Temperature susceptibility of an asphalt cement is defined as the rate of change of viscosity (or other measure of asphalt consistency) with temperature.

The rate of change of **viscosity or consistency** of a given bitumen **determines** its **temperature susceptibility**.

This property is of **great use** in designing satisfactory bituminous mixes (balanced mixes) for use under any given range of temperature change.

The **criterion** is that the **bitumen should exhibits as little change as possible in its viscosity** in the **given range of temperature change**.

The most common method to characterize temperature susceptibility is to find **the penetration index (PI)** which is a dimensionless quantity but there are other methods to characterize temperature susceptibility such as **PVN method**.

One of the best known equations is that describing the **temperature susceptibility** of the penetration of a bitumen (a “wax free” bitumen based crude oil) was developed by **Pfeiffer and Van Doormaal, 1936**. They developed an equation for the temperature susceptibility that assumes a value of about **zero** for road bitumens. For this reason, they assumes that:

1- When the logarithm (base 10) of penetration, log pen, is plotted against temperature, T a straight line is obtained such that:

$$\log pen = AT + K$$

Where **A** (the slope of the line shown in Figure 1) **is an indicator of temperature susceptibility** and **K** is a constant.

The value of **A** varies from about **0.015 to 0.060**, showing that there may be a considerable difference in temperature susceptibility. The slope (A) is determined by the relation:

$$A = \frac{log\ \ pen\ at\ T_1\ \ - log\ \ pen\ at\ T_2}{T_1 - T_2}$$

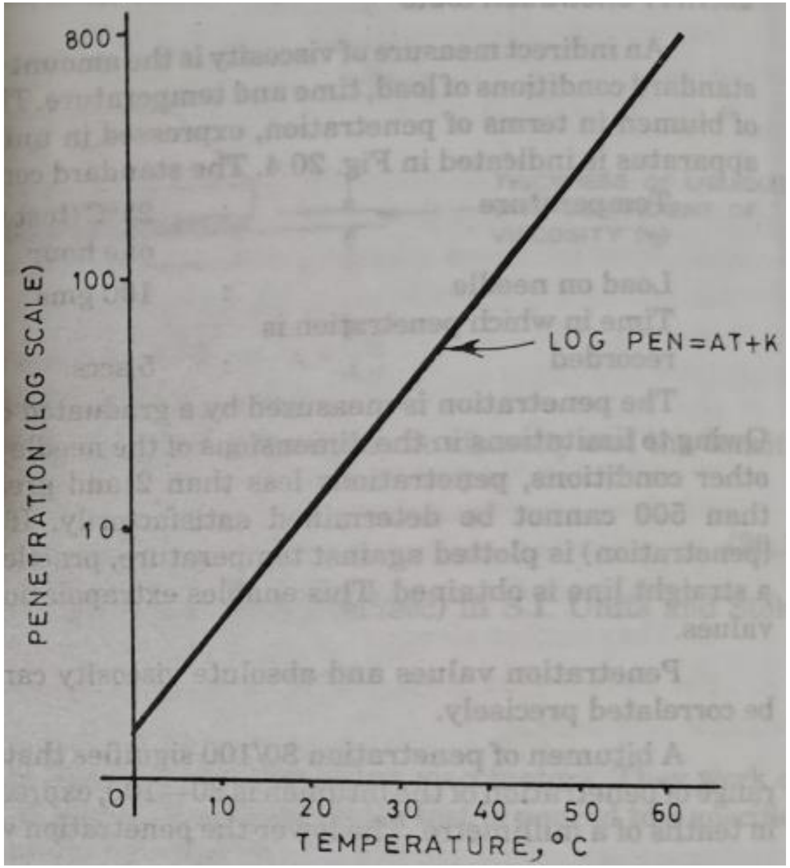


Figure 1: Penetration vs. temperature (penetration test).

The following empirical expression is then used to calculate the penetration index termed PI:

$$PI = \left[\frac{20(1 - 25A)}{(1 + 50A)}\right]$$

This equation was chosen so that a particular Mexican bitumen of 200 Pen (at 25°C) and a softening point of 40°C yielded a PI of zero (See Figure 2).

Rearranging this equation yields new equation to calculate A from PI:

$$A = \left[\frac{(20 - PI)}{50\,(10 + PI)}\right]$$

Bitumens with high PIs are less temperature susceptible (a PI of 20 would indicate a penetration independent of temperature), and low PI binders are more temperature susceptible (a binder with a PI of – 10 would be infinitely susceptible).

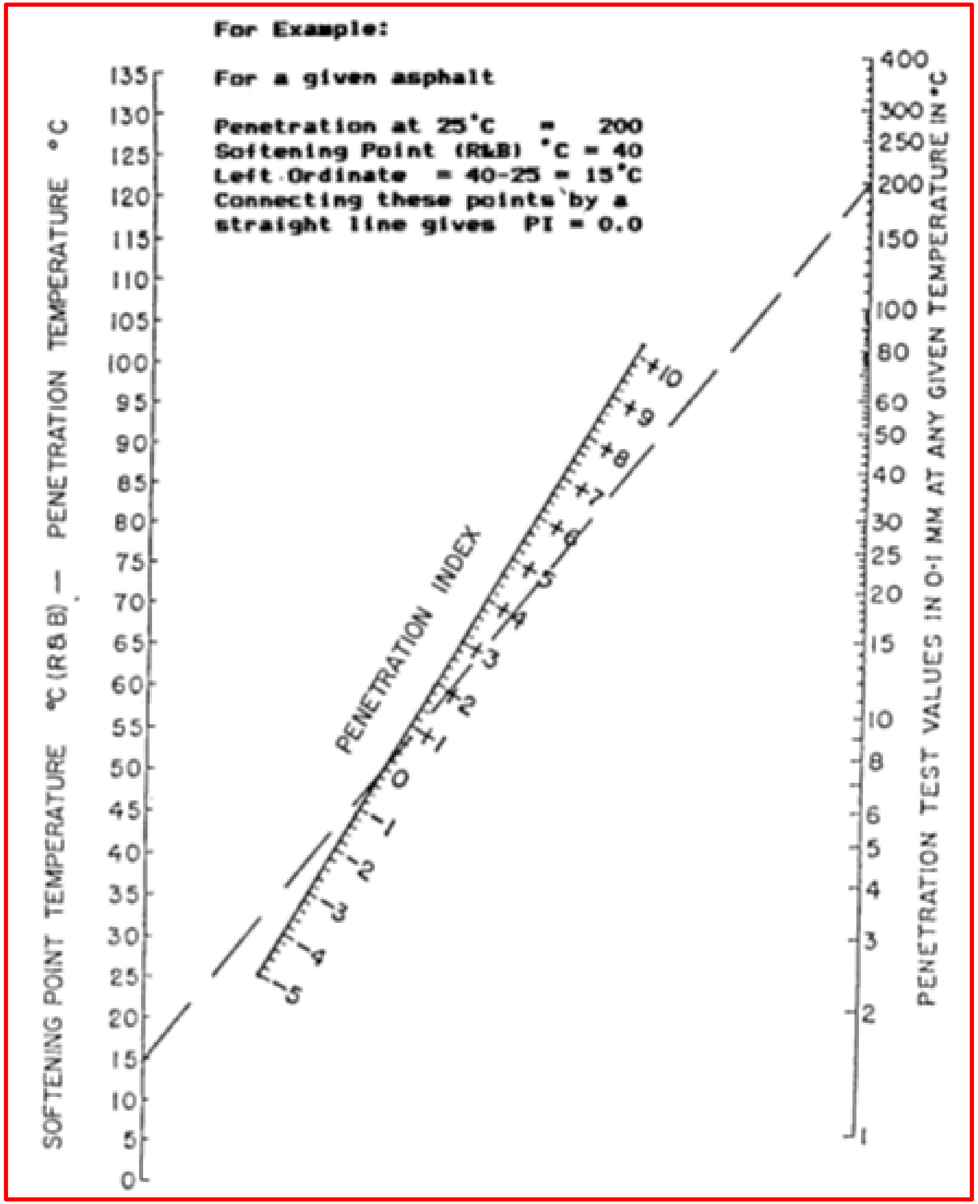


Figure 2: Pfeiffer's and Van Doormaal's Nomograph for Paving Asphalt Temperature Susceptibility.

2- The calculation of the penetration index is based on the assumption that bitumen at the softening point Ring and Ball test has penetration equal to 800 dmm (See Figure 3).

The consistency of bitumen at the softening point temperature was determined in terms of penetration value by **Pfeiffer and Van Doormaal (1936)**.

By linear extrapolation of the logarithm of the penetration versus temperature and by direct measurement with an ***extra long penetration needle*** at the **ASTM softening point temperature**, they found a value of a penetration of **800 dmm** for **many, but not all**, bitumens.

The exact value was found to vary with the penetration index (PI) and the wax content.

It has also been demonstrated by direct measurement that the viscosity at the softening point temperature of the majority of bitumens is about 1300 Pa.s (13 000 poise) (Heukelom, 1973).

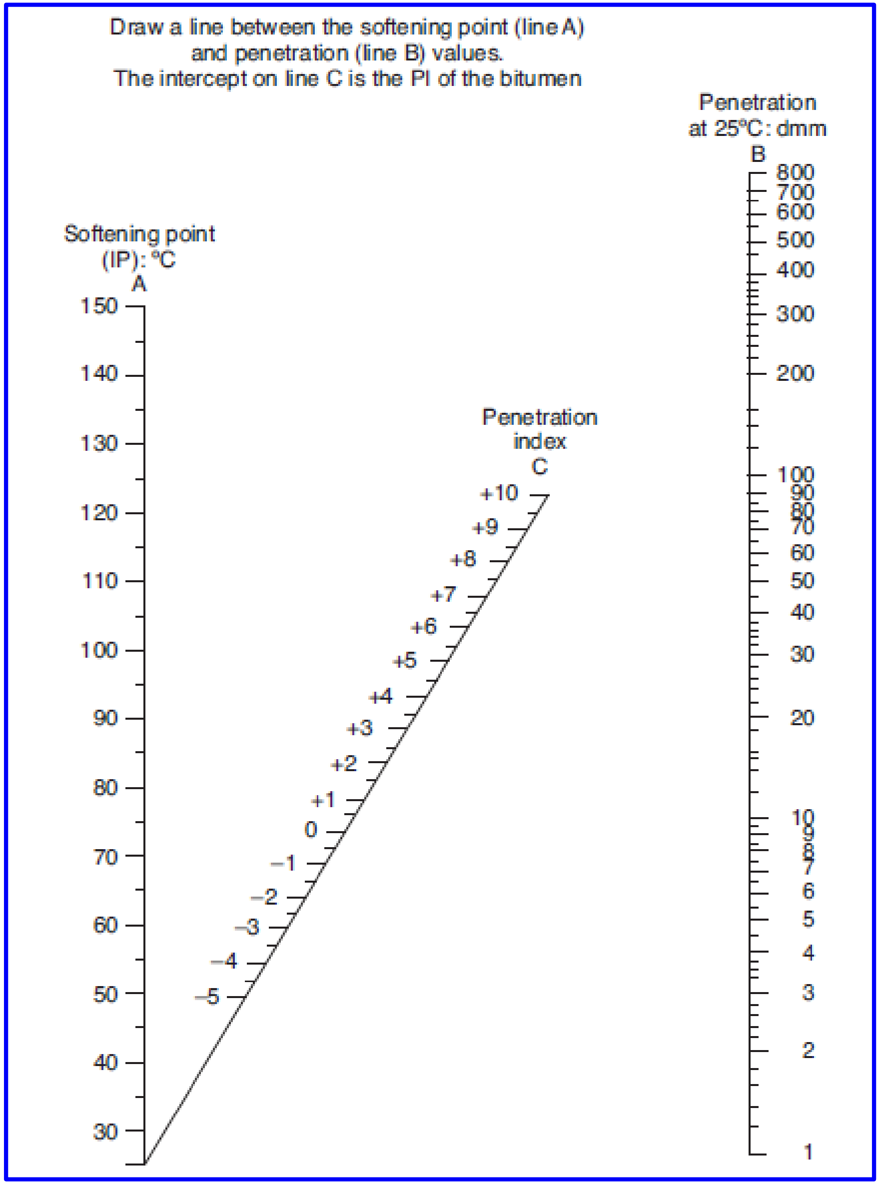


Figure 3 Nomograph for the PI (softening point/pen).

The **PI** is an **unequivocal function of A**, and hence it may be used for the same purpose. The values of **A** and the **PI** can be derived from penetration measurements at two temperatures, T_1 **and** T_2 , using the equation:

$$A = \frac{log\ pen\ at\ T_1\ - log\ pen\ at\ T_2}{T_1 - T_2}$$

- Replacing T_2 in the above equation by the ASTM softening point temperature (SP) and the penetration at T_2 by **800**, they obtained the equation:

$$A = \frac{log\ pen\ at\ T_1\ - log\ 800}{T_1 - SP}$$

or use

$$PI = \frac{20 * T_{R\&B} + 500 * log\ pen - 1952}{T_{R\&B} - 50 * log\ pen + 120}$$

Where:

$T_{R\&B}$: R&B softening temperature in degrees Celsius (°C).

$logpen$: common logarithm of penetration at 25 (dmm).

Notes

1. The limiting theoretical values of the penetration index are **−10** for bitumens with very high susceptibility to temperature variations, up to **+20** for bitumens almost independent of temperature variations.

2. **In practice,** penetration index **varies** from around **−3** for highly temperature-susceptible bitumens to around **+7** for highly blown bitumens with low temperature-susceptible (high PI). For paving grade bitumen used for highways, the typical range is **-1.5 to +1.0**. Some **literature** stated that "typical" asphalts have IP values between **+2 and -2**.

3. **The lower** the penetration index, the **faster** the binder changes its consistency as the temperature changes (shows **greater** temperature sensitivity).

4. It is noted that penetration index value equal to zero (IP = 0) is attributed to a particular Mexican bitumen with a penetration of 200 dmm at 25°C and a softening point of 40°C.

5. The calculation of the penetration index has not been standardized. The **precision** of the measure is dependent on the **precision** of the **measurement** of the **penetration and softening point** or on the **two values of penetration**.

Notes

6. The softening point may be estimated from the penetration value. After extensive laboratory tests, the following equation was derived, for paving grade bitumens with penetration ranging from 40 to 100 dmm, with a very good correlation coefficient (0.983):

$$T_{SP} = 87.3 - 22.5 * Log\ pen$$

7. Although many test methods measure related properties and therefore there will be some relationship, no formal correlation has been found in the papers reviewed between the penetration index and other bitumen tests.

Example 1:

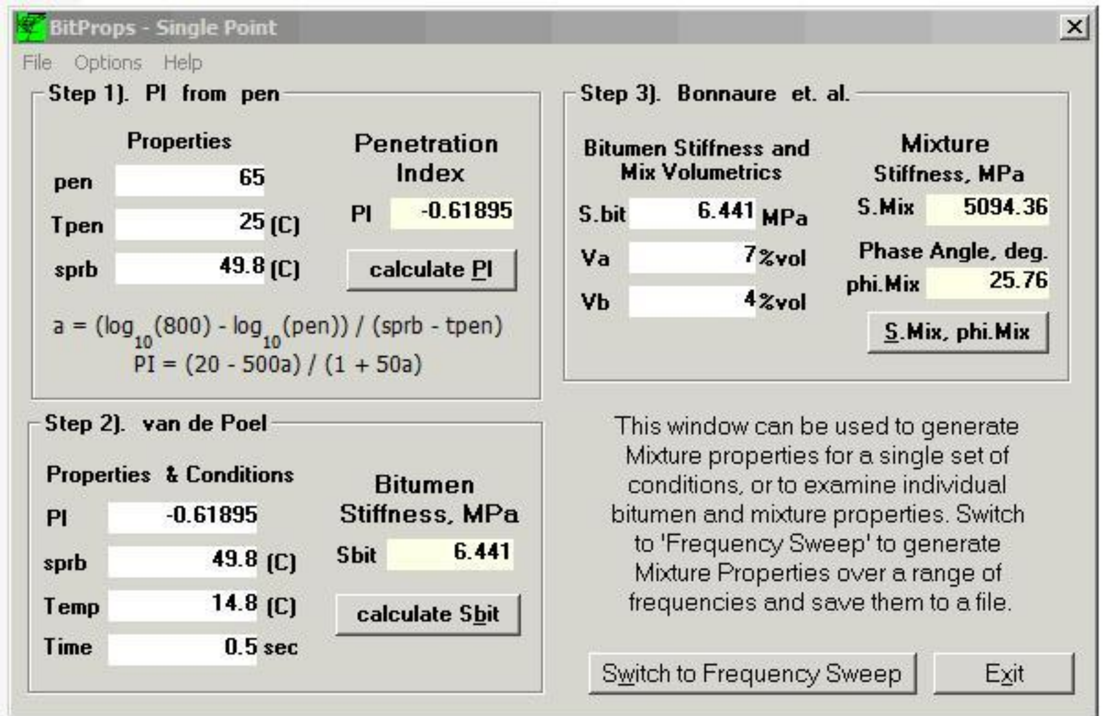
It was found that the penetration grade of asphalt cement is 65 dmm and the softening point is 49.8°C. Determine the PI of this asphalt binder.

$$A = \frac{\log pen\ at\ T_1 \ - \log 800}{T_1 - SP}$$

$$A = \frac{\log 65 \ - \log 800}{25 - 49.8}$$

$A = 0.044$ **(within the range of 0.015 to 0.060)**

$$\mathrm{PI} = \frac{20(1-25\mathrm{A})}{1+50\mathrm{A}} = \frac{20(1-25*0.044\ )}{1+50*0.044}$$



$\mathrm{PI} = -0.619$

(It can be used as conventional paving bitumen)

or use

$$PI = \frac{20*T_{R\&B} + 500*\log pen - 1952}{T_{R\&B} - 50*\log pen + 120} = \frac{(20*49.8) + (500*\log 65) - 1952}{49.8 - (50*\log 65) + 120}$$

$\mathrm{PI} = -0.619$ **(It can be used as conventional paving bitumen)**

Example 2:

Given the following information in the table (shaded in green and yellow).

Sample source	Bitumen grade	Penetration (decimillimetre)	Softening point temperature (°C)	PI	Possible use for paving construction
1	50-70	65	48.1	-1.1	Conventional paving bitumen.
2	250-330	330	30	-3.8	Temperature susceptible bitumen.
3	160-220	170	38.1	-1.6	Conventional paving bitumen.
4	50-70	60	48	-1.3	Conventional paving bitumen.

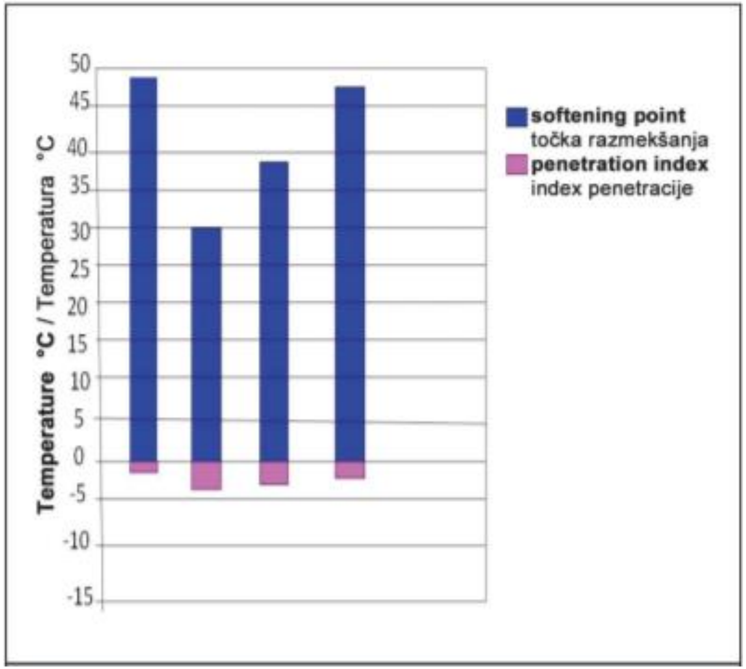


Figure 2. Penetration index and softening point results of Ex.2.

HW No.1

Complete the following table (you can use Excel to solve it):

Bitumen grade	Penetration (decimillimetre)	Softening point temperature (°C)	PI	Possible use for paving construction
20-30	20	63	?	?
30-45	30	60	?	?
35-50	50	50	?	?
40-60	60	48	?	?
50-70	70	46	?	?
70-100	100	43	?	?
100-150	150	41.5	?	?
160-220	200	40	?	?

In addition to the first measure of temperature susceptibility, penetration index (PI), there are two parameters that could be used to measure temperature susceptibility of asphalts: the pen-vis number (PVN), and viscosity- temperature susceptibility (VTS).

1- To find the pen-vis number (PVN):

$$PVN = [\frac{4.258 - 0.7967\, logP - logX}{o.7951 - 0.1858\, logP}](-1.5)$$

<u>Where:</u>

P = penetration at **25°C** in decimillimetre,

X = viscosity at ***135°C*** in **centistoke, (1 stoke = 100 centistoke).**

Typical values of the **PVN** ranges between **-2 and 0.5,** and **higher PVN** indicates a **lower** temperature susceptibility **<u>while</u>** **lower PVN** indicates a **greater** temperature susceptibility.

2- The viscosity-temperature susceptibility parameter is determined from the relation between the viscosity values at a certain temperature. The VTS has been promoted by the Asphalt Institute as a criterion for paving grade bitumen temperature susceptibility. The VTS is based on the difference in the log log viscosity at each of two temperatures, usually 135°C and 60°C which are divided by the difference in the logs of the same two absolute temperatures. To find viscosity- temperature susceptibility (VTS) use:

$$VTS = \frac{log(log\ viscosity\ at\ T_1) - log(log\ viscosity\ at\ T_2)}{log\ T_2 - log\ T_1}$$

Viscosity is measured in **centistokes**, (**1 stoke = 100 centistoke**).

T_1, T_2 : temperature in degrees Kelvin (absolute temperatures= °C+273).

Typical values of the **VTS** ranges between **3.36 and 3.98**, and the **lower** the VTS, the **lower** the temperature susceptibility **or** the **greater** the VTS the **greater** temperature susceptibility.)

Example 3:

The following results were found from performing the penetration, viscosity, and ring and ball tests for an asphalt binder grade, AC-20:

Asphalt grade	Penetration, dmm	Viscosity at 135°C, stoke	Viscosity at 60°C, stoke	Ring and ball softening point, °C
AC-20	58	4	2363	51

Find the pen-vis number (PVN) and viscosity- temperature susceptibility (VTS). Is it possible to use this binder grade for paving construction?

Solution:

$$PVN = [\frac{4.258 - 0.7967\ logP - logX}{o.7951 - 0.1858\ logP}](-1.5)$$

$$PVN = [\frac{4.258 - 0.7967\ log\ 58 - log\ 400}{o.7951 - 0.1858\ log58}](-1.5)$$

$$PVN = \left[\frac{4.258 - 0.7967\ log\ 58 - log\ 400}{o.7951 - 0.1858\ log58}\right](-1.5) = -0.81$$

-0.81 within the typical values of the **PVN** (**-2 and 0.5)** so it can be used for paving construction.

4.258	- 0.7967*log58= -1.405	- Log (4*100)= -2.602	$4.258 - 0.7967\ logP - logX$ = 0.251	(0.251/0.467)*-1.5 = **-0.81**
0.7951	-0.1858*log58= -0.328		$o.7951 - 0.1858\ log58$ = 0.467	

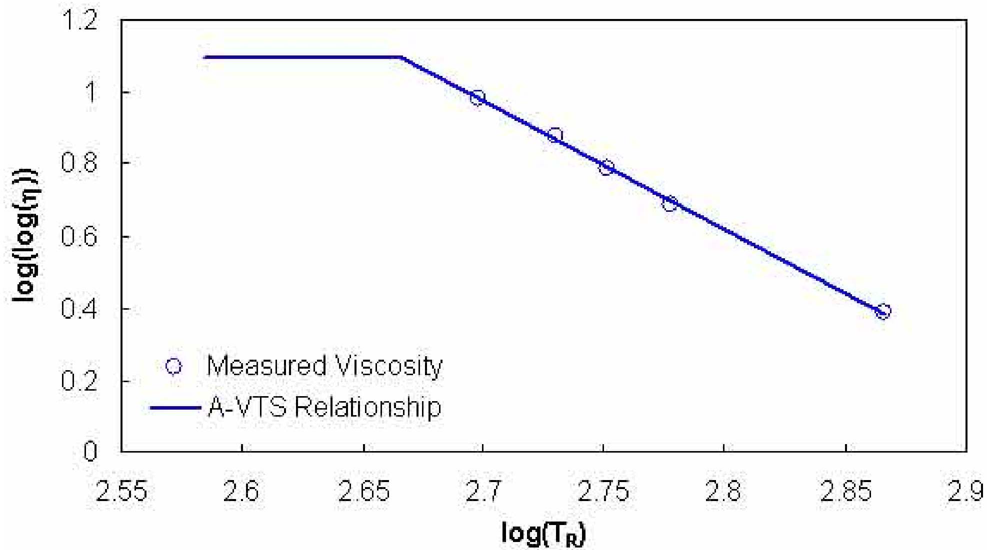
$$VTS = \frac{log(log\ viscosity\ at\ T_1) - log(log\ viscosity\ at\ T_2)}{log\ T_2 - log\ T_1}$$

$$VTS = \frac{log(log\ 236300) - log(log\ 400)}{log\ (135 + 273) - log\ (60 + 273)}$$

$$VTS = \frac{0.730 - 0.415}{2.6107 - 2.5224}$$

$$VTS = \frac{0.3150}{0.0883}$$

$$VTS = 3.57$$



3.57 within the typical values of the **VTS** (ranges between **3.36 and 3.98**), so it can be used for paving construction.

HW No.2

The following results were found from performing the penetration, viscosity, and ring and ball tests for an asphalt binder grade, AR-1000:

Asphalt grade	Penetration, dmm	Viscosity at 135°C, stoke	Viscosity at 60°C, stoke	Ring and ball softening point, °C
AR-1000	131	1.3	556	40.6

Find the pen-vis number (PVN) and viscosity- temperature susceptibility (VTS). Is it possible to use this binder grade for local paving construction? Discuss?

Answer

PVN=-1.71

VTS= 3.98

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