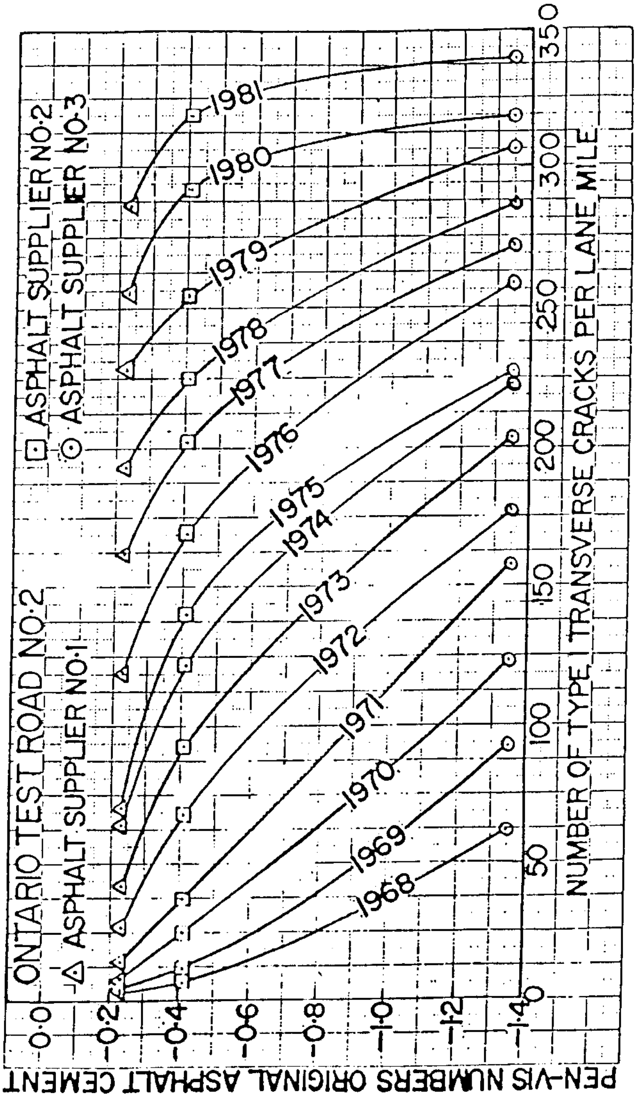

Figure 22: Influence of Paving Asphalt Temperature Susceptibilities on Annual Count of Type 1 Low Temperature Transverse Pavement Cracks per Lane Mile.

Supplier No	1	2	3
Flash Point °F	585	525	615
Soft. Pt. R and B °F	115	115	119
Penetration			
100 g, 5s, 77°F	83	96	87
200 g, 60s, 39.2°F	25	36	22
200 g, 60s, 32°F	22	26	19
Penetration Ratio 39.2/77x100	30.1	37.5	25.3
Ductility at 77°F, 5cm/min, cm	150+	150+	128
Viscosity			
Centistokes at 275°F	460	365	210
Centistokes at 210°F	3953	2763	1472
Thin Film Oven Test			
Loss by weight %	0.1	0.3	0.0
Residue			
% Original Pen at 77°F	67.5	60.4	61.0
Ductility at 77°F, 5cm/min, cm	150+	110	115
Solubility in n-hexane			
% asphaltenes	19.7	24.7	18.8
Penetration Index, PI			
Pfeiffer and Van Doormaal	-1.0	-0.57	-0.21
Pen-Vis Number, PVN	-0.23	-0.41	-1.35

Table 1: Inspection Data on Original Paving Asphalts for the Three Ontario Test Roads.

85/100 penetration asphalt had developed more than 400 Type 1 low temperature transverse cracks per lane mile, Figure 23, while there was not a single crack in the pavement with 150/200 penetration asphalt, Figure 24. Since critics may say that the subgrade or some other factor must have been different in these two test pavements, Figure 25 is presented. In Figure 25, 1700 feet of pavement on the right side were constructed with the 85/100 penetration asphalt, while the pavement on the left side was made with the 150/200 penetration asphalt. In the pavement on the right there are more than 400 type 1 low temperature transverse cracks per lane mile, but no cracks in the pavement on the left (*19*).

From this study of low temperature transverse pavement cracking on the four Ontario Test Roads (*19*), the Ste. Anne Test Road (*20*), from laboratory studies on numerous pavement samples, from observations of many thousands of miles of pavements in service in Canada, the Northern U.S.A., Norway, and from theoretical considerations (*21*), the writer has concluded that the two most important properties of paving asphalt that are associated with low temperature transverse pavement cracking are:

Figure 23: Pavement with **85/100** Penetration Asphalt. West of Orangeville. Four Years Old.

1. Its penetration at 25 C (77 F), and
2. Its temperature susceptibility, which for me is given by its PVN value, that is based on its penetration at 25 C (77 F) and its viscosity at 135 C (275 F).

These two paving asphalt properties influence low temperature transverse pavement cracking as follows:

(a) *If temperature susceptibility is held constant,* low temperature transverse pavement cracking *increases* as the penetration of the paving asphalt at 25 C (77 F) *decreases* (becomes harder), Figure 23, 24 and 25.
(b) *If the penetration of the paving asphalt at 25 C (77 F) is held constant, low temperature* transverse pavement cracking *increases* with an *increase in temperature susceptibility of the paving asphalt, Figure 22.*
(c) Low temperature transverse pavement cracking increases with pavement age, because the asphalt in the pavement hardens with time, its penetration at 25 C (77 F) becomes harder and harder with time (its penetration at 25 C (77 F) becomes lower and lower).

These principles are further supported by the following examples of the very rapid failure of a pavement by low temperature transverse pavement

Figure 24: Pavement with **150/200** Penetration Asphalt. West of Orangeville. Four Years Old.

cracking in one case and by the success of a pavement in another. About 1966 or 1967 Ontario let a contract for paving a road into the Red Lake Mining Centre in Northwestern Ontario, where the minimum winter temperature can be -60 F (-51 C). The asphalt to be used for this pavement was 85/100 penetration at 25 C (77 F) with a high temperature susceptibility (PVN = -1.5). Since the pavement construction was begun but not finished in the first year, it was expected to be completed the following spring. However, during the intervening winter the low temperature transverse pavement cracking that occurred in the new pavement constructed the previous fall was so severe that the paving contract was cancelled.

The other pavement project was the James Bay Access Road in the Province of Quebec. This was for a planned 16-billion dollar hydroelectric project (equal to four Niagara Falls developments). This project was 400 miles north of the end of rail service. It was decided to build a paved highway to service this project rather than rail. The minimum temperature in winter was -60 F (-51 C), and the maximum temperature in summer was 90 F (32 C). The consultants for this road project were Desjardins, Sauriol and Associates of Montreal. They asked the writer to serve with them as consultant for the asphalt pavement. The pavement was to last for 10 years, which was the length of

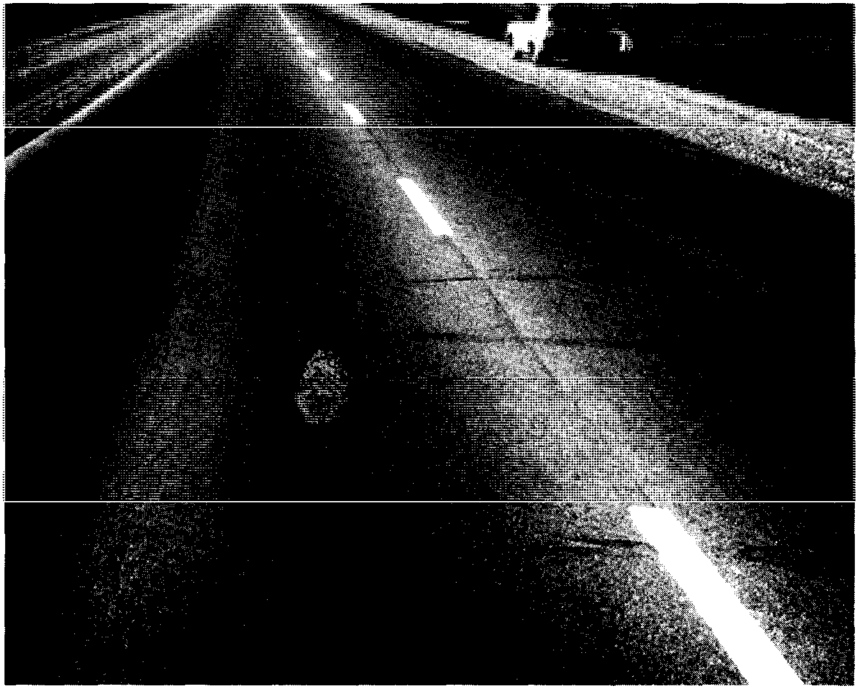

Figure 25: **85/100** Penetration in Pavement in Right Lane. **150/200** Penetration in Left Lane. West of Orangeville. Four Years Old. (Note: Blemish is in the Film Not in the Pavement).

time Quebec Hydro believed was needed to complete the construction of the generating facilities. All the bridges on this road were designed to carry a load of 500 tons, which the pavement also had to support. One of my principal assignments was the selection of the asphalt binder to be used. It had to provide a pavement that would satisfy two basic requirements:

(a) To minimize the amount of low temperature transverse pavement cracking in winter
(b) To provide adequate stability for warm weather traffic.

After considerable study, that is reported in the 1978 AAPT Proceedings, I recommended a paving asphalt of 300/400 penetration at 25 C (77 F) with a low temperature susceptibility, minimum PVN of -0.2, although Quebec Highways had used only 85/100 penetration at 25 C (77 F) up to that time. After some hesitation, this recommendation was adopted.

To pave this road five contracts of approximately 40 miles each were let and finished in 1975 and five contracts of about 40 miles each were let and constructed in 1976. I have not seen this project since 1977, but from conversation with those who have, it is still providing acceptable service 13 and 14 years later.

The first project failed immediately because the penetration at 25 C (77 F) of the paving asphalt, 85/100, was much too low for that environment, and its temperature susceptibility, PVN = -1.5, was much too high. The second project is still giving good service because the paving asphalt was sufficiently soft 300/400 penetration at 25 C (77 F), and its temperature susceptibility, PVN = -0.2, was low enough that the pavement had good resistance to low temperature transverse cracking in winter, and had adequate stability for summer traffic.

These two projects indicate that for greater resistance to low temperature transverse pavement cracking, softer paving asphalts are required that include *both* a higher penetration at 25 C (77 F) *and* low temperature susceptibility. As clearly shown by Figure 4, the low temperature susceptibility also assures higher pavement stability under warm summer temperatures and a softer asphalt at minimum winter temperatures.

Quantitative data are also available to support these three principles from a limited number of other projects:

1. The three 6-mile Ontario Test Roads that were built in 1960, where the penetration at 25 C (77 F) of the paving asphalts was held constant at 85/100, and the temperature susceptibilities ranged from low to medium to high (PVN = -0.23, -0.41, and -1.35). Figure 22 shows that for the average minimum winter temperature conditions prevailing at these projects, -20 C (-4 F), after any given period of time, the amount of low temperature transverse pavement cracking increased markedly with an increase in temperature susceptibility. For example, at the pavement age of 10 years, in Test Road No. 2, there were 15 times as many Type 1 low temperature transverse pavement cracks per lane mile in the pavement containing the asphalt of highest temperature susceptibility, PVN = -1.35, as in the pavement made with the asphalt of lowest temperature susceptibility, PVN = -0.23.
2. Ontario Test Road 4, Figure 1, was constructed in 1961. The temperature susceptibility of the two paving asphalts employed was kept constant, high temperature susceptibility, PVN = - 1.35, and their penetrations at 25 C (77 F) were 85/100 in one test section, and 150/200 in the other, Figures 23, 24 and 25. The minimum winter temperature at this test road was -23.3 C (-10 F). After four years of service, after which they were overlaid, the test pavement containing 85/100 penetration asphalt had more than 400 Type 1 thermal cracks per lane mile, Figure 23, while the test pavement made with the 150/200 penetration asphalt had no low temperature transverse pavement cracks of any type, Figure 24.
3. Table 2 lists data reported by Kandhal and Koehler (17) for six asphalt test pavements in Pennsylvania. The six paving asphalts employed represent the entire spectrum of temperature susceptibility from low to medium to high, Group A, PVN 0.0 to -0.5, Group B, PVN -0.5 to -1.0 and Group C, PVN -1.0 to -1.5, Figure 14. One asphalt, T-6, was of low temperature suscepti-

PENDOT STUDY

ASPHALT TYPE	PI (PEN/PEN) ORIGINAL	PI JUST AFTER CONSTRUCTION	PI 20 MONTHS	PI 7 YEARS	PVN (PEN-VIS NUMBER) ORIGINAL	PVN JUST AFTER CONSTRUCTION	PVN 20 MONTHS	PVN 7 YEARS
T-1	-2·77	-2·24	+0·34	+1·82	-1·04	-1·13	-1·07	-1·12
T-2	-0·71	-0·80	+1·22	+1·52	-0·70	-0·68	-0·54	-0·60
T-3	-1·51	-0·99	-0·12	-0·58	-0·61	-0·72	-0·65	-0·56
T-4	-1·05	-0·65	+0·93	+0·39	-0·86	-1·03	-0·76	-0·79
T-5	-2·23	-2·03	-0·32	-0·87	-1·03	-1·16	-1·07	-1·12
T-6	-1·29	-0·64	+0·60	-0·46	-0·45	-0·47	-0·40	-0·39

MINIMUM WINTER TEMPERATURE -29 C (-20 F)

Table 2: Temperature Susceptibilities of Original and Aged Asphalts.

DESIGN

ASPHALT SURFACE COURSE	1.5 INCHES
ASPHALT BASE COURSE	1.5 INCHES
ASPHALT TREATED BASE	8.0 INCHES

ASPHALT SOURCE	PVN VALUES ORIGINAL	RECOVERED AFTER 3.5 YEARS	GROUP PVN RANGE	THERMAL CRACK SPACING IN FEET AFTER 3.5 YEARS
SUGAR CREEK	-1.2	-1.04	C -1.0 to -1.5	35
WOOD RIVER	-0.60	-0.61	B -0.5 to -1.0	170
STANDARD AC 10 + 1.0% (ATB)				528

MINIMUM WINTER TEMPERATURE -29 C (-20 F)

Table 3: Iowa Thermal Crack Study.

bility, three asphalts, T-2, T-3 and T-4 were of medium temperature susceptibility, while T-l and T-5 were of high temperature susceptibility. All being AC20 asphalts, their penetrations at 25 C (77 F) varied from 42 to 80. Nevertheless, the combination of lowest penetration at 25 C (77 F) and highest temperature susceptibility, resulted in pavements with the highest number of low temperature thermal cracks after seven years of service.

Table 2 lists PI data by Heukelom's method and PVN data on the original asphalts and on asphalts recovered from the pavements just after construction, after 20 months and after seven years in service. These data show that the PVN values for each asphalt are approximately constant regardless of time in pavement service, while Heukelom's PI data have no recognizable pattern.

The minimum winter temperature at the site of the PenDot Test pavements was -29 C (-20 F).

4. Table 3 indicates that similar conclusions are indicated by Iowa data reported by Marks and Huisman (22). A test pavement containing paving asphalt of 75 penetration at 25 C (77 F) with a high temperature susceptibility, Group C, had low temperature thermal crack spacing of only 35 feet after 3.5 years in service when the pavements were overlaid, but the other test pavement had a thermal crack spacing of 170 feet for the pavement in which the asphalt had a penetration of 100 at 25 C (77 F) and a medium temperature susceptibility, Group B. In the first pavement, the paving asphalt with an original PVN of -1.2, when recovered from the pavement after 3.5 years had a PVN of -1.4. In the second pavement, a paving asphalt with an original PVN of -0.6, had a PVN value of -0.61 when recovered from the pavement after the same period of service. Furthermore, Marks and Huisman report that PVN values for asphalts recovered from other pavements on a routine basis, have remained relatively constant over a period of years.

   The minimum winter temperature at the site of the Iowa test pavements was also -29 C (-20 F).

5. Data from the Ste. Anne Test Road, reported by Deme and Young (*20*), and shown in Table 4, indicate that recovered paving asphalt PVN values remain essentially unchanged after pavement service periods up to 20 years. For example, 150/200 penetration asphalt of medium temperature susceptibility, had an original PVN value of -0.59, Group B, a PVN value of -0.75, Group B, when recovered from the pavement after three years of service, and a PVN of -0.73, Group B, when recovered from the test pavement after 20 years. After five years of service this pavement had 41 thermal cracks per kilometer. Another test pavement containing 150/200 penetration asphalt of high temperature susceptibility, Group CC, had an original PVN of -1.61, a PVN of -1.71, Group CC, when recovered from the pavement after three years, and a PVN of -1.80, Group CC, when recovered from the pavement after 20 years. A third test pavement, made with 300/400 penetration asphalt of high temperature susceptibility, had an original PVN of -1.52, Group CC, a PVN of -1.78, Group CC, when recovered after three

MINIMUM WINTER TEMPERATURE -40 C (-40 F)

PERIOD OF SERVICE	PVN VALUES		
	150/200 PEN HIGH VISCOSITY AT 275 F	150/200 PEN LOW VISCOSITY AT 275 F	300/400 PEN LOW VISCOSITY AT 275 F
ORIGINAL 1967	-0.59	-1.61	-1.52
RECOVERED 1970	-0.75	-1.71	-1.78
RECOVERED 1987	-0.73	-1.80	-1.76
GROUP PVN	B -0.5 to -1.0	CC -1.5 to -2.0	CC -1.5 to -2.0

Table 4: Ste. Anne Test Road.

McASPHALT STUDY

ORIGINAL ASPHALT		PI PEN/PEN (HEUKELOM)			PVN		
NO	PEN	ORIGINAL	THIN FILM RESIDUE	PUGMILL DISCHARGE	ORIGINAL	THIN FILM RESIDUE	PUGMILL DISCHARGE
1	85/100	-2.86	-2.33	-1.81	-0.61	-0.67	-0.56
2	85/100	-1.63	-2.06	-2.00	-0.67	-0.69	-0.69
3	85/100	-2.73	-1.64	-2.18	-0.70	-0.68	-0.67
4	150/200	-1.73	-1.16	-0.65	-0.59	-0.67	-0.64
5	85/100	-1.98	-2.38	-0.81	-0.67	-0.69	-0.56
6	85/100	-1.23	-1.06	-0.84	-0.77	-0.64	-0.49
7	85/100	-0.94	-0.21	-0.80	-0.47	-0.41	-0.36
8	85/100	-1.11	-2.88	-1.93	-0.55	-0.56	-0.47
9	85/100	-1.24	-1.49	-1.92	-0.53	-0.52	-0.34

Table 5: Temperature Susceptibilities of Original and Aged Asphalts.

years of service, and a PVN of -1.76, Group CC, when recovered after 20 years of service.

The minimum winter temperature at the site of the Ste. Anne Test Road was -40 C (-40 F).

6. For the data in Table 5 (*18*), one of our asphalt sales engineers went to nine hot-mix plants located in different parts of Ontario and obtained a sample of the asphalt going into the hot-mix plant and a sample of the hot-mix being discharged. In our laboratory PVN values were determined for the samples of asphalt going into the mixer, on the thin-film oven test residues from these samples, and on asphalts recovered from the paving mixtures being discharged. Parallel tests were made to determine Heukelom's PI values for each of these three conditions. Table 5 shows that for all nine paving asphalt samples, the PVN values for the original asphalts, for their thin-film oven test residues, and for asphalt recovered from the paving mixture samples, remain essentially unchanged. On the other hand, Heukelom's PI values are scattered with no discernible pattern.

   All asphalts in Table 5 (18) had to meet Ontario's specification for which the requirements for minimum penetration at 25 C (77 F) and minimum viscosity at 135 C (275 F) correspond to a minimum PVN value of about -0.8. It will be noted that every one of the nine paving asphalts meets this minimum PVN requirement.

7. The data in Tables 6 and 7 pertain to an overseas project. We are interested at the moment only in Stage 1, the first 3-lanes of an eventual 6-lane pavement, which was eight years old when sampled. The paving asphalt was 80/100 penetration at 25 C (77 F), provided by Supplier 1, that Table 6 indicates had a PVN of -0.31, which was Group A, Figure 14. The PVN values of the asphalt samples recovered from the pavement after eight years of service, are also seen to be Group A, PVN = 0.0 to -0.5.

   The minimum average monthly temperature at this site is 10 C (50 F).

8. Professor Haas from the University of Waterloo and Associates (23) has recently completed a very thorough investigation of pavement samples from 26 airports across Canada, Figure 26, some of them more than 30 years old. The PVN values for the bitumens recovered from these pavement samples were found to be very near to what the PVN values for the original bitumens must have been,

   With respect to older pavements there is always the question of whether the asphalt in the pavement had developed some internal structure with time that would be lost when the asphalt was recovered for PVN testing. However, Professor Haas made direct tensile strength tests on three undisturbed briquettes that were cut from the pavement samples from each airport. These direct tensile tests were made at temperatures of 0 C, -17 C and -34 C. When I quizzed Professor Haas directly on this point, after reexamining his data, he stated that his tensile strength tests showed no evidence of the development of any internal structure within the paving asphalts themselves in these pavement samples. Consequently, the PVN values represented the condition of the asphalt in the pavements in place.

Asphalt Blend	SUPPLIER 2	BLEND 3:1	BLEND 1:1	BLEND 40:60	BLEND 1:3	SUPPLIER 1	SUPPLIER 1 SAMPLES 1	SUPPLIER 1 SAMPLES 2
Pen @ 77 F	59	72	81	83	89	88	57	63
Soft Point (R&B) F	124.5	121.5	118	115	115	114	118	119
Kin Vis @ 275 F	684	574	505	488	421	412	362	359
295 F	410	327	303	305	257	237	209	210
315 F	286	234	200	192	183	150	139	121
S.G. @ 77 F	.9828	.9978	1.0076	1.0106	1.0191	1.0325		1.0274
Ductility @ 77 F cm	32.5	51.5	110+	110+	110+	110+	110+	110+
PVN	-.02	-0.06	-0.12	-.14	-0.28	-.31	-.96	-.88
PI	-.46	-0.37	-.58	-.99	-.79	-1.00	-1.47	-1.09
Thin Film Oven Test % Loss	.011	.027	.018	.0126	.0122	.035	.0356	.0484
Pen @ 77 F	46	50	60	60	59	57	37	42
% Ret Pen	78.0	69.4	74.1	72.3	66.3	64.8	64.9	66.7
Kin Vis @ 275 F	988	819	656	640	580	532	479	455
Soft Point F	127.5	126	122.5	121.5	120	117	125	124
Ductility @ 77 F	15	30	110+	110+	110+	110+	110+	110+
PVN	+0.19	0.03	-0.08	-.11	-0.27	-.43	-.98	-.93
PI	-0.66	-.66	-0.70	-.84	-1.10	-1.62	-1.44	-1.31

Table 6: Inspection Data.

PENETRATION AT 25°C AND CORRESPONDING PVN VALUES FOR BITUMEN RECOVERED FROM PAVEMENT SAMPLES

Location	Contract	BITUMEN PROPERTIES			
		Penetration at 25°C		PVN Values	
		Surface	Base	Surface	Base
1	STAGE 1	20	24	-0.18	-0.03
2	STAGE 1	23	22.5	+0.08	-0.17
3	STAGE 1	26	21	-0.40	-0.43
4	STAGE 1	25	23	+0.19	-0.27
5	STAGE 1	19	23	-0.08	-0.29
6	STAGE 2	31	51	+0.37	-0.48
7	STAGE 2	49	21	-0.59	-0.25
8	STAGE 2	38	58.5	-0.95	-0.81
9	STAGE 2	40	27	-0.26	-0.23
10	STAGE 2	41	32	-0.22	-0.07
16	STAGE 2	67	63	-0.63	-0.63
17	STAGE 2	42	65	-0.33	-0.64
18	STAGE 2	31	28	-0.62	-0.28
19	STAGE 2	65	77	-0.20	-0.48
20	STAGE 2	44	31	-0.28	-0.21
21	STAGE 2	25	23	-0.68	-0.33
22	STAGE 2	26	27	-0.16	-0.37
23	STAGE 2	29	26	-0.03	-0.25

MINIMUM WINTER TEMPERATURE +10 C (+50 F)

Table 7: Penetration at 25°C and Corresponding PVN Values for Bitumen Recovered from Pavement Samples.

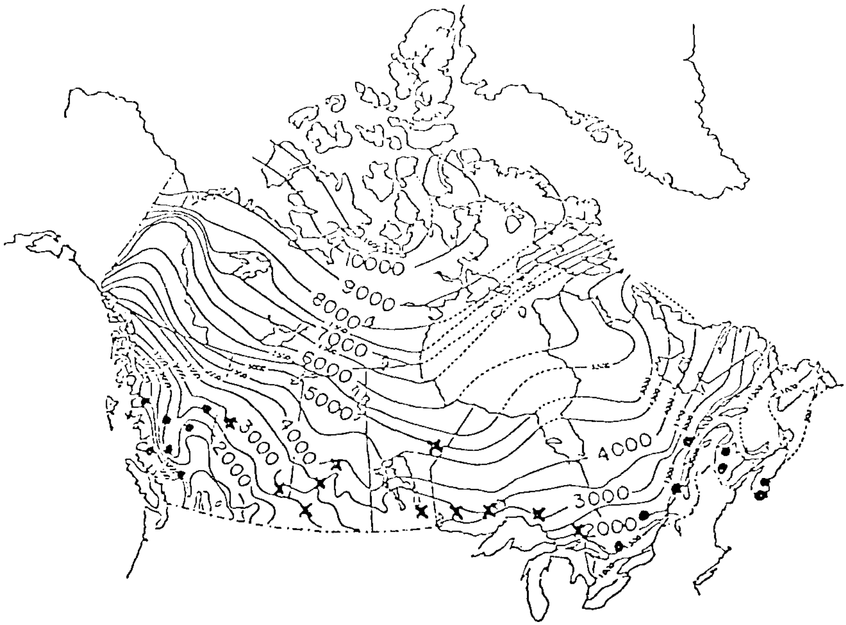

Figure 26: Approximate locations of the 26 airports (Where x's Indicate Interior Airports and o's Indicate Coastally Associated Airports). Freezing Index Countours are in °F Days. (With Credit to Ralph **Haas**).

9. In his 1974 paper, Fabb (*24*), after a very thorough laboratory study, reported that during cooling to low temperatures, cracking was initiated in any asphalt paving mixture when the asphalt binder in a mix was chilled to a critical modulus of stiffness on which changes in paving mixture design had little or no influence.

A number of important conclusions can be drawn from the data in Tables 2, 3, 4, 5, 6, 7 and Figure 26:

1. They show that asphalts recovered from pavements in service indicate that *the PVN of an asphalt remains constant regardless of its time in pavement service up to 20 years at the Ste. Anne Test Road, and in excess of 30 years for pavements from 26 Canadian airports,* that were investigated by Haas and Associates (23). The PVN of the paving asphalt that was fed into the pugmill at the hot-mix plant did not change over these long periods of time.
2. The data in these tables and Figure 26 also demonstrate that *regardless of wide differences in temperature in pavement service, the PVN of the original paving asphalt and of the asphalt recovered from a pavement after the same 20 to 30 years of time, is also constant.* It remains constant whether subjected to a temperature of 163 C (325 F) for five hours in the Thin-film

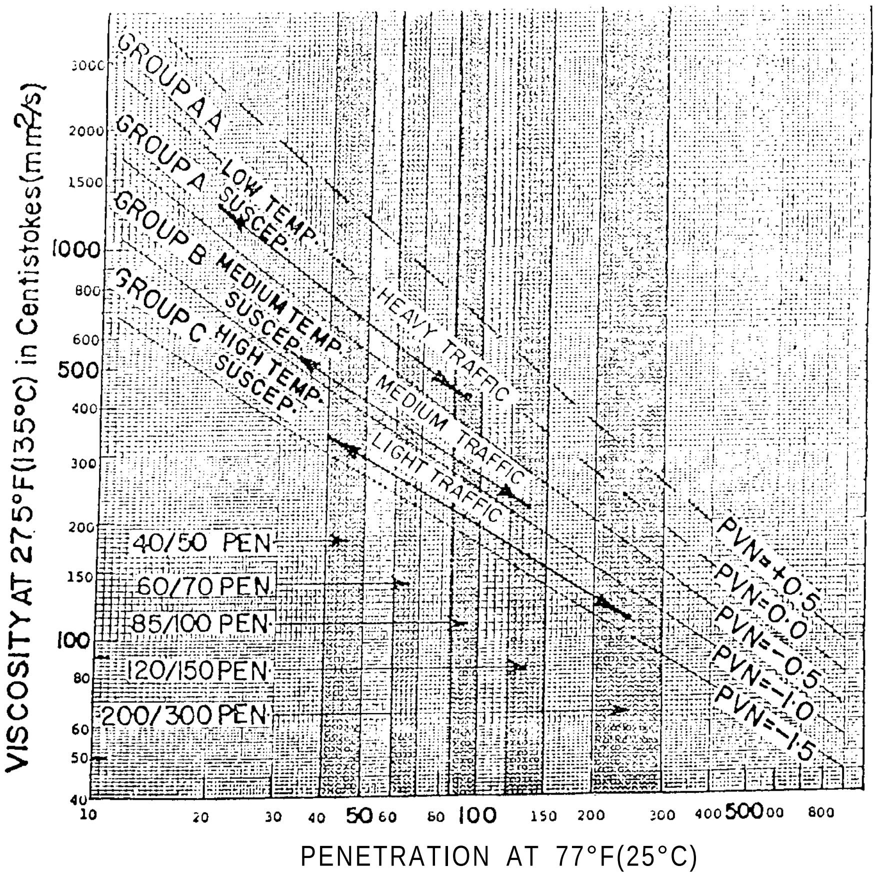

Figure 27: Illustrating A Specification Based on Penetrations at 77°F (25°C), Viscosities at 275°F (135°C), and Temperature Susceptibilities of Paving Asphalt.

Oven Test, or after temperatures in pavement service that have been as low as -40 C (-40 F), Table 4.

This latter fact indicates that PVN is the best measure of paving asphalt temperature susceptibility that has been developed so far.

3. Professor Haas' conclusions concerning the reversing of the direction of the PVN values of aged asphalt recovered from pavements to their same original PVN values, supports the double-headed arrows in Figure 27. This means that an original asphalt in the Group A category, low temperature susceptibility, remains Group A throughout its service life. An original asphalt in the Group B category, medium temperature susceptibility, remains in Group B, and original asphalts in the Group C category, remain in Group C. Throughout their service lives. It also means that the direction of harden-

ing with time for an original paving asphalt, and the direction through which hardening of an aged asphalt has occurred, are on the same path but in opposite directions.

4. At present, oxidation, which consists of blowing air through a soft asphalt maintained at a temperature of about 260 C (500 F), is commonly used to increase the softening point for any given penetration at 25 C (77 F) for roofing and industrial asphalt products, and when producing paving asphalts, to increase their viscosity at 135 C (275 F). Oxidation is an extra stage in manufacture and increases the cost of asphalt production. When a specified ductility requirement of 100 cm at 25 C (77 F), 5 cm/min must be satisfied, oxidation is of very limited usefulness for increasing the viscosity at 135 C (275 F) of a paving asphalt. At most, it may be able to increase the viscosity at 135 C (275 F) from a Group C to a Group B, or from a Group B to a Group A in Figure 14. By adding an appropriate polymer, the viscosity at 135 C (275 F) of a Group C paving asphalt can be easily increased to that of a Group A or higher. Consequently, all paving asphalts could be manufactured by steam or vacuum distillation, and when necessary to satisfy a paving asphalt specification, their viscosities at 135 C (275 F), or their PVN values, could be increased to any required degree by incorporating a small percentage of a suitable polymer.
5. Critics have suggested that PVN cannot be associated with the cause or cure of thermal cracking, because neither penetration at 25 C (77 F), nor viscosity at 135 C (275 F) of a paving asphalt, on which PVN is based, can be correlated with low temperature transverse pavement cracking. In reply, the writer would like to point out that he has used a completely different criterion for low temperature pavement performance, namely, the number of low temperature transverse pavement cracks per lane mile, or per lane kilometer, or crack spacing in feet or meters, that have developed when a pavement is chilled to a minimum winter temperature. When all other factors are equal, this criterion shows that Group A asphalts, as indicated by penetration at 25 C (77 F) and viscosity at 135 C (275 F), or by PVN values of 0.0 to -0.5, develop the smallest number of low temperature transverse cracks per lane mile of pavement, or equivalent, while Group C asphalts, as indicated by penetration at 25 C (77F) and viscosity at 135 C (275 F), or by PVN values of -1.0 to -1.5, develop the greatest number of low temperature transverse cracks per lane mile of pavement, or equivalent. For pavements made with Group B asphalts, as indicated by penetration at 25 C (77 F) and viscosity at 135 C (275 F), or PVN values of -0.5 to -1.0, the number of low temperature transverse cracks per lane mile of pavement, or equivalent, is inbetween the number of transverse cracks developed by Group A and Group C asphalts, Figure 22. This is further verified by the close relationship between Groups A, B and C paving asphalt groupings, and the corresponding numbers of low temperature transverse cracks per lane mile of pavement, or equivalent, in Tables 2, 3, 4, 7, 8 and Figure 26. Therefore, penetration at 25 C (77F) and viscosity at 135 C (275 F), or corresponding PVN values, are very accurate indicators of low temperature pavement performance. The PVN values of paving asphalts appear to vary

only with the crude oil or crude oil blend from which they are manufactured by steam or vacuum distillation, Figure 10. Furthermore, as is also true for human beings, PVN is an asphalt finger print that remains constant throughout an asphalt pavement's service life.

WHY CAN PVN VALUES FOR NORMAL SPECIFICATION PAVING ASPHALTS BE READ WITH SUFFICIENT PRECISION FROM A PVN CHART FOR "WAX-FREE" ASPHALTS MANUFACTURED FROM "WAX-FREE" ASPHALT BASED CRUDE OILS?

It should be made clear again, that the PVN charts of Figures 13, 14, and 27, are based on PVN values for "wax-free" asphalts from "wax-free" asphalt based crude oils. Why then can the PVN values for normal paving asphalts meeting an ordinary paving asphalt specification be taken with sufficient accuracy from these PVN charts?

The constancy of the PVN values for the original paving asphalt and for the corresponding paving asphalts recovered from pavements in service up to 20 or 30 years as demonstrated unanimously by the data recorded in Tables 2, 3, 4, 7, 8 and Figure 26, indicate that this procedure is very close to being correct. This is particularly true when the differences in temperature of the asphalts in pavement service is considered. The principal difference in PVN values, if any, would probably be due to small amounts of wax retained in a normal paving asphalt. Consequently, the writer is offering Table 8 as evidence that any wax remaining in a normal paving asphalt is so small, that its effect on the asphalt's PVN value is probably insignificant.

For Table 8, 0.0, 0.5, 1.0, 2.0, 5.0 and 10.0 percent of refinery slack wax with a ring and ball softening point of 64.4 C (148 F) and a viscosity of 3.39 centistokes at 135 C (275 F), were blended into 85/100 penetration at 25 C (77 F) paving asphalts of Group A, low temperature susceptibility in one case, of Group B, medium temperature susceptibility in the second case, and of Group C, high temperature susceptibility in the third case. Data for percent of slack wax, penetration at 25 C (77 F), viscosity in centistokes at 135 C (275 F), PVN value, ductility in cm at 25 C (77 F), 5 cm/min, and softening point °C and °F, ring and ball, are listed in Table 8 for each added percent of slack wax, for Group A, Group B and Group C paving asphalts.

At a temperature of 135 C (275 F), the slack wax is a very fluid material with a viscosity of 3.39 centistokes. Consequently, with increasing wax content, the penetration at 25 C (77 F) of the blend is increased, and the viscosity of the blend at 135 C (275 F) is decreased. For the addition of very small increases in wax contents, these changes in penetration at 25 C (77 F) and in viscosity at 135 C (275 F) compensate each other in such a way that the PVN values of the blends are not noticeably affected. For example, for an increase of from 0.0 to 2.0 percent in slack wax, the PVN changed from -0.24 to -0.55 for the Group A asphalt, from -0.73 to -0.87 for the Group B asphalt, and from -1.59 to -1.73 for the Group C asphalt. Therefore, the PVN values for the normal paving asphalts and for the corresponding asphalts in the charts in Figures 13, 14 and 27 do not appear to differ significantly. Consequently, the

% Wax	Penetration at 25 C (77 F)	Viscosity cs 135 C (275 F)	PVN	Ductility cm 25 C (77 F)	Soft Point F (C)
Group A Asphalt - Lloydminster					
100	-	3.39	-	-	148.0
0.0	93	417	-0.24	135+	111.0
0.5	98	386	-0.32	135+	107.0
1.0	100	368	-0.35	135+	108.0
2.0	107	307	-0.55	135+	109.0
5.0	115	227	-0.95	135+	109.5
10.0	119	148	-1.59	42	115.0
Group B Asphalt - Mixed Blend					
100	-	3.39	-	-	148.0
0.0	87	318	-0.73	145+	116.5
0.5	90	304	-0.79	145+	117.5
1.0	90	312	-0.72	145+	116.0
2.0	93	275	-0.87	145+	116.5
5.0	100	225	-1.11	96	120.0
10.0	101	145	-1.77	27	123.0
Group C Asphalt - Redwater					
100	-	3.39	-	-	148.0
0.0	94	171	-1.59	130+	115.0
0.5	97	167	-1.59	130+	117.5
1.0	100	162	-1.61	130+	118.5
2.0	112	140	-1.73	130+	116.0
5.0	116	112	-2.06	101	116.5
10.0	126	116	-2.09	28	125.0

Table 8: Influence of Wax on PVN.

PVN charts of Figures 13, 14 and 27, that are based on "wax-free" crude oils can be used with confidence to obtain the PVN values of normal paving asphalts satisfying a minimum ductility requirement of 100 cm, 5 cm/min, at 25 C (77 F). Nevertheless, Table 8 indicates that the accuracy of this comparison could be improved, if the wax content of ordinary specification paving asphalts could be further reduced.

For each of the asphalts recovered from pavements in Tables 2, 3, 4, 5, 7 and 8 and Figure 26, the penetration of the asphalt at 25 C (77 F) has decreased with age, but the viscosity of each asphalt at 135 C (275 F) has increased with age. The decrease in penetrations at 25 C (77 F) and the corresponding increase in viscosities at 135 C (275 F) occur in such a way that the PVN values of the recovered asphalts remain constant and unchanged, Tables 2, 3, 4, 5, 7 and 8 and Figure 26, regardless of the time and temperature in pavement service.

PAVING ASPHALT SELECTION

In colder climates asphalt pavements must be designed with three principal criteria in mind:

1. Avoiding or greatly reducing low temperature transverse pavement cracking in winter.
2. Providing adequate stability for summer traffic.
3. Eliminating pavement rutting.

In warmer climates only the second and third of the above three criteria are important.

This is too big a topic to be handled in detail in this paper. However, some general guidelines can be presented. A detailed treatment is given in references (25) and (26).

(a) Paving Asphalt Selection for Colder Climates

Figures 28 and 29 indicate how paving asphalts should be selected to avoid low temperature transverse pavement cracking in winter and to provide adequate pavement stability and elimination of rutting under summer traffic.

Figure 28 is based on Test Road data (*19,20*), on theoretical considerations (21), and on the field performance of thousands of miles of paved highways in Canada, the U.S.A. and Norway, and represents the writer's best estimate of the combinations of penetration at 25 C (77 F) and viscosity at 135 C (275 F) for the original asphalts to be selected, to eliminate or at least greatly reduce low temperature transverse pavement cracking at the minimum winter temperature at a pavement site, *throughout a pavement's service life.* For example, if the minimum pavement temperature anticipated at a pavement site is -10 F (-23 C), only combinations of penetrations at 25 C (77 F) and viscosities at 135 C (275 F) that lie on or to the right of the oblique line in Figure 28 that is labelled -10 F (-23 C) should be selected if the pavement is to avoid low temperature transverse cracking at -10 F (-23.3 C) throughout its service life. Grades of paving asphalt that lie to the left of this line are too hard, and would result in thermal cracking at the anticipated minimum temperature of -10 F (-23.3 C). This is also true of each of the other oblique lines in Figure 28 representing other anticipated minimum winter temperatures.

On the other hand, it should be noted that with all other factors being equal, to obtain the highest pavement stability in warm weather, the combinations of penetration at 2.5 C (77 F) and of viscosity at 13.5 C (275 F) that lie on each pertinent oblique temperature – labelled line in Figure 28 should also be selected, because these will provide the lowest penetrations at 25 C (77 F) and therefore the highest pavement stabilities that can be obtained without causing low temperature transverse pavement cracking.

Pavement performance in cold climates would be much improved, when all other variables are equal, if paving asphalts were selected for heavy, medium and light traffic as indicated by Figure 29. To avoid low temperature transverse cracking for the service life of the pavement, Figure 29 makes it quite clear that Group A paving asphalts of low temperature susceptibility, (PVN = 0.0 to -0.5), and with lower penetrations at 25 C (77 F), provide pavements that withstand lower winter temperatures without low temperature transverse pavement cracking. Their lower penetrations at 25 C (77 F) also provide pavements with higher stability for summer traffic. Therefore, only Group A

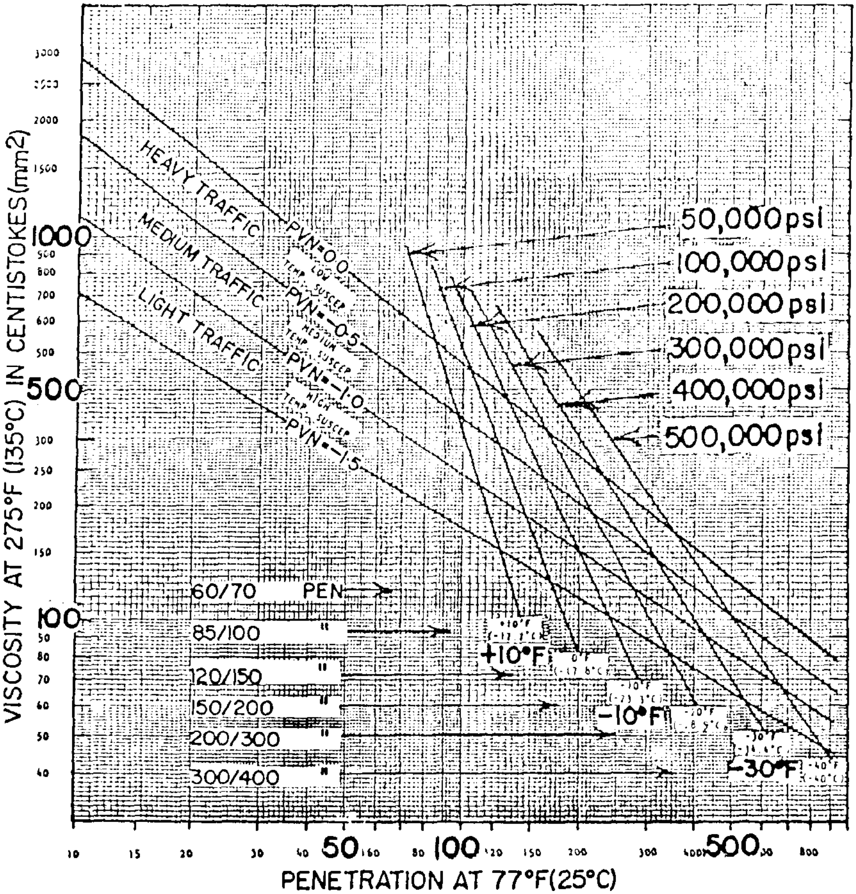

Figure 28: Chart for Selecting Paving Asphalts with Various Combinations of Temperature Susceptibilities and Penetrations at 77°F (25°C) to Avoid Low Temperature Transverse Pavement Cracking at Selected Minimum Winter Temperatures.

asphalts of low temperature susceptibility should be selected for heavy traffic. To avoid low temperature transverse pavement cracking, Figure 29 shows that Group B asphalts of medium temperature susceptibility, (PVN = -0.5 to -l.0), must be of higher penetration at 25 C (77 F) to withstand low temperature transverse pavement cracking at any given minimum winter pavement temperature. These higher penetrations at 25 C (77 F) provide pavements of lower stability for summer traffic. Consequently, considerations of thermal cracking at winter temperatures and lower stabilities at summer temperatures assign these Group B asphalts of medium temperature susceptibility to pavements for the medium traffic category. Figure 29 also indicates that Group C asphalts of high temperature susceptibility, (PVN = -1.0 to -1.5), must be of still higher

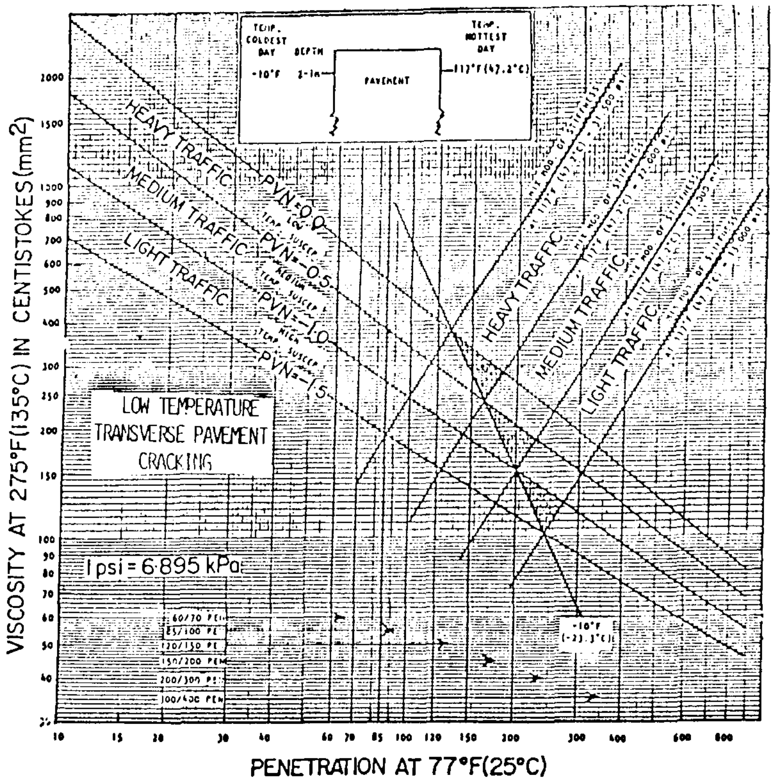

Figure 29: illustrating Selection of Combinations of Temperature Susceptibility (PVN) and Penetration at 25°F for Paving Asphalts for Heavy, Medium and Light Traffic in Cold Climates.

penetration at 25 C (77 F) to withstand thermal cracking at any given minimum winter temperature. When other factors are equal, these still higher penetrations at 25 C (77 F) provide pavements with still lower stability for summer traffic. Therefore, when their lesser ability to withstand thermal cracking in winter and to provide adequate stability for summer traffic are considered, it is clear that these Group C asphalts of high temperature susceptibility should be limited to pavements for the light category of traffic. In addition, roads for light traffic are often lacking in foundation support that further justifies the limitation to pavements made with Group C asphalts.

However, if only Group A asphalts are available in any region, they are more than satisfactory for pavements for either the medium or light traffic category, and the same is true for Group B asphalts for pavements for light traffic. On the other hand, by the incorporation of small percentages of a suitable polymer, the temperature susceptibility of a Group B paving asphalt can be improved to that of Group A, and the temperature susceptibility of a Group C as-

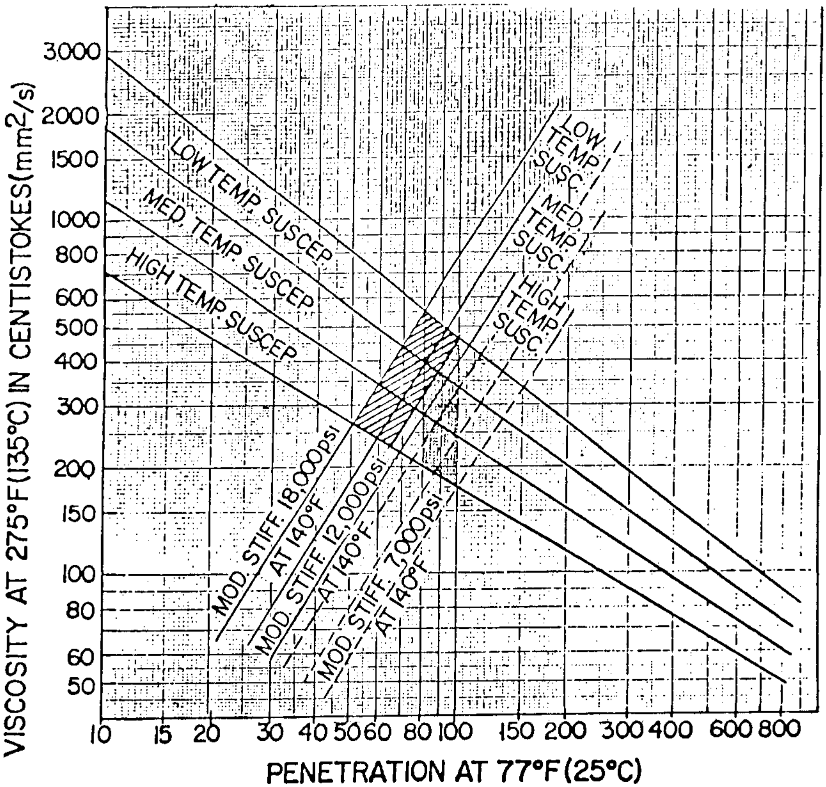

Figure 30: Illustrating How Paving Asphalt Temperature Susceptibility Can be Made to Work For or Against Engineers in Warm Climates.

phalt can be improved to that of either Group B or Group A. Therefore, when required, the temperature susceptibilities of either Group C or Group B asphalts can be easily improved to that of Group A or Group AA by incorporating a small percentage of an appropriate polymer to make them suitable for pavements for the higher traffic category.

(b) Paving Asphalt Selection for Climates Without Frost

Figure 30 illustrates the proper selection of paving asphalts in climates where there is no frost.

At present, paving asphalts for any paving project in these climates is generally specified as a single grade, for example, 85/100 penetration, without the slightest regard for the asphalt's temperature susceptibility.

As illustrated by Figure 30, one solution for this problem, Van der Poel's nomographs (*12,13*), requires that as the temperature susceptibility of the asphalt increases, its penetration at 25 C (77 F) must be decreased in order to provide a constant pavement stability (modulus of stiffness) as follows:

(a) 80/100 penetration asphalt, if its PVN is 0.0
(b) 70/86 penetration asphalt, if its PVN is -0.5
(c) 60/75 penetration asphalt, if its PVN is -1.0
(d) 50/65 penetration asphalt, if its PVN is -1.5

Although in this case, the paving asphalt of 80/100 penetration at 25 C (77 F) and the 50/65 penetration asphalt, for example, both provide the same pavement stability at a temperature of 60 C (140 F), the 50/65 penetration asphalt could be expected to be much harder (lower penetration at 25 C (77 F) in pavement service after 10 years for instance, than the originally softer 80/100 penetration asphalt.

This greater hardening of particularly the 50/65 and 60/75 penetration grades of higher temperature susceptibility, could be avoided by incorporating into these grades a small percentage of an appropriate polymer, Figure 31, to increase their penetrations at 25 C (77 F) to 80/100 penetration within the Group A or even Group AA category of low temperature susceptibility.

PAVEMENT RUTTING

Paving asphalts have two basic properties, elastic and viscous, depending on temperature and time of loading. Under fast traffic even on a warm day, the asphalt binder in a pavement can perform very largely as an elastic material. However, in parking areas where pavements are subject to stationary tire loadings for long periods of time, the viscous property of the asphalt becomes important, and because of its viscous flow under load, the pavement can begin to rut. Therefore, apart from the important role played by the aggregate, pavement rutting is associated with the viscous property of paving asphalts. The viscous resistance of an asphalt binder can be increased by increasing its viscosity. Therefore with all other mix variables the same, because of their higher viscosity at 135 C (275 F), for the same penetration at 25 C (77 F), asphalts of low temperature susceptibility, Group A, can be expected to provide a pavement with higher viscous resistance than asphalts of medium temperature susceptibility, Group B. Similarly, Group B asphalts, in turn, can be expected to provide a pavement with more viscous resistance than asphalts of high temperature susceptibility (Group C). This is demonstrated by Figure 3.

Since, as shown by Figure 31, a paving asphalt's viscosity at 135 C (275 F) can be substantially increased by incorporating a small percentage of an appropriate polymer, providing it with a higher PVN, this treatment should provide a pavement with still greater resistance to rutting.

The Elastic Recovery Test indicates that paving asphalts treated with certain polymers (elastomers) are much more elastic than the untreated asphalt. This test is made on specimens formed in the ductility molds used for a normal ductility test. One mold is filled with a normal asphalt as a control, and another mold with a polymer modified asphalt. The ductility bath is maintained at a temperature of 10 C (50 F). The procedure for a normal ductility test is em-

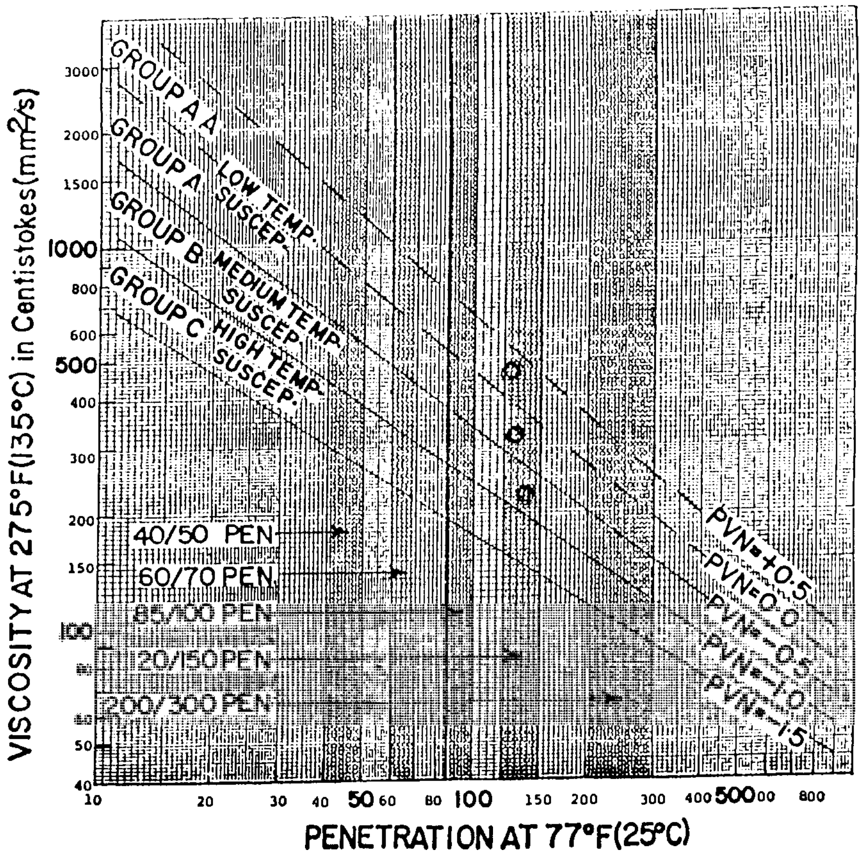

Figure 31: Illustrating How Small Percentages of an Appropriate Polymer can Improve the Temperature Susceptibility of a Paving Asphalt.

ployed when preparing the specimens. When brought to the test temperature of 10 C (50 F), the molds are placed on the pins of the ductility machine and pulled at a rate of 5 cm/min to a length of exactly 20 cm. They are maintained at this length for 5 minutes after which the ductility threads are cut in the middle into two equal segments of 10 cm each, and allowed to stand undisturbed for one hour. The threads are then brought together until the cut ends just touch, and their total length is again measured. The ductility thread of the normal asphalt is now from 90 to 95 percent of its original 20 cm length. The length of the thread of the polymer modified asphalt is from 20 to 40 percent of its original length of 20 cm, depending on the polymer (elastomer) employed. That is, because of elastic recovery, for the normal asphalt, its original length of 20 cm has contracted to from 18 to 19 cm, while for the polymer modified asphalt, its original 20 cm length has contracted to from 4 to 8 cm,

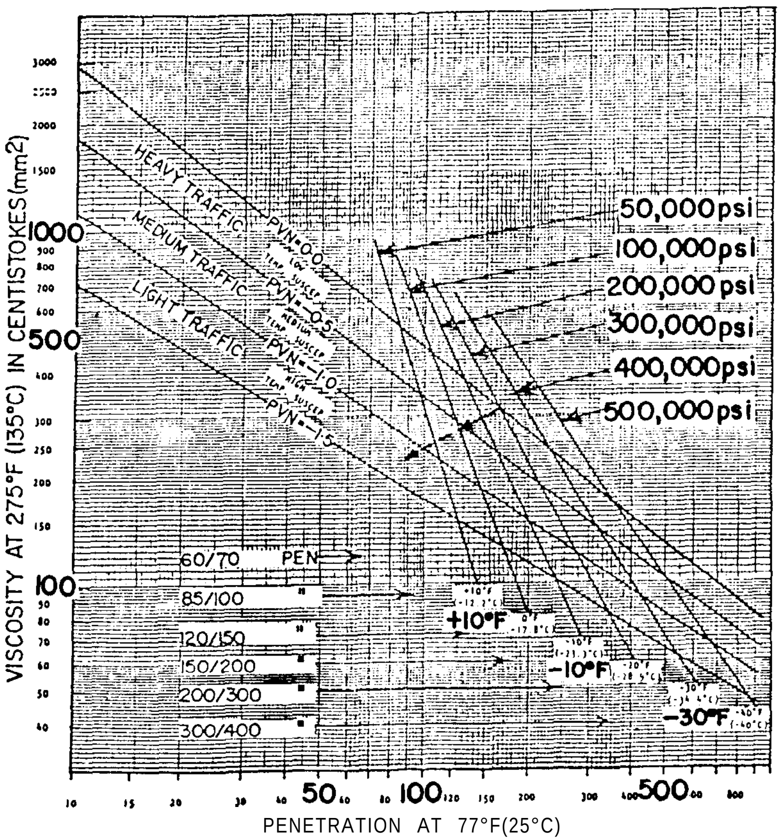

Figure 32: Illustrating a Possible Shift to a Lower Temperature at which Low Temperature Transverse Pavement Cracking Might Begin because of the Greater Elasticity of Certain Polymer Modified Aspahlts.

depending on the type and quantity of polymer incorporated. Therefore, the polymer modified asphalt normally has a very much higher elastic recovery than normal asphalts.

This at present is only a laboratory test. Its influence on pavement properties such as low temperature transverse pavement cracking and pavement rutting must still be determined by the performance of test pavements in the field. However, expressed briefly, the possible benefits of the use of certain polymer modified asphalts that are implied by the results of the Elastic Recovery Test would appear to be as follows:

(a) As illustrated by the arrow in Figure 32, it could result in a shift to the left to a noticeably lower temperature at which low temperature transverse pavement cracking would begin.

(b) This in turn would result in a shift of one or two grades toward lower penetration at 25 C (77 F), which in turn would provide a higher pavement stability for summer traffic.
(c) The increased elasticity of certain polymer modified asphalts should result in greater pavement resistance to rutting.
(d) The increased pavement stability at summer temperatures should also provide greater resistance to the rutting of pavements.

THE ROLE OF POLYMERS

Chiefly by lowering their temperature susceptibilities (increasing their PVN values) a number of polymers, when incorporated into a paving asphalt, can greatly increase the effectiveness of the polymer modified asphalt in pavements to attain or exceed each of the six objectives stated initially in this paper.

Figure 31, illustrates the role of polymers in this respect. The lowest small circle in Figure 31 indicates the temperature susceptibility, PVN = about -0.8, that has normally been available for paving asphalts marketed in Ontario in recent years. The incorporation of one percent of a certain polymer lowered its temperature susceptibility to a PVN of about -0.2, while two percent of the same polymer lowered its temperature susceptibility to a PVN of +0.4. A PVN value of +0.4 is well above the range of temperature susceptibility of normal paving asphalt from any crude oil produced in Canada at present, and this is also true for nearly all normal paving asphalts produced or marketed in the U.S.A.

Neither ASTM nor AASHTO has a temperature susceptibility requirement in its specification for paving grades of asphalt. Although Table 1 in these specifications permits the use of paving asphalts of higher temperature susceptibility than Table 2, nowhere in these specifications is any mention made of temperature susceptibility. From investigations of pavement failures in the U.S.A. that the writer has read, no mention of the temperature susceptibility is ever made.

In many cases, insofar as a completely informative report is concerned, ignoring the temperature susceptibilities of the paving asphalt that was used, is like sending a boxer into the ring with one hand tied behind his back. All the information, for example, as illustrated by Figure 3, required for a thorough explanation of the pavement failure is not being employed.

I am quite aware that aggregates, voids properties, stability, flow index and good or poor pavement design and construction practice all have an influence on pavement performance. This is not a paper on paving mixture design and construction practice. However, assuming that all variables referred to above, except the asphalt cement, have been adequately provided for, this paper attempts to indicate the very important influence on good pavement performance that is provided by the paving asphalt's penetration at 25 C (77 F) *and its temperature susceptibility as measured by its PVN value.*

In the U.S.A., since no mention of temperature susceptibility is made in either ASTM or AASHTO specifications, it appears that in general, paving asphalts in Group A, low temperature susceptibility, Group B, medium temperature susceptibility, and Group C, high temperature susceptibility, are selected indiscriminately for pavement design regardless of the traffic category, heavy, medium, or light, the pavement is to carry. Therefore, Group C paving asphalts of high temperature susceptibility, or Group B paving asphalts of medium temperature susceptibility compete on an even footing with Group A paving asphalts for pavements for heavy traffic. Similarly all three Groups, A, B or C, compete on an even footing for pavements for any other traffic category.

U.S. Highway Departments pay a heavy price for this misunderstanding in the form of millions of dollars for filling cracks that should never have been there in the first place, and other millions of dollars in the form of shortened pavement service lives. They will continue to do so until they recognize the need for specifying the temperature susceptibility of paving asphalts as outlined in Figure 27 or in Appendix B(2). They must recognize in particular, that in general, only Group A asphalts should be permitted for heavy traffic, Group B asphalts for medium traffic, and Group C paving asphalts for light traffic.

In Canada, cold winter temperatures have forced us to recognize the need for softer asphalts in terms of *both* penetration at 25 C (77 F) and temperature susceptibility to avoid or reduce low temperature transverse pavement cracking. Consequently, most provincial paving asphalt specifications completely reject Group C paving asphalts of high temperature susceptibility. However, we still do not write paving asphalt specifications for each particular paving site as we should, and we still allow Group B asphalts of medium temperature susceptibility to be used for pavements for heavy traffic, where in general, only Group A asphalts of low temperature susceptibility should be permitted, if pavement rutting it to be avoided.

The writer believes there is a place in our highway construction programs for all three groups of paving asphalts, Group A, B and C. Roads to carry light traffic seldom have a uniformly adequate foundation. Therefore, provided they are selected with care for the minimum penetration at 25 C (77 F) and minimum viscosity at 135 C (275 F) required for the minimum winter temperature at the job site, Group C asphalts should provide pavements with satisfactory service. For medium traffic, the road foundation is usually better designed and constructed, and the selection of a Group B asphalt at the correct minimum penetration at 25 C (77 F) and minimum viscosity at 135 C (275 F), for the minimum winter temperature associated with the pavement site, should provide a pavement with good service performance. For heavy traffic the road foundation is or should be uniform and firm and the selection of a Group A asphalt of a minimum penetration at 25 C (77 F) and minimum viscosity at 135 C (275 F), appropriate for the expected minimum winter temperature, should be mandatory to provide the stability required for summer traffic, and to avoid pavement rutting.

As stated previously, in any region where only Group A asphalts are available, they are more than satisfactory for pavements for either medium or light traffic categories. If only Group B asphalts are available, they are equally suitable for pavements for light traffic. On the other hand, by the addition of small percentages of an appropriate polymer, the temperature susceptibility of

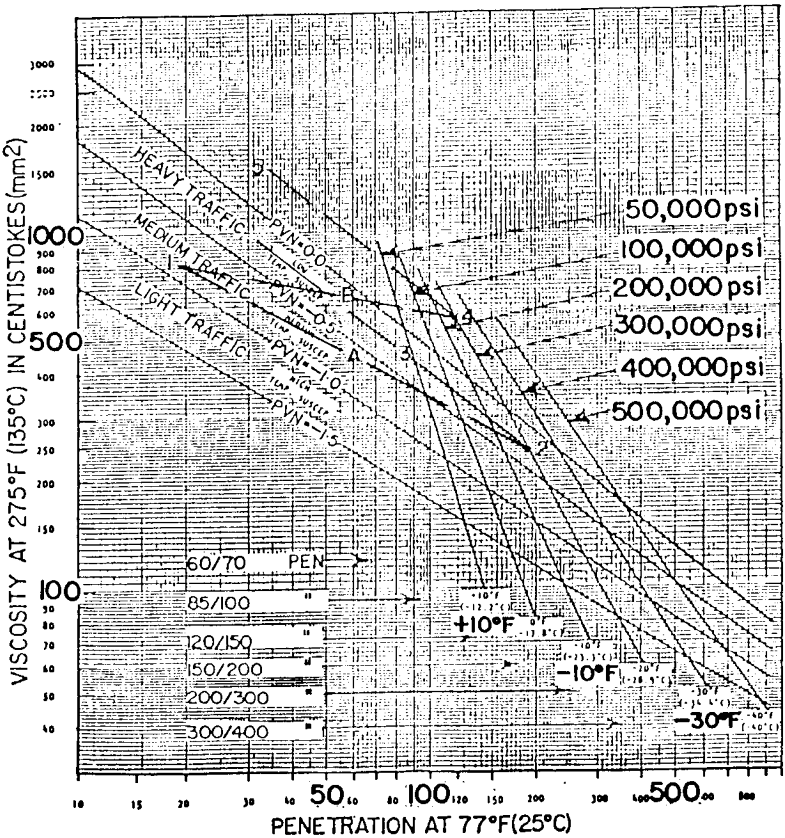

Figure 33: Illustrating a Rational Method for Pavement Recycling in Regions Subject to Freezing.

a Group B paving asphalt can be improved to that of a Group A asphalt when required, and the temperature susceptibility of a Group C asphalt can be improved to that of either Group B or Group A, whenever a specification calls for a Group B or a Group A paving asphalt.

For anyone who is further interested in the broad scope and present status of polymer modified paving asphalts, the low-key, comprehensive and concise paper by Gayle King and associates (*27*) is recommended.

PAVEMENT RECYCLING

(a) Pavement Recycling in Cold Climates

Avoidance of low temperature transverse pavement cracking is as important after pavement recycling, as it should have been for the original pavement.

Suitable guidelines to achieve this do not appear to be in use at the present time. However, recognition of paving asphalt temperature susceptibility seems to offer a promising approach to this problem, as illustrated in Figure 33, for pavement recycling in cold climates.

The background for Figure 33 is Figure 28, which illustrates the selection of bitumens for original paving mixtures to avoid low temperature transverse pavement cracking throughout the service life of a pavement. For Figure 33, it is assumed that the minimum winter pavement temperature at Location 1 in some given area is -28.9 C (-20 F). Location 1 is the site of the proposed recycling project because the existing pavement shows serious low temperature transverse pavement cracking and other evidence of severe pavement distress.

Ordinarily, everyone will have forgotten what the characteristics of the original asphalt binder were when the badly cracked pavement at Location 1 was constructed many years ago, which upon extraction is found to have a penetration of 20 at 25 C (77 F) and viscosity at 135 C (275 F) of 820 centistokes, (PVN = -0.9). This indicates that the asphalt binder in this pavement is of medium temperature susceptibility, or in Group B category, (PVN = -0.5 to -1.0).

It is assumed that the recycled pavement is to carry much more traffic, and that it is to be designed for the heavy traffic category in Figure 33. For the middle of the heavy traffic band (PVN = -0.25), and for a minimum winter pavement temperature of -28.9 C (-20 F), Figure 33 indicates that this would require a bitumen of 180 penetration at 25 C (77 F) and viscosity at 135 C (275 F) of 250 centistokes (PVN = -0.25), and would be in the Group A traffic category (Point 2). This would be provided by Treatment A, consisting of a single or a combination of softening agents that would change the penetration from 20 at 25 C (77 F), and a viscosity of 820 centistokes at 135 C (275 F), in the old pavement, to a penetration of 180 at 25 C (77 F) and a viscosity of 250 centistokes at 135 C (275 F), (PVN = -0.25), in the recycled paving mixture. A large assortment of softening agents, including soft asphalts and commercial modifiers is available to the designer for this purpose.

After this treatment, according to the finger print effect, the asphalt binder in the recycled pavement would slowly harden in service as indicated by Line 3 in the heavy traffic category of Figure 33.

The engineer responsible for the recycled pavement project might decide that Treatment A resulting in an asphalt binder of 180 penetration at 25 C (77 F) and a viscosity of 250 centistokes at 135 C (275 F) (PVN = -25), would not have the required minimum stability at summer temperatures for the anticipated heavier traffic. He might therefore, favor Treatment B, for example, for the recycled pavement, to provide a bitumen with a penetration at 25 C (77 F) of 120 and a viscosity at 135 C (275 F) of 575 centistokes (PVN = +0.5), Point 4. This would also avoid low temperature transverse cracking at -28.9 C (-20 F) throughout the pavement service life of the pavement if it were properly designed and constructed.

It would be difficult to locate a normal combination of softening agents that could change the penetration of 20 at 25 C (77 F) for the bitumen in the old pavement to 120 penetration at 25 C (77 F), in the recycled pavement and at

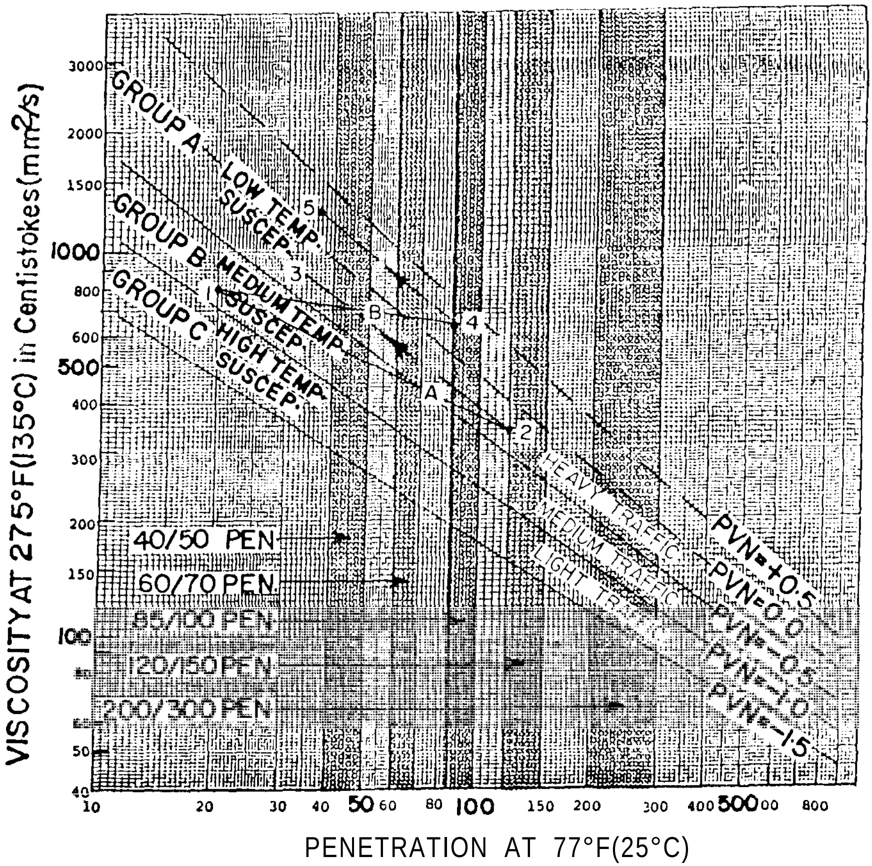

Figure 34: Illustrating a Rational Method for Pavement Recycling in Warm Climates Without Freezing.

the same time increase the bitumen's PVN from -0.9 to +0.5. Therefore this might require the addition of a suitable polymer.

Following Treatment B, and in accordance with the finger print effect, the bitumen in the recycled paving mixture could be expected to gradually harden in service along Line 5 within the heavy traffic portion of Figure 33.

A similar method would be required for pavement recycling for other minimum winter pavement temperatures illustrated in Figure 33.

(b) Pavement Recycling in Climates Without Frost

Figure 34 indicates a similar approach to the design of recycled paving mixtures for a given region that is free from frost. For the bitumen recovered from an old pavement, by determining its penetration at 25 C (77 F) and its viscosity at 135 C (275 F), and plotting these data as a point on Figure 34, the temperature susceptibility (Group A, B or C) to which the bitumen in the old pavement belongs, can be very quickly established. The background of Figure 34 is that of Figure 28.

Suppose for example, the recovered bitumen has a penetration of 20 at 25 C (77 F), and that it lies in Group B (PVN = -0.5 to -l.0), which is suitable for medium traffic, Point 1. Because of increased traffic on this old pavement, the engineer has decided to design the recycled pavement for the heavy traffic category for which a Group A bitumen is required, for example 120 penetration at 25 C (77 F) and a minimum viscosity of 340 centistokes at 135 C (275 F). By adding an appropriate softening agent or group of softening agents (Treatment A) the bitumen of 20 penetration and Group B can be softened to a Group A asphalt of 120 penetration as shown by Point 2 on Figure 34. After reconstruction the bitumen in the recycled pavement will remain in Group A and will harden in service along Line 3, if it conforms to the finger print principle.

However, after further consideration, the engineer may decide that he requires a harder bitumen of 85 penetration at 25 C (77 F) with a still lower temperature susceptibility (higher PVN), for the recycled paving mixture to carry the anticipated traffic loading. In this case, starting with the recovered bitumen of 20 penetration from the old pavement, and incorporating the softening material or materials indicated by Treatment B, he may soften the 20 penetration bitumen recovered from the old pavement to a penetration of 85 at 25 C (77 F) and with a PVN of +0.3, in the recycled paving mixture, Point 4 on Figure 34. However, because a PVN of +0.3 is higher than normal paving bitumens or other softening agents can provide, he may have to incorporate a small percentage of a suitable polymer to achieve a PVN of +0.3. This may also be necessary for Treatment A. After Treatment B, the bitumen in the recycling paving mixture can be expected to harden in service along Line 5 (finger print effect).

Because of the addition of the required softening materials, the bitumen content of a 100 percent recycled paving mixture would probably be too high for adequate stability and resistance to rutting, and the incorporation of new aggregate would most likely be necessary. In this case, the proportion of old pavement in the recycled paving mixture would have to be reduced. This however, would have the advantage of providing an opportunity for correcting any deficiency is the gradation of the old pavement to be recycled.

For cold mix pavement recycling, Treatments A or B, etc., can be applied in the form of an emulsion.

Figure 35 indicates that about six months time is required for an asphalt emulsion to thoroughly cure and to develop the pavement stability that its base asphalt would develop if it were used in a hot paving mixture (28). Figure 36 provides data on cured Types I, II and III emulsified asphalt paving mixtures made with increasingly inferior aggregates. The stabilities of the fully cured asphalt emulsion mixes are shown to compare favorably with corresponding hot-mixes (28).

Because of the fluxing action between the old bitumen and the softening agent that has been applied, the time to cure in cold recycling will probably be

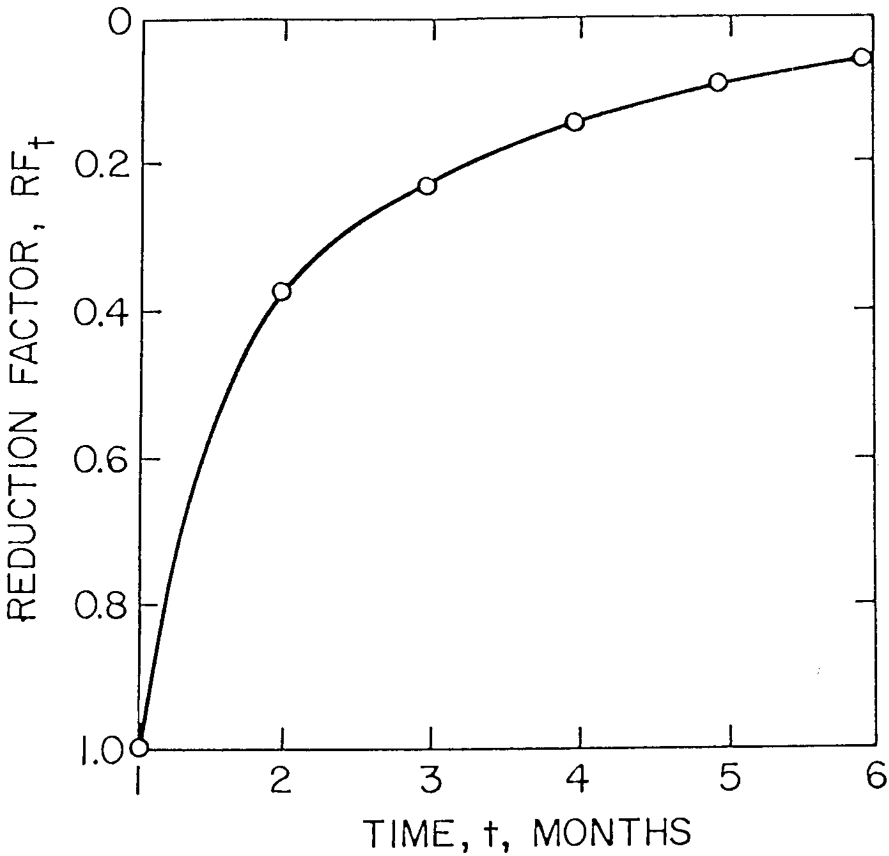

Figure 35: Demonstrating that a Curing Period of about Six Months is Required for an Asphalt Emulsion Mix to Develop its Full Strength.

longer than is indicated by Figures 35 and 36. This may also be true for hot-mix recycling.

MONITORING PAVEMENT RECYCLING

Tables 2, 3, 4, 7, 8 and Figure 26 indicate that PVN provides user agencies with an entirely new and extremely useful method for monitoring the construction of new pavements including recycling. The PVN of asphalt recovered after pavement construction should be the same, or very nearly the same (experimental error) as the PVN of the original asphalt that was selected for the pavement design. As stated earlier in this paper, the PVN of a paving asphalt does not change with either time or temperature in pavement service. At present, the only method available to user agencies to monitor the asphalt recov-

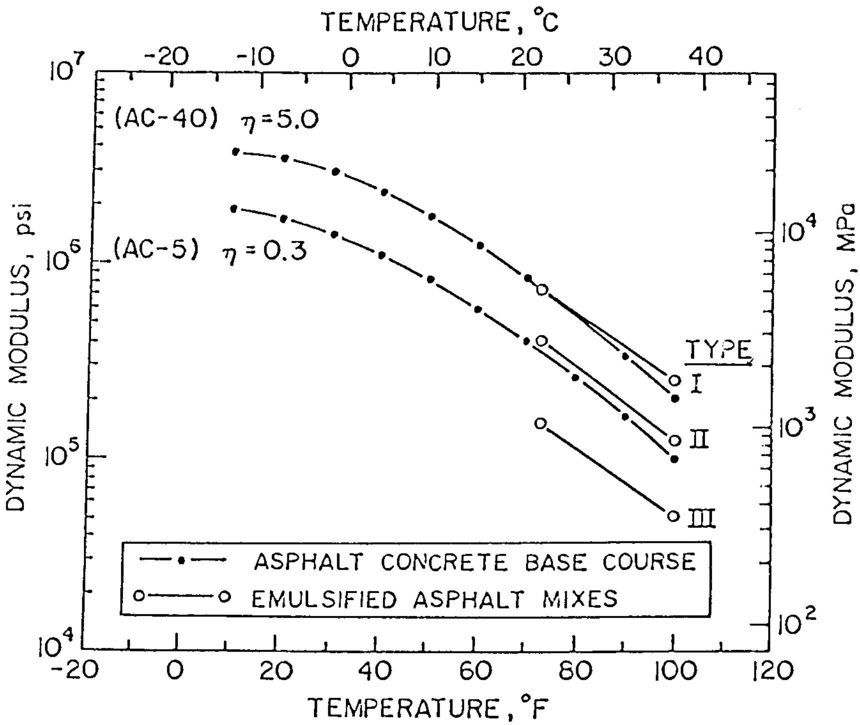

Figure 36: Demonstrating that Depending on its Type (I, II, or III) an Asphalt Emulsion Mix Eventually Develops Strength Equivalent to that of a Corresponding Hot-Mix.

ered from a pavement after construction, has been to compare its penetration at 25 C (77 F) with that of the asphalt employed for the pavement design. To obtain the PVN of the recovered asphalt, only the measurement of its viscosity at 135 C (275 F) is required in addition to the measurement of its penetration at 25 C (77 F). Determining the PVN of the recovered asphalt provides completely different information from the measurement of its penetration at 25 C (77 F).

The use of PVN to monitor the construction of a recycled pavement is of particular value to user agencies, because unknown to the user, more RAP (recovered asphalt pavement) may be added by a contractor to the recycled mix than the design calls for. For example, when the asphalt recovered from the RAP has a lower PVN than that of the final blend of old (RAP) asphalt and new asphalt plus commercial softeners, if any, employed as the asphalt binder for the recycled mix, an increase in the percentage of RAP added to the recycled mix will lower the PVN of the recovered asphalt, and can be quickly detected. This would not be so easily detected by the penetration at 25 C (77 F) alone. In any case, the two tests can be used to reinforce each other.

All of this is illustrated in Tables 7 and 8 which provide data on an overseas 6-lane highway project that was built in two stages. Three lanes were constructed as Stage 1 and 10 years ago and the other three lanes were added over the period between 1981-83. The data in Table 8 pertains to Stage 1 and to a section of Stage 2, both of which were built by the same contractor. For Stage, 1 80/100 penetration asphalt, Group A, was used and the pavement is still in very good condition. For the portion of Stage 2 built by the same contractor, the asphalt was changed to 60/70 penetration. Because of either a shortage of asphalt at the time, or for economic reasons, the contractor found a second source of asphalt, Supplier 2, at lower cost. It had a penetration of 40/80 at 25 C (77 F), was also a Group A with a PVN value between 0.0 and -0.5, but had a ductility at 25 C (77 F) that was well below 100 cm, which was specified, as shown by the inspection data given in Table 7.

As demonstrated by Table 7, by blending 60 percent of Supplier l's 80/100 penetration with 40 percent of Supplier 2's 40/80 penetration, the ductility requirement could be met, and this blend still belonged to Group A, PVN = 0.0 to -0.5. For the samples submitted to us however, as shown by Table 7, the penetration at 25 C (77 F) was 83 instead of being 60/70. Other samples of this blend may have been 60/70 penetration, and in any case this 60:40 blend was supposed to have been used for the paving project. The blending operation was conducted in a crude mixing unit at the hot-mix plant. Consequently, as shown by the penetration data in Table 8 on asphalt recovered from the Stage 2 pavement samples, the actual asphalt being blended appears to have varied all the way from 100 percent of the original 40/80 penetration from Supplier 2 to 100 percent of the original 80/100 penetration from Supplier 1. Table 7 lists inspection data for Supplier 2's 40/80 penetration asphalt for 3: 1, 1: 1, 40:60, and 1:3 blends of the 40/80 penetration and Supplier l's 80/100 penetration. These blends were all Group A asphalts and as stated earlier, it was decided to use the 40:60 blend of 40/80 and 80/100 penetration asphalts, since probably other samples than those we received, when blended in these proportions, were of the 60/70 penetration specified for Stage 2. Data are also included for two samples of Supplier l's 60/70 penetration asphalt which had PVN values of -0.96 and -0.88, which belong to Group B and are bordering on Group C. The pavement placed on this portion of Stage 2 by this contractor rutted very badly and had to be replaced.

Incidentally, it should be observed that for each of the asphalts and asphalt blends referred to in Table 7, the PVN values for the asphalts and for their blends, and for their Thin-film Oven Test Residues are practically identical.

For Stage 1, where the original paving asphalt was 80/100 penetration and belonged to Group A with a PVN within the range of 0.0 to -0.5, the recovered asphalt from all five randomized sample locations for both surface and base course was still Group A with a PVN value within the range of 0.0 to -0.5. Consequently, this is another example, in addition to these referred to earlier, where the PVN values of the recovered asphalts have remained unchanged from the original PVN values, over a service period of eight years. The penetration values at 25 C (77 F) for the recovered asphalts from the Stage 1 samples vary between 19 and 26 which are also very consistent.

For Stage 2, the original asphalt, 60/70 penetration, was also supposedly Group A with a PVN of -0.14 (Table 7), and the recovered asphalt from pavement samples should also have been Group A with a PVN of 0.0 to -0.5. However, for the base course at sample Locations 8, 16 and 17 the recovered asphalt was Group B with PVN values of -0.81, -0.63 and -0.64 respectively; and for the surface course at sample Locations 8, 16, 18 and 21, the recovered asphalt was also Group B with PVN values of -0.95, -0.63, -0.62 and -0.68, respectively. At Location 8 for example, where PVN values of -0.95 and -0.81 were obtained for the surface and base, respectively, this could have happened if the original 60/70 penetration asphalt had been obtained from Supplier 1, since two samples of this material are shown in Table 7 to have had PVN values of -0.96 and -0.88.

The data for Stage 2 in Table 8 illustrates what is happening to recycled pavement construction in North America at the present time. RAP obtained from several probably often widely different locations and with quite different PVN values for the recovered asphalts, is being deposited at random in the same stockpiles. For hot-mix recycling at least two asphalts are usually employed, the hard asphalt recovered from the old pavement, RAP, and the new softer asphalt, with or without modifiers. The recommended blend of these old and new asphalts will have a certain PVN value and a certain penetration at 25 C (77 F). Since the PVN of the asphalt recovered from the RAP will in most cases be less than the PVN of the asphalt blend used for the design of the recycled mix, to maintain a constant PVN value before and after construction means that very close control of the PVN of the asphalt recovered from the RAP going into the recycled mix will be needed. Separate stockpiles of RAP, each with a relatively constant PVN value will be required. Furthermore, no longer will contractors be able to change the percentages of RAP at will in the recycled mix, since this will change the PVN of the asphalt recovered after recycled pavement construction. Consequently, PVN values provide a very powerful new tool for user agencies to employ for the control of recycled pavement construction.

For pavement recycling, if a pavement was originally designed for light traffic and a Group C asphalt of high temperature susceptibility was used, when recycled, because of increasing traffic, the pavement should be designed for medium traffic at least, and a Group B asphalt of medium temperature susceptibility should be employed. If the pavement was designed initially for medium traffic and a Group B asphalt of medium temperature susceptibility was specified, when recycled it should usually be designed for heavy traffic and Group A asphalt of low temperature susceptibility should be required. The need for this is illustrated in Figure 3 which shows that with everything else being equal, as the temperature susceptibility of an asphalt is decreased from high to medium to low, thermal cracking begins at a lower and lower temperature, pavement stability under summer traffic is increased, and resistance to pavement rutting is greatly improved. For each of the above cases, when necessary to achieve a lower temperature susceptibility, an appropriate polymer can be employed to change the temperature susceptibility of a Group C asphalt to that of either a Group B or Group A, or improve the temperature susceptibility of a Group B asphalt to that of a Group A or Group AA, or to change the temperature susceptibility of a Group A asphalt to that of Group AA.

Axle loads have increased, the use of radial tires has greatly elevated tire pressures on pavements, petroleum refiners are running crude oils for their distillates and the asphalts produced do not always have the properties required.

With the exceptions noted earlier in this paper, no longer will a paving asphalt manufacturer be able to sell any asphalt just as it comes from the bottom of a vacuum tower and market it indiscriminately for heavy, medium and light traffic. The user agencies, whenever they elect to do so, are now in a position to employ Group C asphalts of high temperature susceptibility in pavements for light traffic, Group B asphalts of medium temperature susceptibility in pavements for medium traffic, and to demand and obtain Group A or Group AA asphalts of low temperature susceptibility in pavements for heavy traffic, Figures 3 and 27. The introduction of polymer modified paving asphalts has changed control of the marketing of paving asphalts from the manufacturer to the user. For the first time, the user can obtain paving asphalts with the engineering properties required for any paving project. If the paving asphalt from the bottom of the vacuum tower does not have the temperature susceptibility required, it can be easily obtained by the incorporation of a small percentage of a suitable polymer. From the user's point of view, this is chiefly a matter of the cost versus benefits ratio, namely, comparing the greater cost of polymer modified asphalt with the savings resulting from reduced thermal cracking, higher pavement stability for summer traffic, reduction in pavement rutting, and better performance of recycled pavements.

The attitude toward the manufacture and marketing of paving asphalts must change just as it did for lubricants. No salesman for lubricants today, would think of trying to sell a raw lubricating oil fraction just as it comes from a vacuum tower. It must be further refined and appropriate additives incorporated to provide the properties required for various uses as lubricants. It is just beginning, but something similar is starting to happen for the production of improved paving asphalts, particularly to improve their temperature susceptibility properties, or PVN values, that have been ignored far too long.

PVN AND SURFACE TREATMENTS (CHIP SEALS)

Asphalts emulsions are generally favored for surface treatments in North America at the present time. In the USA, with regard to chip seals, for the emulsion distillation residue, both ASTM and AASHTO require a minimum penetration of 100 at 25 C (77 F). In Canada, a minimum penetration of 100 at 25 C (77 F) is also usually specified for the distillation residue of an asphalt emulsion. In neither country is there a corresponding limit for minimum viscosity at 135 C (275 F). Therefore, in neither country is a corresponding minimum PVN value specified for an emulsion distillation residue.

This means that in both the USA and Canada, the distillation residue from an asphalt emulsion could belong to Group A, PVN = 0.0 to -0.5, low temperature susceptibility, to Group B, PVN = -0.5 to -1.0, medium temperature susceptibility, or to Group C, PVN = -1.0 to -1.5, high temperature susceptibility. In turn, this means, as shown by Figures 3 and 27, that for asphalts of the same penetration at 25 C (77 F), at all temperatures above 25 C (77 F) the temperature susceptibility of the emulsion distillation residue could range from high, Group C, high temperature susceptibility, to medium, Group B, medium temperature susceptibility, or to low, Group A, low temperature susceptibility. Similarly, at all temperatures below 25 C (77 F), the consistency of the emulsion distillation residue could vary from hard, Group C, high temperature susceptibility, to substantially softer, Group B, medium temperature susceptibility, to still softer, Group A, low temperature susceptibility. Therefore, when the emulsion distillation residue belongs to Group C, at all temperatures above 25 C (77 F), surface treatments containing these emulsions can be expected to have the least stability, and the greatest tendency to flush or bleed. They would also be the hardest at all temperatures below 25 C (77 F), and surface treatments made with these emulsions would be candidates for most thermal cracks. At the other extreme, if the emulsion distillation residues belong to Group A, at all temperatures above 25 C (77 F), surface treatments made with these emulsions should have the highest stability and the least tendency to flush or bleed. At all temperatures below 25 C (77 F), surface treatments containing these emulsions would have the least tendency for thermal cracking. When the emulsion distillation residue belongs to Group B, medium temperature susceptibility, at all temperatures either above or below 25 C (77 F), surface treatments made with these emulsions should have service performance properties superior to those of Group C but inferior to those of Group A. Consequently, the above information indicates that the most serviceable surface treatments should be those for which the emulsion distillation residues belong to Group A.

It has been shown earlier in this paper that the addition of small percentages of appropriate polymers can improve the temperature susceptibility of a Group C asphalt to that of a Group B or Group A, and of a Group B to Group A. If required, a small percentage of a suitable polymer can also improve the temperature susceptibility of a Group A asphalt to Group AA.

In addition, this paper demonstrates the need for a meaningful minimum viscosity at 135 C (275 F), or a significant minimum PVN value, in ASTM, AASHTO and Canadian specifications for emulsion distillation residues for chip seals, as well as a minimum penetration at 25 C (77 F).

ITEMS FOR FURTHER INVESTIGATION

The data presented in this paper, while unanimous in their support of the conclusions presented, are limited in number, and further investigation is required either for or against these findings. Some of the items requiring more study are the following:

1. While PVN values for the considerable number of asphalts referred to in the paper support the concept of PVN being an asphalt finger print that does not change with either time or temperature in pavement service, more data are required for a larger number of asphalts produced by steam or vacuum dis-

tillation from a much wider range of crude oils to either support or modify this conclusion.

2. The PVN value for any paving asphalt is presently based on penetration at 25 C (77 F) and viscosity in centistokes at 135 C (275 F). This is due to the abundance of these data that are available on paving asphalts. However, other combinations of penetration and viscosity might provide still more accurate values of PVN, particularly at the extremes of consistency of paving asphalts. Combinations of penetrations at 10 C (50 F), 15.6 C (60 F), 25 C (77 F) and 37.8 C (100 F) with corresponding viscosities at 121.1 C (250 F), 135 C (275 F) and 148.7 C (300 F) should be investigated. For example, combinations of penetration at 37.8 C (100 F) with viscosity in centistokes at 148.7 C (300 F) might be more useful for calculating PVN values for quite hard asphalts recovered from some aged pavements for recycling, while combinations of penetration at 10 C (50 F) with corresponding viscosity at 12 1.1 C (250 F) might provide a more accurate measure of PVN for the softer asphalts now used for recycling.
3. Table 6 indicates that small percentages of added refinery crude wax, more than two percent, incorporated into a normal paving asphalt, can make the PVN of the normal asphalt deviate away significantly from the PVN value given by Figures 13, 14 and 27, for a corresponding "wax free" asphalt. In North America, we depend on a minimum ductility of 100 cm, 5 cm/min, at 25 C (77 F) to provide paving asphalts that are relatively free from wax, although this criterion provides no data on the actual wax content of the asphalt. However, hard asphalts of about 30 penetration at 25 C (77 F), are often too brittle at this temperature and the ductility briquettes fracture when the ductility molds are extended by a very small amount, often less than one cm. Consequently, the ductility test cannot be used as a significant indicator for wax removal for these hard asphalts, which may be recovered from RAP. Also, for paving asphalts that are quite soft, e.g. 300/400 penetration at 25 C (77 F), meaningful ductility values cannot be measured at 25 C (77 F), although significant ductility values may be given if a test temperature of 60 F (15.6 C) is employed.

   In Europe, a maximum wax content, determined by a standard wax content test, is sometimes specified for paving asphalts. This presumably gives the total percentage of wax in a paving asphalt sample.

   PVN appears to be such a useful concept for paving asphalts that an investigation of the ductility test at different temperatures and different rates of pull, and of the actual wax content by a suitable standard test method, would appear to be necessary to obtain the critical wax content at which the PVN of a normal paving asphalt begins to diverge significantly from the corresponding PVN value obtained from Figures 13, 14 and 27 for "wax free" paving asphalts.
4. Figure 28 illustrates a finding that is intended to facilitate the selection of paving asphalts for sites with various minimum winter temperatures, that will avoid low temperature transverse pavement cracking for the service life of a pavement, which is assumed to be 20 years. More data are needed to fine tune Figure 28 and to revise it if necessary.

5. Further data are needed to confirm or revise Figure 29 which attempts to show that an asphalt selected to avoid low temperature transverse pavement cracking at any minimum winter temperature, will provide a pavement with sufficient stability to carry summer traffic. Will the pavement have adequate stability for light, medium or heavy traffic? If only light traffic can be carried, can the pavement stability be further increased for medium or heavy traffic by the incorporation of a small percentage of a suitable polymer to provide a polymer modified asphalt?
6. Reference is made in the paper to the "Elastic Recovery Test", which shows that by incorporating an appropriate polymer into a normal asphalt, the elastic recovery of the polymer modified asphalt can be from 60 to 80 percent of its original stretched length of 20 cm, depending on type and quantity of polymer, versus an elastic recovery for a normal asphalt of only 5 to 10 percent. At present, this is only a laboratory test, but it implies a marked reduction in the minimum winter temperature at which low temperature transverse cracking begins. It also implies a much greater resistance to pavement rutting than can be provided by normal paving asphalts.
7. For the same reasons, the use of polymer modified asphalts for pavement recycling requires investigation.
8. It has been shown that the PVN of the asphalt blend (recovered from the RAP and the added asphalt including other softening agents, if any) used for the design of a recycled paving mixture, and the PVN of the asphalt recovered from the recycled pavement after construction should be very nearly the same. At present, RAP from several completely different sources is being added to the same stock pile. This can result in widely different PVN values for the asphalt recovered from samples of RAP taken from different points in the stockpile. As a consequence, an investigation is required to determine the best way to handle RAP so that the PVN values of the asphalt recovered from random samples taken from the RAP stockpile are approximately constant.
9. The advantages of Group A asphalts for surface treatment operations should also be a subject for inquiry because of the benefits it appears to offer over the use of the Group B and Group C asphalts now commonly employed in asphalt emulsions for surface treatments. This includes examining the use of appropiate polymers for improving the temperature susceptibilites of Group C and Group B asphalts to that of Group A or Group AA for the asphalt base for these emulsions.

WARNING! DANGER!

New asphalt pavements or overlays, that have been designed to avoid pavement cracking throughout their service lives, should never be placed on a badly cracked asphalt or portland cement pavement, because the cracks in the underlying surface will very quickly reflect through the new pavement.

In their 1988 AAPT paper, Haas and Phang (29) have indicated that if through poor design (usually through poor asphalt binder selection), low temperature transverse pavement cracking is going to develop in the new pavement, this cracking is normally initiated at the surface of the new pavement by contraction stresses due to low winter temperatures, because its immediate surface is subjected to the lowest temperature. With the successive thermal contraction and expansion stresses due to the cycles of higher and lower temperatures, these cracks gradually propagate downward through the full depth of the new pavement.

On the other hand, when a new pavement is placed on a cracked asphalt or portland cement pavement, thermal cracks, due to excessive contraction and expansion stresses in the old pavement caused by cycles of higher and lower temperatures, are initiated at the bottom of the new pavement at its interface with the old pavement, and are very quickly propagated upward completely through new pavement.

Therefore, to obtain the most serviceable crack-free performance from a carefully designed and constructed new pavement, it should be built on a properly designed and thoroughly compacted granular base course or equivalent.

SUMMARY

1. This paper should be read as though much of the data presented are being spoken by the pavements in service in response to all of the varied environmental conditions to which they are exposed, *and not as being given* by some sanitary laboratory test or group of laboratory tests that try to tell the pavements how they *should be responding* to these conditions *but quite obviously are not doing* so. In other words, find out first what a pavement in service can tell about a problem, *and then use this as the basis* for the laboratory investigation, and not vice versa.
2. This paper explains that the use of paving asphalts of lower temperature susceptibility (higher PVN values) could:
   a) improve paving asphalt specifications.
   b) increase pavement stability under traffic in summer.
   c) avoid or greatly reduce low temperature transverse cracking in winter.
   d) greatly reduce or eliminate pavement rutting.
   e) provide a much more rational method for pavement recycling and its monitoring.
   f) provide surface treatments with improved service performance.
3. The temperature susceptibility of a paving asphalt is the change in consistency (penetration or viscosity) that the asphalt undergoes for a given change in temperature.
4. PVN as a measure of temperature susceptibility of a paving asphalt, is based on the penetration at 25 C (77 F) and the viscosity in centistokes at 135 C (275 F) of the asphalt.
5. Tables of data "spoken by" the pavements themselves are presented to show that *PVN values* of the original asphalts and of corresponding asphalts recovered from pavements up to from 20 to *30* years old, *remain constant regardless of time in service.* The same data also show that the *PVN values* of the original asphalts, of the corresponding residues from

the Thin Film Oven Test at 163 C (325 F) and of corresponding asphalts recovered from pavements in service up to from 20 to 30 years, also *remain constant regardless of temperature in service. This latter fact indicates that PVN is the best measure of paving asphalt temperature susceptibility that has been developed so far.*

6. It is shown that current mainstream paving asphalts can be divided into three groups of temperature susceptibility, those of low temperature susceptibility, Group A, PVN = 0.0 to -0.5, those of medium temperature susceptibility, Group B, PVN = -0.5 to -1.0, and those of high temperature susceptibility, Group C, PVN = -1.0 to -1.5.
7. A chart is presented with double-headed arrows to indicate either the direction of hardening of an original asphalt that will occur in a pavement in service, or the opposite direction through which hardening has already taken place in an aged pavement. The chart shows that Groups A, B or C asphalts remain essentially as Groups A, B or C asphalts respectively, throughout their pavement service lives.
8. A chart is provided in terms of PVN values that will enable paving asphalts to be selected that will avoid low temperature transverse pavement cracking throughout the service life of the pavement, in regions with a wide range of minimum winter temperatures. Another chart is provided in terms of PVN values, for the selection of paving asphalts for pavements that will avoid low temperature transverse pavement cracking, and will at the same time provide adequate stability for summer traffic.
9. For the avoidance of low temperature transverse pavement cracking, harder Group A asphalts (lower penetration at 25 C (77 F), PVN = 0.0 to -0.5, should be used for lowest minimum winter temperatures, somewhat softer, (higher penetration at 25 C (77 F)), Group B asphalts, PVN = -0.5 to -1.0, will give protection against thermal cracks for somewhat higher minimum winter temperatures, still softer (higher penetration at 25 C (77 F), Group C asphalts, PVN = -1.0 to -1.5, must be used to provide protection against thermal cracking at still higher minimum winter temperatures.
10. For the same protection against low temperature transverse pavement cracking, Group A asphalts should be used for heavy traffic, Group B asphalts can be used for medium traffic, and Group C asphalts can be used for light traffic. That is, as the temperature susceptibility of the paving asphalt increases, softer and softer paving asphalts, in terms of penetration at 25 C (77F) and corresponding viscosities at 135 C (275 F), must be used if low temperature transverse pavement cracking is to be avoided.
11. For climates without frost, to have a constant pavement stability as the temperature susceptibility of the paving asphalt increases, the asphalt penetration at 25 C (77 F) must become lower and lower (harder and harder).
12. Paving asphalts exhibit two different properties, elastic and viscous, depending on pavement temperature and time of loading. Under very rapid loading they can perform as purely elastic materials even at summer tem-

peratures, but under sustained loading, as in a parking area, their viscous property become important, viscous flow can take place and pavement rutting can begin. Consequently, as demonstrated by Figure 3, when all other factors are equal, the higher the viscosity at 135 C (275 F), that is, the higher the PVN of the paving asphalt, the greater will be the pavement's resistance to rutting.

13. In regions subject to frost penetration, either completely new or recycled pavements should be designed to avoid low temperature transverse pavement cracking at the minimum winter temperature at any pavement site throughout the service life of a pavement, and to provide adequate stability for summer traffic. Methods for achieving this are described in the paper.
14. A method is also described for the selection of paving asphalts for pavements in regions without frost, that points out the advantages of using Group A asphalts for this application.
15. For either new or recycled pavements, recognition that the PVN value of asphalts recovered from the pavement following construction should be the same as the PVN of the original asphalt used for the design of the paving mixture, provides user agencies with a powerful and highly useful new tool for monitoring the construction of these pavements.
16. It is shown that the performance of surface treatments would be greatly improved by using asphalts of lower temperature susceptibility, that is with higher PVN values. Therefore, ASTM, AASHTO and Canadian specifications should require a meaningful minimum viscosity at 135 C (275 F), or a significant minimum PVN value, in addition to a minimum penetration at 25 C (77 F) for the distillation residues of the asphalt emulsions employed.
17. While the data provided in the paper unanimously support the conclusions presented, the need for more data to either confirm or modify these findings is recognized. A brief list of useful further investigations for this purpose is included.
18. At several intervals throughout the paper, the benefits of using paving asphalts of low temperature susceptibility, or higher PVN, have been emphasized. For example, Figure 3 demonstrates very clearly that for the same penetration at 25 C (77 F), Group A asphalts, of low temperature susceptibility, or high PVN, are more viscous and firmer at all temperatures above 25 C (77F), and at the same time, are of lower consistency, or softer, at all temperatures below 25 C (77 F) than Group B asphalts of medium temperature susceptibility, medium PVN, or Group C asphalts of high temperature susceptibility, or lowest PVN. In terms of pavement performance, with all other variables constant, this means that pavements made with Group A asphalts, low temperature susceptibility or high PVN, should provide higher stability at all temperatures above 25 C (77 F), and should have greater resistance to low temperature transverse pavement cracking at all temperatures below 25 C (77 F), than pavements made with Group B asphalts of medium temperature susceptibility, or Group C asphalts of high temperature susceptibility or lowest PVN.

It is also pointed out that the incorporation of a small percentage of an appropriate polymer can improve the temperature susceptibility of a Group C asphalt to that of a Group B or Group A, or improve the temperature susceptibility of a Group B asphalt to that of a Group A, or of a Group A asphalt to that of a Group AA, or even lower temperature susceptibility. This improved temperature susceptibility should provide pavements containing these polymer modified asphalts with much better pavement performance for each of the six important items listed in the introduction of this paper, more effective paving asphalt specifications, more stability for warm weather traffic, more resistance to low temperature transverse cracking in winter, more resistance to pavement rutting, more serviceable completely new or recycled paving mixtures, and surface treatments with much improved service performance.

19. Two appendices are included with the paper. Appendix A provides equations for the accurate calculation of the PVN value for any asphalt manufactured by steam or vacuum distillation, and gives an example of its application. Appendix B-l provides a general use specification for penetration-graded asphalts with temperature susceptibility requirements. Appendix B-2 provides a similar specification to B-l, but includes additional information that avoids the need for a separate manual to indicate its proper application.
20. The introduction of temperature susceptibility requirements, as measured by PVN, into asphalt paving technology, would open a whole new world of understanding of the service behavior of asphalt pavements and how they should be designed for longer lives and superior pavement performance.
21. It is quite remarkable that most of the highly useful benefits implied by this paper, could be made available by the use of two simple, long standing laboratory tests, penetration at 25 C (77 F) and viscosity at 135 C (275 F), on which values for PVN are based.

REFERENCES

1. Norman W. McLeod, "Transverse Pavement Cracking Related to Hardness of The Asphalt Cement", *Proceedings, Canadian Technical Asphalt Association,* Volume 13, 1968.
2. Norman W. McLeod, Discussion of Paper by Shook and Kallas, *Proceedings, Association of Asphalt Paving Technologists,* Vol. 38, 1969.
3. Norman W. McLeod, Discussion of Paper by F.D. Young, I. Deme, R.A. Burgess and O. Kopvillem, *Proceedings, Canadian Technical Asphalt Association,* Volume 14, 1969.
4. J.A.A. Lefebvre, "A Modified Penetration Index for Canadian Asphalts", *Proceedings, Association of Asphalt Paving Technologists,* Volume 39, 1970.
5. Norman W. McLeod, Discussion of Paper by J.A.A. Lefebvre, *Proceedings, Association of Asphalt Paving Technologists,* Volume 39, 1970.
6. V.Ph. Pfeiffer and P.M. Van Doormaal, "The Rheological Properties of Asphaltic Bitumen", *Journal of the Institute of Petroleum Technologists,* Volume 22, 1936.
7. W. Heukelom, "An Improved Method of Characterizing Asphaltic Bitumen with the Aid of Their Mechanical Properties", *Proceedings, Association of Asphalt Paving Technologists,* Volume 42, 1973.

8. N.W. McLeod, "A 4-Year Survey of Low Temperature Transverse Pavement Cracking on Three Ontario Test Roads", *Proceedings, Association of Asphalt Paving Technologists,* Volume 41, 1972.
9. J.Y. Welborn and W.J. Halstead, "Properties of Highway Asphalts, Part I, 85/100 Penetration Grade", *Public Roads,* Volume 10, No 9, August, 1959.
10. J.Y., Welborn, W.J. Halstead, and J.G Boone, "Properties of Highway Asphalts, Part II, Various Grades", Public Roads, Volume 3 1, No 4, October, 1960.
11. V.P. Puzinauskas, "Properties of Asphalt Cements", *Proceedings, Association of Asphalt Paving Technologists,* Volume 48, 1979.
12. C. Van der Poel, "A General System Describing the Visco-Elastic Properties of Bitumens and Its Relation to Routine Test Data," Journal of Applied Chemistry, Volume 4, 1954.
13. C. Van der Poel, "Time and Temperature Effects on the Deformation of Asphalt Bitumens and Bitumen-Mineral Mixtures", *Society of Plastic Engineers Journal,* Volume 11, No 7, 1955.
14. J.F. Meidinger and D.A. Kasianchuk, "Asphalt Specifications for British Columbia Highways", *Proceedings, Canadian Technical Asphalt Association,* Volume 19, 1974.
15. D.A. Anderson, D.L. Dukatz, J.C. Peterson, "The Effect of Antistrip Additives on the Properties of Asphalt Cements", *Proceedings, Association of Asphalt Paving Technologists,* Volume 51, 1982.
16. E.L. Dukatz, Jr., D.A. Anderson and J.L. Rosenberger, "Relationship Between Asphalt Flow Properties and Asphalt Composition", *Proceedings, Association of Asphalt Paving Technologists,* Volume 53, 1984.
17. P.S. Kandhal and W.C. Koehler, "Effect of Rheological Properties of Asphalts on Pavement Cracking", *American Society for Testing and Materials, Special Technical Publication 941,* December, 1985.
18. Norman W. McLeod. Discussion, *Proceedings, Sixth International Conference on the Structural Design of Asphalt Pavements,* Volume 2, July, 1987.
19. Norman W. McLeod, "Test Data from Three Ontario Test Roads after 15 Years of Service", *Proceedings, Canadian Technical Asphalt Association,* Volume 23, 1978.
20. I.J. Deme and F.D. Young, "Ste. Anne Test Road Revisited Twenty Years Later", Proceedings, Canadian Technical Asphalt Association, Volume 32, 1987.
21. Norman W. McLeod, "The Case of Grading Asphalt Cements by Penetration at 77 F (25 C)", *Proceedings, Canadian Technical Asphalt Association,* Volume 20, 1975.
22. Vernon J. Marks and Charles L. Huisman, "Reducing the Effects of Transverse Cracking", *Proceedings, Association of Asphalt Paving Technologists,* Volume 56, 1987.
23. R. Haas, F. Meyer, G. Assaf and H. Lee, "A Comprehensive Study of Cold Climate Airport Pavement Cracking", *Proceedings, Association of Asphalt Paving Technologists,* Volume 56, 1987.
24. A.J. Fabb, "The Influence of Mix Composition, Binder Properties and Cooling Rate on Asphalt Cracking at Low Temperatures", *Proceedings, Association of Asphalt Paving Technologists,* Volume 43, 1975.
25. Norman W. McLeod, "Using the Freezing Index for the Optimum Selection of Paving Asphalts with Different Temperature Susceptibilities for any Pavement Site", *Proceedings, Canadian Technical Asphalt Association,* Volume 10, 1985.
26. Norman W. McLeod, "Using Paving Asphalt Rheology to Improve or Impair Asphalt Pavement Design and Performance", *American Society for Testing and Materials, Special Technical Publication,* STP 941, 1985.
27. Gayle N. King, Helen W. King, Otto Harders and Pierre Chaverot, "Low Temperature Benefits of Polymer Modified Asphalts", *Proceedings, Canadian Technical Asphalt Association,* Volume 33, 1988.
28. The Asphalt Institute, "Research and Development of the Asphalt Institute's Thickness Design Manual, (MS-l)". Ninth Edition, *Research Report* No 82.2, August, 1982.

29. R.C.G. Haas and W.A. Phang, "Relationships Between Mix Characteristics and Low Temperature Transverse Pavement Cracking", *Proceedings, Association of Asphalt Paving Technologists,* Volume 57, 1988.

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APPENDIX A
DETERMINATION OF THE PVN VALUE FOR ANY PAVING ASPHALT MANUFACTURED BY STEAM OR VACUUM DISTILLATION

Appendix A provides the basic equation for PVN, and gives an example of its application.

As indicated by Fig. A, the equation for the least squares line representing a PVN of 0.0 is:

$$\log V = 4.25800 - 0.79674 \log P \qquad (1)$$

and for the least squares line representing a PVN of -1.5:

$$\log V = 3.46289 - 0.61094 \log P \qquad (2)$$

where V is the viscosity in centistokes at 275 F (135 C) and P is the penetration at 77 F (25 C).

The PVN of any asphalt cement for which the penetration at 77 F (25 C) and viscosity in centistokes at 275 F (135 C) are known, can be calculated from the following equation:

$$PVN = [(\log L - \log X)/(\log L - \log M)]\,(-1.5) \qquad (3)$$

where

X = viscosity in centistokes at 275 F (135 C) associated with the penetration at 77 F (25 C) of an asphalt cement,

L = viscosity in centistokes at 275 F (135 C) for a PVN of 0.0 for the penetration at 77 F (25 C) of the asphalt cement, and

M = viscosity in centistokes at 275 F (135 C) for a PVN of -1.5 for the penetration at 77 F (25 C) of the asphalt cement.

Suppose, for example, that the penetration at 77 F (25 C) of a certain asphalt cement is 150 and its viscosity at 275 F (135 C) is 194 centistokes (1.94×10^{-4} m^2/s). What is its PVN?

The viscosity L at 275 F (135 C) for a PVN = 0.0, for an asphalt cement of 150 penetration at 77 F (25 C), is obtained by substitution in Eq 1

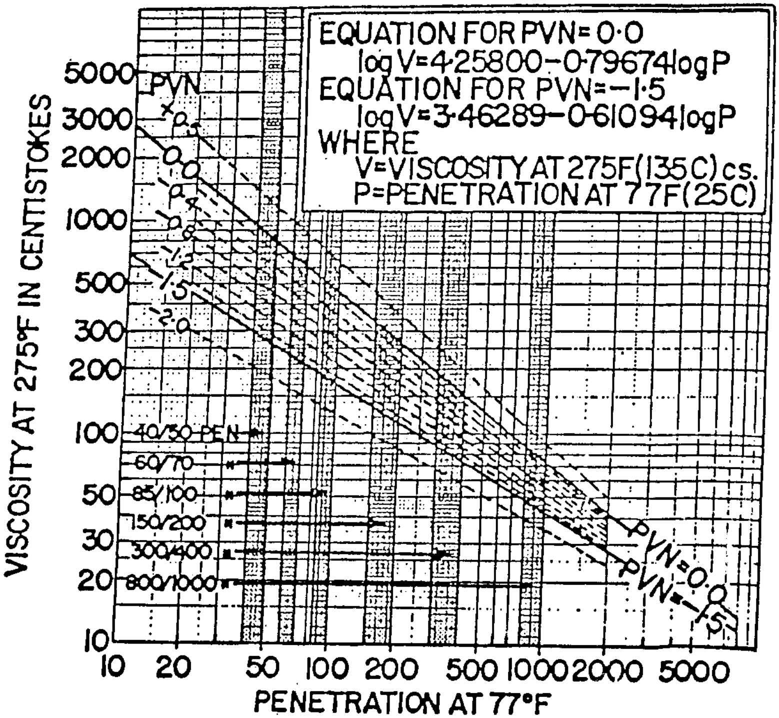


Figure A1: A Chart for the Determination of Approximate Values for PEN-VIS Numbers for Asphalt Cements.

$$\log V = 4.25800 - 0.79674 \log 150$$
$$= 4.25800 - 0.79674\ (2.17609) = 2.52422$$
$$L = V = 334.4 \text{ centistokes } (3.344 \times 10^{-4} \text{ m}^2/\text{s})$$

The viscosity M at 275 F (135 C) for a PVN = -1.5, for an asphalt cement of 150 penetration is provided by substitution in Equation 2.

$$\log V = 3.46289 - 0.61094 \log 150$$
$$= 3.46289 - (061094)(2.17609) = 2.13343$$
$$M = V = 136.0 \text{ centistokes } (1.36 \times 10^{-4} \text{ m}^2/\text{s})$$

The PVN for the 150 penetration asphalt with a viscosity of 194 centistokes (1.94×10^{-4} m^2/s) at 275 F (135 C) can be obtained by substituting the values for log L, log M, and log X into Equation 3.

$$PVN = [(2.52422 - \log 194)/(2.5422 - 2.13342)]\ (-1.5)$$
$$= [(2.52422 - 2.28780)/(2.52422 - 2.13343)]\ (-1.5)$$

= (0.23642/0.39079) (-1.5)
= -0.91

Therefore, the PVN for an asphalt cement of 150 penetration at 77 F (25 C) with a viscosity of 194 centistokes (1.94 x 10^{-4} m^2/s) at 275 F (135 C) is -0.91.

To assist with the determination of an approximate value for the PVN for any paving asphalt, Fig. A has been prepared on the basis of Equations l-3. By plotting the point representing corresponding values for penetration at 77 F (25 C) and for viscosity in centistokes at 275 F (135 C) for any paving asphalt in Fig. A, an approximate value for the PVN of the asphalt cement can be obtained by interpolation.

The equation for PVN can be easily stored in a computer. We have a Hewlett-Packard 97. The Director of Technical Services, Mr. Keith Davidson, put the required programs on three chips to cover penetration at 25 C (77 F), viscosity in centistokes at 135 C (275 F) and PVN. If we have data for any two of these three variables, the value of the third variable can be obtained by feeding the appropriate chip into the computer, and punching in the other two known values.

APPENDIX B- 1

This specification is for general use for penetration-graded paving asphalts with temperature susceptibility requirements, manufactured by steam or vacuum distillation. It is modelled after ASTM D946 to which temperature susceptibility requirements have been added.

STANDARD SPECIFICATION FOR PENETRATION-GRADED PAVING ASPHALTS WITH TEMPERATURE SUSCEPTIBILITY REQUIREMENTS FOR USE IN PAVEMENT CONSTRUCTION

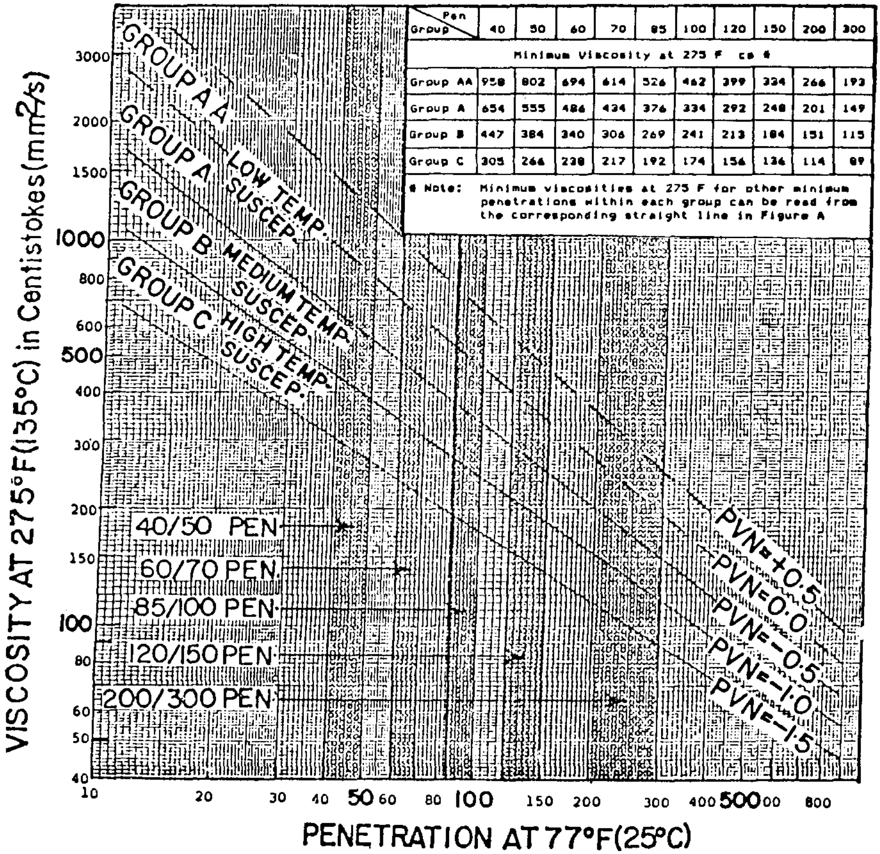
1. Scope

1.1 this specification covers asphalt cement for use in the construction of pavements.

1.2 This specification covers the following penetration grades:

40 - 50	120 - 150 and
60 - 70	200 - 300
85 - 100	

1.3 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. This specification is illustrated in Figure B1 .



Pen / Group	40	50	60	70	85	100	120	150	200	300
Minimum Viscosity at 275 F cs *										
Group AA	958	802	694	614	526	462	399	334	266	193
Group A	654	555	486	434	376	334	292	248	201	149
Group B	447	384	340	306	269	241	213	184	151	115
Group C	305	266	238	217	192	174	156	136	114	89

* Note: Minimum viscosities at 275 F for other minimum penetrations within each group can be read from the corresponding straight line in Figure A

Figure B-l: Illustration of a Specification Based on Penetrations at 77°F (25°C), Viscosities at 275°F (135°C) and Temperature Susceptibilities of Paving Asphalts.

2. Referenced Documents

2.1 ASTM Standards

D5 Test Method for Penetration of Bituminous Materials
D92 Test Method for Flash and Fire Points by Cleveland Open Cup
D113 Test Method for Ductility of Bituminous Materials
D140 Methods of Sampling Bituminous Materials
D1754 Test Method for Effect of Heat and Air on Asphaltic Materials (Thin-Film Oven Test)
D2042 Test Method for Solubility of Asphalt Materials in Trichloroethylene
D2170 Standard Test Method for Kinematic Viscosity

3. Manufacture

3.1 Asphalt cement shall be prepared by the refining of crude petroleum by steam or vacuum distillation.

4. Properties

4.1 The asphalt cement shall be homogeneous and shall not foam when heated to 347 F (174 C).
4.2 The various grades of asphalt cement shall conform to the requirements prescribed in Table A 1.

5. Methods of Sampling and Testing

5.1 The materials shall be sampled and the properties enumerated in this specification shall be determined in accordance with the following ASTM methods:

5.1.1 Sampling- Method D 140
5.1.2 Penetration – Method D5
5.1.3 Flash Pint-Method D92
5.1.4 Ductility-Method D113
5.1.5 Thin Film Oven Test-Method D1754
5.1.6 Solubility in Trichloroethylene-Method D2042
5.1.7 Kinematic Viscosity – Method D2170

APPENDIX B-2

This specification is for use with penetration-graded paving asphalts with temperature susceptibility requirements, for paving asphalts manufactured by steam or vacuum distillation. It is modelled after ASTM D946 to which temperature susceptibility requirements have been added.
This specification avoids the need for a manual to indicate its proper application.

STANDARD SPECIFICATION FOR PENETRATION-GRADED PAVING ASPHALTS WITH TEMPERATURE SUSCEPTIBILITY REQUIREMENTS FOR USE IN PAVEMENT CONSTRUCTION

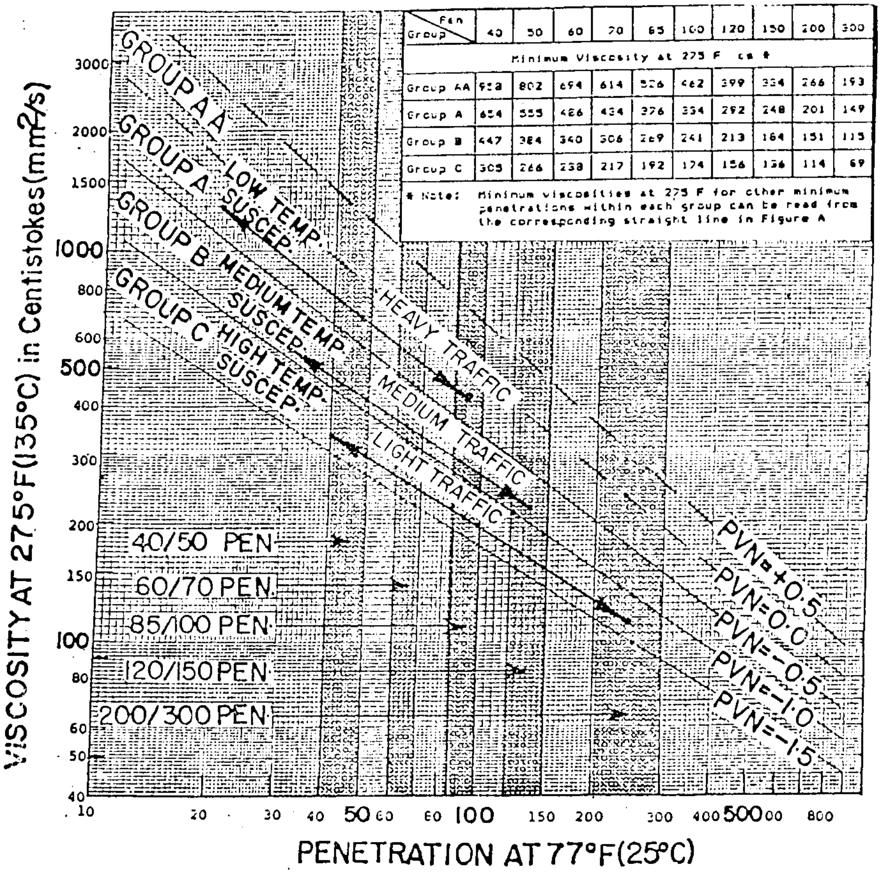
1. Scope

1.1 This specification covers asphalt cement for use in the construction of pavements.
1.2 This specification covers the following penetration grades:

40 - 50   120 - 150 and
60 - 70   200 - 300
85 - 100

	PENETRATION GRADE									
	40-50		60-70		85-100		120-150		200-300	
	min	max	min	max	min	max	min	max	min	max
Penetration at 25 C (77 F) 100g 5s	40	50	60	70	85	100	120	150	200	300
Kinematic Viscosity at 135 C (275 F) mm/s										
Group A	see Fig B-1	-	see Fig B-1	-	see Fig B-1	-	see Fig B-1	-	see Fig B-1	-
Group B	see Fig B-1	-	see Fig B-1	-	see Fig B-1	-	see Fig B-1	-	see Fig B-1	-
Group C	see Fig B-1	-	see Fig B-1	-	see Fig B-1	-	see Fig B-1	-	see Fig B-1	-
Flash Point (Cleveland Open Cup) F	450	-	450	-	450	-	425	-	350	-
Ductility at 25 C (77 F) 5 cm/min cm	100	-	100	-	100	-	100	-	100	-
Solubility in Trichloroethylene, %	99.0	-	99.0	-	99.0	-	99.0	-	99.0	-
Retained penetration after thin-film oven test, %	55+	-	52+	-	47+	-	42+	-	37+	-
Ductility at 25 C (77 F) 5 cm/min cm after thin-film oven test	-	-	50	-	75	-	100	-	100^{A}	-

Table A1: Requirements for Use in Pavement Construction.



Group \ Pen	40	50	60	70	85	100	120	150	200	300
	Minimum Viscosity at 275 F cs *									
Group AA	928	802	694	614	526	462	399	334	266	193
Group A	654	555	486	434	376	334	292	248	201	149
Group B	447	384	340	306	269	241	213	164	151	115
Group C	305	266	238	217	192	174	156	136	114	69

* Note: Minimum viscosities at 275 F for other minimum penetrations within each group can be read from the corresponding straight line in Figure A

Figure B-2: Illustration of a Specification Based on Penetrations at 77°F (25°C), Viscosities at 275°F (135°C), and Temperature Susceptibilities of Paving Asphalts.

1.3 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 ASTM Standards

D5 Test Method for Penetration of Bituminous Materials
D92 Test Method for Flash and Fire Points by Cleveland Open Cup
D113 Test Method for Ductility of Bituminous Materials

	PENETRATION GRADE									
	40-50		60-70		85-100		120-150		200-300	
	min	max	min	max	min	max	min	max	min	max
Penetration at 25 C (77 F) 100g 5s	40	50	60	70	85	100	120	150	200	300
Kinematic Viscosity at 135 C (275 F) mm/s										
Group A	see Fig B-2	-	see Fig B-2	-	see Fig B-2	-	see Fig B-2	-	see Fig B-2	-
Group B	see Fig B-2	-	see Fig B-2	-	see Fig B-2	-	see Fig B-2	-	see Fig B-2	-
Group C	see Fig B-2	-	see Fig B-2	-	see Fig B-2	-	see Fig B-2	-	see Fig B-2	-
Flash Point (Cleveland Open Cup) F	450	-	450	-	450	-	425	-	350	-
Ductility at 25 C (77 F) 5 cm/min cm	100	-	100	-	100	-	100	-	100	-
Solubility in Trichloroethylene, %	99.0	-	99.0	-	99.0	-	99.0	-	99.0	-
Retained penetration after thin-film oven test, %	55+	-	52+	-	47+	-	42+	-	37+	-
Ductility at 25 C (77 F) 5 cm/min cm after thin-film oven test	-	-	50	-	75	-	100	-	100[A]	-

[A] If ductility at 25 C (77 F) is less than 100 cm, material will be accepted if ductility at 15.5 C (60 F) is 100 cm minimum at a pull rate of 5 cm/min.

Table B1: Requirements for Use in Pavement Construction.

D140 Methods of Sampling Bituminous Materials
D1754 Test Method for Effect of Heat and Air on Asphaltic Materials (Thin-Film Oven Test)
D2042 Test Method for Solubility of Asphalt Materials in Trichloroethylene
D2170 Standard Test Method for Kinematic Viscosity

3. Manufacture

3.1 Asphalt cement shall be prepared by the refining of crude petroleum by steam or vacuum distillation.

4. Properties

4.1 The asphalt cement shall be homogeneous and shall not foam when heated to 347 F (174 C).

4.2 The various grades of asphalt cement shall conform to the requirements prescribed in Table B1 and illustrated in Figure B2.

5. Methods of Sampling and Testing

5.1 The materials shall be sampled and the properties enumerated in this specification shall be determined in accordance with the following ASTM methods:

5.1.1 Sampling- Method D 140
5.1.2 Penetration- Method D5
5.1.3 Flash Point-Method D92
5.1.4 Ductility-Method D113
5.1.5 Thin Film Oven Test-Method D1754
5.1.6 Solubility in Trichloroethylene -Method D2042
5.1.7 Kinematic Viscosity -Method D2170