V.I. Too Resistant to Change?

Anthony Bradshaw

By Jack Zakarian

The rating number known as viscosity index — V.I. — is universally used by people working in all aspects of the lubricants business. The concept of V.I. was first proposed in 1929 by E.W. Dean and G.H.B. Davis, two researchers working for Standard Oil of New Jersey (now ExxonMobil). The continued usage and popularity of V.I., 84 years after its introduction, is a testament to its utility and simplicity. The V.I. method, detailed in ASTM D2270, is based on a comparison of the oil to be rated (the candidate oil) with two reference oils. The method yields a single number which purports to quantify the relative change in viscosity with temperature of the candidate oil.

The fact that just one arbitrary number can be claimed to represent the change of viscosity with temperature should already be a red flag to anyone familiar with the actual viscosity-temperature response of lubricating oils. My objective in this article is to educate users about the limitations of the V.I. method and the potential for misapplication and misinterpretation of an oil's V.I. rating.

First, we need to review how V.I. is calculated. Figure 1, page 56, shows a plot of viscosity at 100 degrees Celsius versus the viscosity at 40 degrees. It shows two curves, which correspond to the reference oil series used by Dean and Davis in their 1929 paper. The two series are named L and H, corresponding to 0 (Low) and 100 (High) V.I. oils, respectively.

The rectangular data points on the red L Series line in Figure 1 are the original data used to define the "0 V.I." reference line. Similarly, the diamond-shaped data points on the blue H Series line are the original data used to define the "100 V.I." reference line. The L Series data was derived from a sample of Louisiana Gulf Coast crude, and the H Series data came from a sample of Pennsylvania crude. (Note: The

1929 paper used temperatures of 100 and 210 F and viscosity units of Saybolt Universal Seconds. For convenience, the original data have been converted to the currently used units of Celsius and centiStokes.)

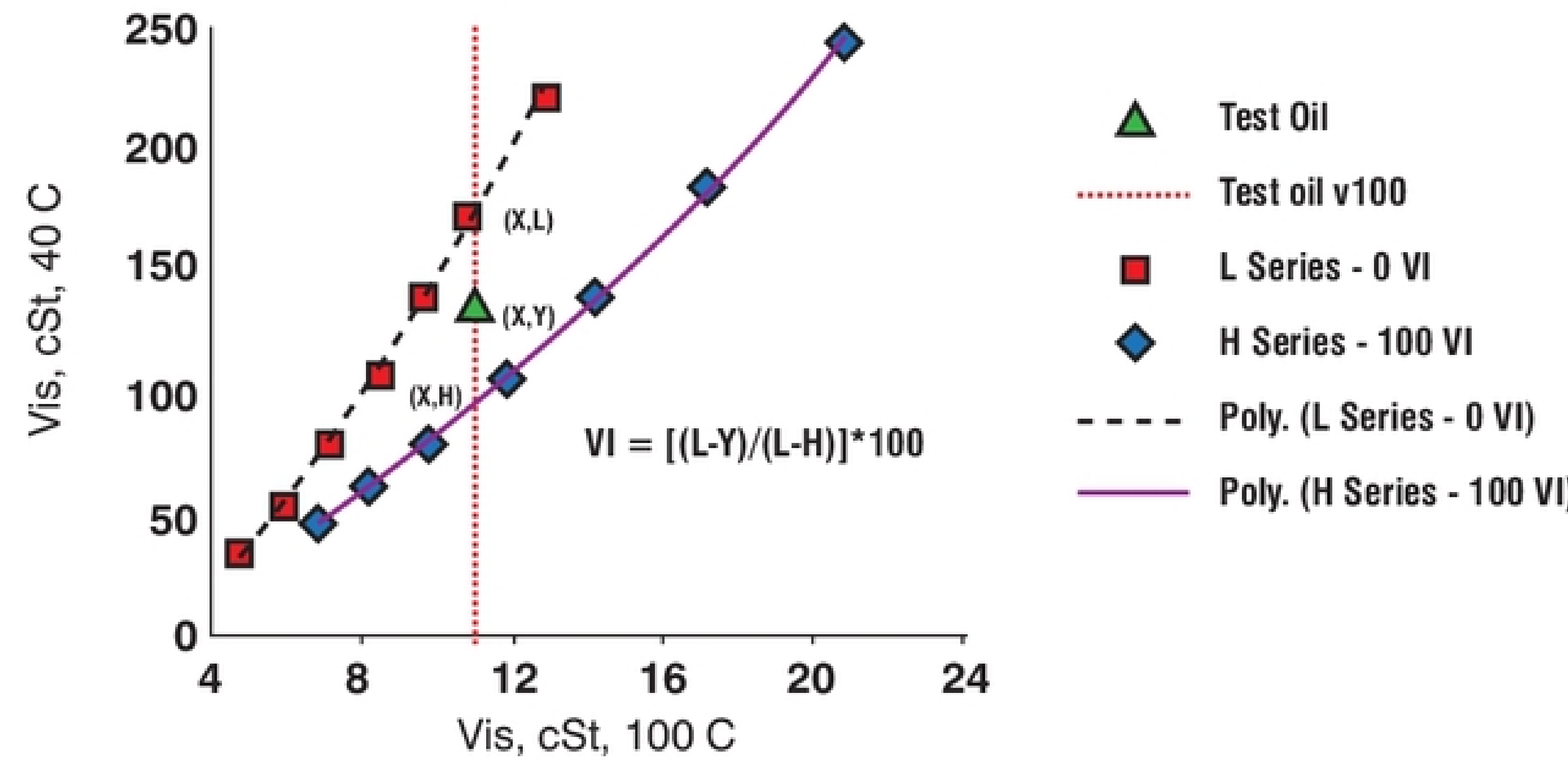
The calculation of V.I. is very straightforward and is shown with an example in Figure 1. In this figure, X denotes the viscosity of a candidate oil at 100 C and Y denotes the viscosity of this same oil at 40 C. Figure 1 depicts a green triangle with the coordinates X = 11 cSt. and Y = 134.5 cSt. Let L denote the viscosity at 40 C of the L Series when the viscosity at 100 C is the same as the candidate oil, namely 11 cSt. Similarly, let H denote the viscosity at 40 C of the H Series when the viscosity at 100 C is the same as the candidate oil.

Viscosity Index is defined as:
*VI = [(L-Y)/(L-H)]*100*

As you can see, the candidate oil in question lies halfway between the L and H Series and the calculated V.I. is 50. If you had a candidate oil whose viscosity at 100 C fell on the H Series line, then Y would equal H, and the V.I. of the candidate would be 100.

Thus, from its definition, one can see that the V.I. is an arbitrary, relative, and unscientific method. It is *arbitrary* in the choice of reference oils (more to follow on that topic). It is a *relative* method because it is based on the comparison of a candidate oil with two reference oils. Finally, V.I. is *unscientific* because the rating number has no fundamental relationship to the actual change in viscosity with temperature for the candidate oil.

Figure 1.
Original Data used by Dean & Davis to define the H & L Reference Series



Flawed Data, Bad Calculations

Other problems are apparent from the curves in Figure 1. One is that the original data set for the reference oils is quite limited. For example, the H Series data goes from 6.79 to 20.85 cSt. at 100 C. There are a number of modern lubricating base oils and finished products with viscosities well below and well above this original data range. Several reasons explain the lack of a wider choice of H Series reference oils. One is that lower viscosity oils were not commonly used in the early part of the 20th century. Another is that the Saybolt viscometer gave inaccurate measurements below 50 seconds, which corresponds to about 7.3 cSt. at 98.9 C.

A second problem is that the reference curves converge tightly as the viscosity decreases. Thus, the calculated V.I. in the region below about 5.5 cSt. at 100 C is very sensitive to the actual viscosity measurements. Very small viscosity differences can lead to very large V.I. differences.

A third problem is that Dean and Davis used second-order (quadratic) polynomials to curve-fit their original data. The quadratic equations served as the basis for calculating the V.I. These equations proved to be a very poor choice because they gave wildly unrealistic values for L and H oils as the viscosity went below 40 Saybolt Universal Seconds. The quadratic equations also allowed two very different oils to have the same V.I. That is, for a given value of viscosity at 100 F, an oil could have the same V.I. with two different values of viscosity at 210 F.

That problem became increasingly more unbearable as higher V.I. oils, made from synthetic processes, became more prevalent. This irregularity proved to be so intolerable that it was finally corrected in 1964 with new logarithmic equations defined for oils above 100 V.I. At that time, the V.I. method was changed from ASTM D567 to the present ASTM D2270.

The main point to remember is that the original reference oil equations were so bad that V.I. values greater than 100 are now calculated in a different manner than V.I. values in the range of 0 to 100.

Continued on page 58

Table 1.
Influence of Viscosity at 100 C on ASTM V.I. Rating

Name of Base Oil	Vis, cSt @ 100 C	ASTM 2770 V.I.
ExxonMobil Spectrasyn 4	4.1	126
ExxonMobil Spectrasyn 6	5.9	138
Chevron Phillips Chemical Synfluid 2.5	2.4	104
Chevron Phillips Chemical Synfluid 4	3.9	124
Chevron Phillips Chemical Synfluid 6	5.9	137
Neste Nexbase 3020	2.2	90
Neste Nexbase 3030	3.0	111
Neste Nexbase 3043	4.3	123
Neste Nexbase 3060	6.0	129
Neste Nexbase 3080	7.8	130

Continued from page 56

From Bad to Worse?

Very soon after the original V.I. scale was proposed, its inventors worked on modifications to address some of the practical shortcomings. The detailed history of these changes is discussed in other publications, but I will summarize below. Unfortunately, despite the good intentions of the inventors, the modifications were patchwork measures that made the V.I. ratings even more arbitrary and unscientific.

In brief, during the period from 1929 to 1940, Dean, Davis and coworkers tried to extend the definitions of the L and H reference oils so that they covered a wider range of practical lubricating oil viscosities. Their final solution was to have three different definitions of the reference oils — depending on the viscosity range of interest. That solution would have unforeseen and serious consequences years later.

- **For the viscosity range of 2.0 to 4.2 cSt.** at 210 F, the inventors measured more accurate kinematic viscosities on a different set of reference oils — thought to be similar to the original oils, but in reality not. They proposed a new set of quadratic equations to define the L and H oils in this low viscosity region.
- **For the range 7.30 to 30.0 cSt.** at 210 F, the authors used the original 1929 set of quadratic equations to define the reference oils. However, in order to use the more modern centiStoke viscometers, the authors proposed that one measure the viscosity first in centiStokes, then convert to Saybolt Seconds to use the equations, and then convert the result back to centiStokes.
- **For the range 4 to 7.29 cSt.** at 210 F, the inventors used a special method of calculation which was equivalent to graphical interpolation on a highly magnified piece of graph paper. The interpolation was necessary because the inventors could not match up their original higher viscosity reference oils with their later choices of lower viscosity reference oils.

The bottom line is that, after 1940, the V.I. method used three different sets of reference oils. The end result was that lower viscosity oils (below about 5.5 cSt. at 100 C) were not rated on the same basis as higher viscosity oils. The assumed connection of V.I. to the rate of change of viscosity with temperature was severely broken.

Is There a Problem Here?

Nevertheless, the V.I. method has been working relatively well since its last major revision in 1964. Why should we now be concerned with understanding the problems in the definition of reference oils?

As noted in the introduction, I wanted to educate people about potential misinterpretation and misapplication of V.I. If one understands the limitations, it is

Continued on page 60

Continued from page 58

perfectly fine to continue to use the V.I. method as currently defined. However, one of the more significant impacts comes from API Document 1509, which classifies base oils in terms of V.I. and other chemical properties.

In Document 1509, API Group II and III base oils are distinguished solely in terms of their V.I. These API Group classifications affect the guidelines for product approval testing and read-across in a number of product areas, such as passenger car motor oils, diesel engine oils, transmission fluids, gear lubricants and others.

I first started researching the V.I. scale in 1979 as a freshman development engineer working on the process flow scheme for Chevron's Richmond Lube Oil Plant in California, which started up in 1983-84. During my hydrocracking pilot plant studies, I noticed the well-known phenomenon of "V.I. droop," whereby one feedstock, going through the same hydroprocessing operation, would result in lower V.I. for lower viscosity lube oils compared to the higher viscosity oils. This violated the fundamental assumption of the V.I. scale, which stated that oils produced from a given distillation or refining process would have the same V.I. rating, irrespective of the particular distillation cut (and viscosity).

Indeed, the very oils that Dean and Davis used to define the 0 and 100 V.I. series came from distillate cuts of the same two crudes, L and H respectively. As I struggled to explain why different lube oil cuts from the same process were assigned different V.I., I realized that the definition of the V.I. scale was responsible. The different V.I. ratings had no correlation to the actual viscosity-temperature properties of the lube oil cuts. Instead, the different V.I. ratings were a direct consequence of the irrational and inconsistent definition of the V.I. reference series.

Continued on page 62

Read More About It

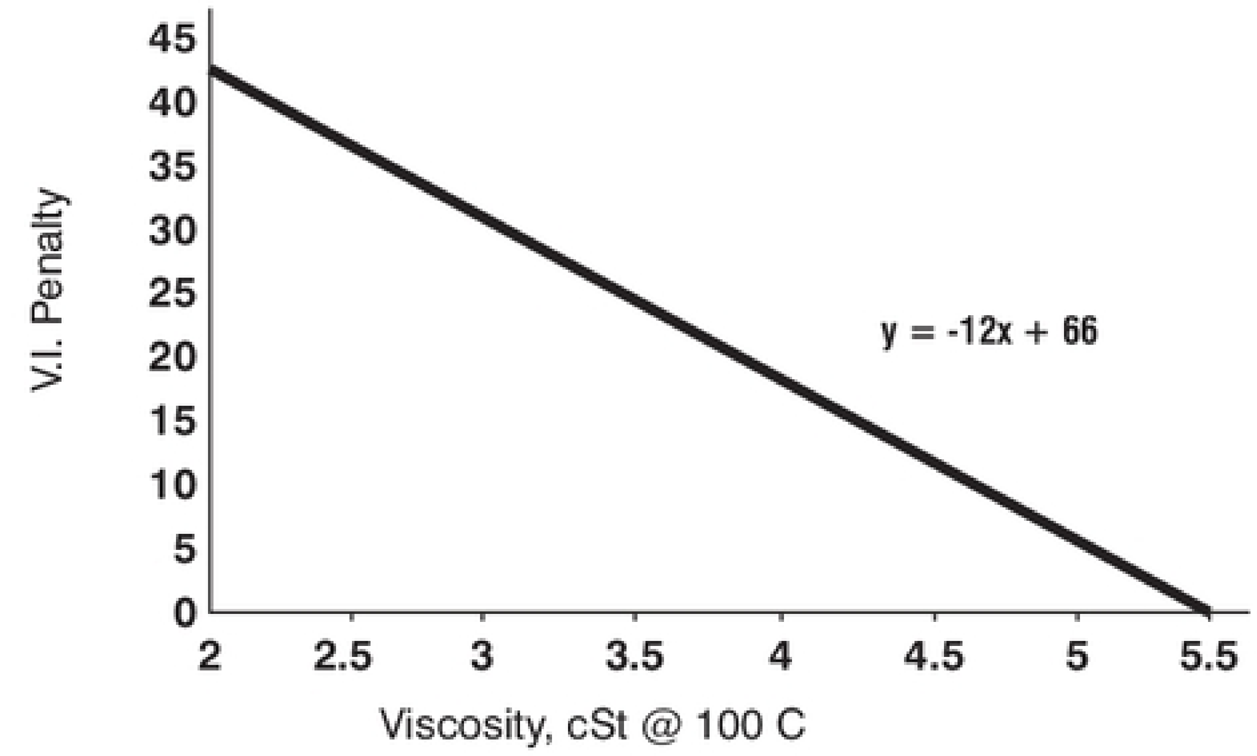
• Dean, E.W. & Davis, G.H.B., "Viscosity Variations of Oils with Temperature", Chem. Met. Eng., v36, 618 (1929).

• Wright, W.A., "A Proposed Modification of the ASTM Viscosity Index", Proc. API, v44, III, 535 (1964).

• Zakarian, J.A., "The ASTM Viscosity Index and Other Systems for Classifying Lubricating Oils", Nat. Petr. Ref. Assoc. Paper FL-82-85 (1982).

• Zakarian, J.A., "The Limitations of the Viscosity Index and Proposals for Other Methods to Rate Viscosity-Temperature Behavior of Lubricating Oils," SAE Paper 2012-01-1671.

Figure 2.
ASTM V.I. Penalty for Low Viscosity Oils



Continued from page 60

To truly appreciate the problem of the V.I. scale and the underrating of low viscosity oils, I did more research into the fundamental viscosity-temperature behavior of a consistent "100 VI" reference oil series. Based on that work, I developed a rough guide to the "V.I. Penalty" for low viscosity oils (Figure 2), which shows how the "V.I. droop" manifests itself if the original 100 V.I. oil were cut into different fractions.

Figure 2 shows that, as oil viscosity drops below 5.5 cSt. at 100 C, the ASTM V.I. does not accurately represent the "real V.I." for the oil. The ASTM V.I., because of the incorrect choice for low viscosity reference oils, will give a lower rating than that obtained by more consistent and scientific methods. For example, an oil of 3 cSt. viscosity will have an ASTM V.I. that is **30 numbers lower** than a comparable oil with viscosity greater than 5.5 cSt.

The V.I. penalty can be also be seen by examining V.I. ratings for other oils produced by the same process, but distilled to different viscosities. Table 1 on page 56 compares the V.I. ratings for 4 cSt. and 6 cSt. PAO products produced by both ExxonMobil Chemical and ChevronPhillips Chemical. The PAOs come from the same synthesis operation and should form a homologous series by the original assumption of V.I. But the 4 cSt. products are rated 12 to 13 V.I. numbers lower than the 6 cSt. products. The underrating is even more severe for PAO viscosities below 4 cSt.

Similarly, the table shows an example of oils from a commercial Group III supplier, Neste Oil. As the base oil viscosity drops from 8 to 2 cSt., **the V.I. declines by 40 numbers**. Yet these oils are made with same degree of refining severity from the same feed source.

In summary, the ASTM Viscosity Index is widely used as a measure of oil "quality." However, the rating method suffers from a number of inconsistencies that penalize lower viscosity oils compared to their higher viscosity counterparts. In addition, V.I. has no fundamental relation to the true viscosity-temperature behavior of an oil, even though it is widely presumed to have one. At best, V.I. is a very rough guide to viscosity-temperature behavior.

By understanding the deficiencies in the rating method, users will be better able to interpret and understand the actual V.I. numbers. ∎

Jack Zakarian, Ph.D., is manager of Global Driveline Technology at Chevron Lubricants in Richmond, Calif. For information about this article, reach him by e-mail at JAZA@chevron.com or phone (510) 242-3595.