

# The Limitations of the Viscosity Index and Proposals for Other Methods to Rate Viscosity-Temperature Behavior of Lubricating Oils

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## ABSTRACT

The Viscosity Index (VI), now defined by ASTM D 2270, is a relative number intended to represent the degree of change in viscosity versus temperature for lubricating oils. The basis for the rating scale, which was first defined in 1929, is a comparison of a candidate oil with two reference oils, one defined as “100 VI” and the other defined as “0 VI”. The VI scale has been widely used since its inception because of its simplicity and good correlation to a number of physical and chemical properties. However, the rating method suffers from a number of fundamental problems which are not realized by most users of the method today. This paper examines the assumption basis and historical development of the VI scale with an emphasis on the arbitrary and non-systematic manner in which the “100 VI” and “0 VI” reference series have been defined and modified over the years. This paper has 3 major objectives: (1) to educate users about the limitations of the VI method and the potential for misapplication and misinterpretation of an oil's VI rating; (2) to propose other, more systematic ways to define the viscosity-temperature behavior of a lubricating oil; (3) to stimulate further discussion and research on ways to improve the VI method.

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## ORIGINAL DEFINITION OF VISCOSITY INDEX

In 1929, two researchers at Standard Oil Development Company of New Jersey - E.W. Dean & G.H.B. Davis - published a short note in “Chemical and Metallurgical Engineering” [1] describing a way to compare the viscosity-temperature behavior of lubricants. Their proposed method produced a single number, termed “Viscosity Index”, which served as a relative ranking value for the rate of change of viscosity with temperature. The Viscosity Index (or VI) has since become one of the most popular, most useful, and most frequently quoted properties of a lubricating oil. [Figure 1](#) shows the original data used by Dean & Davis to develop their rating scale. Their data has been recalculated from Saybolt Universal Second viscosities to kinematic viscosities in centistokes, and the temperatures have been adjusted from the original 100°F and 210°F to 40°C and 100°C, respectively. Dean & Davis selected two reference oil families, one called the “L Series” (lower lubricating quality) and the other called the “H Series” (higher lubricating quality).

The calculation of VI is very straightforward and is shown with an example in [Figure 1](#). Let X denote the viscosity of a test oil at 100°C and let Y denote the viscosity of the test oil at 40°C. [Figure 1](#) depicts a triangle with the coordinates X = 11 cSt and Y = 134.5 cSt. The figure also shows a vertical dashed line passing corresponding to the 11 cSt test oil viscosity. Let L denote the viscosity at 40°C of the L Series when the viscosity at 100°C is the same as the test 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 test oil. The Viscosity Index is defined as:

$$VI = (L - Y) * 100 / (L - H) \quad (1)$$

The test oil in question lies halfway between the L and H Series and the calculated VI is 50.

There are a number of shortcomings readily 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 the 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

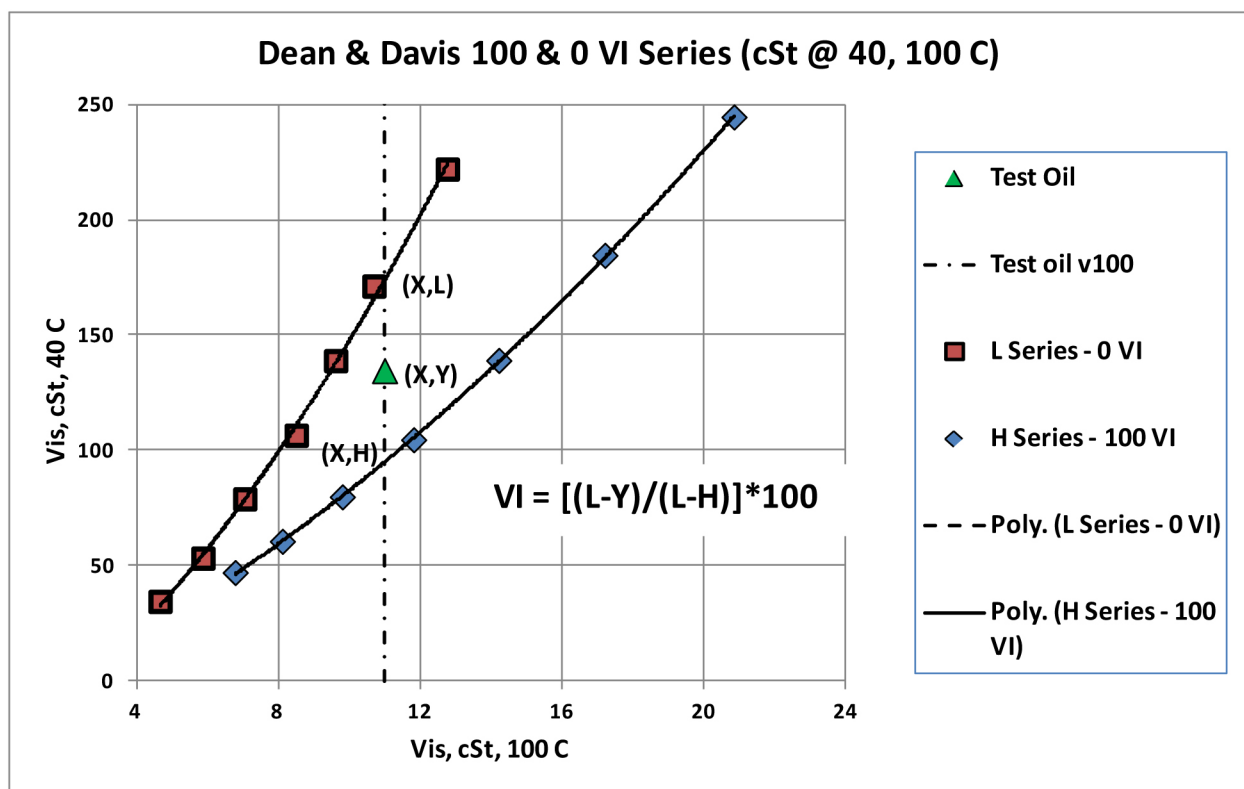


Figure 1. Original data used to define the 100 and 0 VI series. Data converted from SUS to cSt and from °F to °C.

commonly used in the early part of the 20<sup>th</sup> century. Another is that the Saybolt viscometer was not very accurate below about 50 seconds, which corresponds to about 7.3 cSt at 98.9°C.

A second shortcoming is that the reference curves converge tightly as the viscosity decreases. Thus, the calculated VI in the region below about 5.5 cSt @ 100°C is very sensitive to the actual viscosity measurements. Very small viscosity differences can lead to very large VI differences. A third shortcoming is that Dean & Davis used a second-order polynomial to curve fit their original data. The regression polynomial served as the basis for calculating the VI. We shall discuss the consequence of that choice later in this paper.

## FURTHER MODIFICATIONS TO VISCOSITY INDEX

Very soon after the original VI scale was proposed, its inventors worked on modifications to address some of the practical shortcomings. The accuracy of the ASTM D88-30 Saybolt Viscosity measurement was  $\pm 1\%$ . For an oil with 40 SUS at 210 F, this could result in an error of 33 points in the VI! So, in 1932, Davis, Lapeyrouse, and Dean [2] used the more accurate Ostwald viscometer to redetermine the kinematic viscosities of the H and L Series oils in the range of 40-50 SUS at 210°F. The viscosities were measured in centistokes and converted to SUS for purposes of

constructing VI tables. However, the authors noted that the newer data deviated from the values predicted by the second-order polynomials describing the original H and L series.

In 1940, Dean, Bauer, and Berglund [3] proposed further revisions to the VI tables in the range of 40-50 SUS at 210°F in order to make the reference oil data fall on a smooth curve. They also presented new second-order polynomial equations, covering the range below 40 SUS (4.2 cSt). The extended equations were meant for centistoke measurements only.

Concurrently, Fenske and coworkers at Pennsylvania State College [4] were also working on ways to describe the viscosity-temperature coefficient of lubricating oils. They collected a large number of lubricating oils from Pennsylvania sources and fractionated the samples in efficient columns under high vacuum. They then measured the viscosities of the fractions at both 100°F and 210°F. Fenske et. al. proposed their data as the basis for a more consistent H Series. Dean & Davis did not describe the origin of their H Series samples, however, the samples were believed to be derived from Pennsylvania crude. Fenske's H Series data set consisted of 230 oils, ranging in viscosity from 3.31 to 181.5 cSt at 210°F. Figure 2 is a log-log plot of the Fenske H Series compared to the original data of Dean & Davis. The data are well represented by an equation of the form:

$$\log(\text{vis, cSt, 40 C}) = A + B \cdot \log(\text{vis, cSt, 100 C})$$

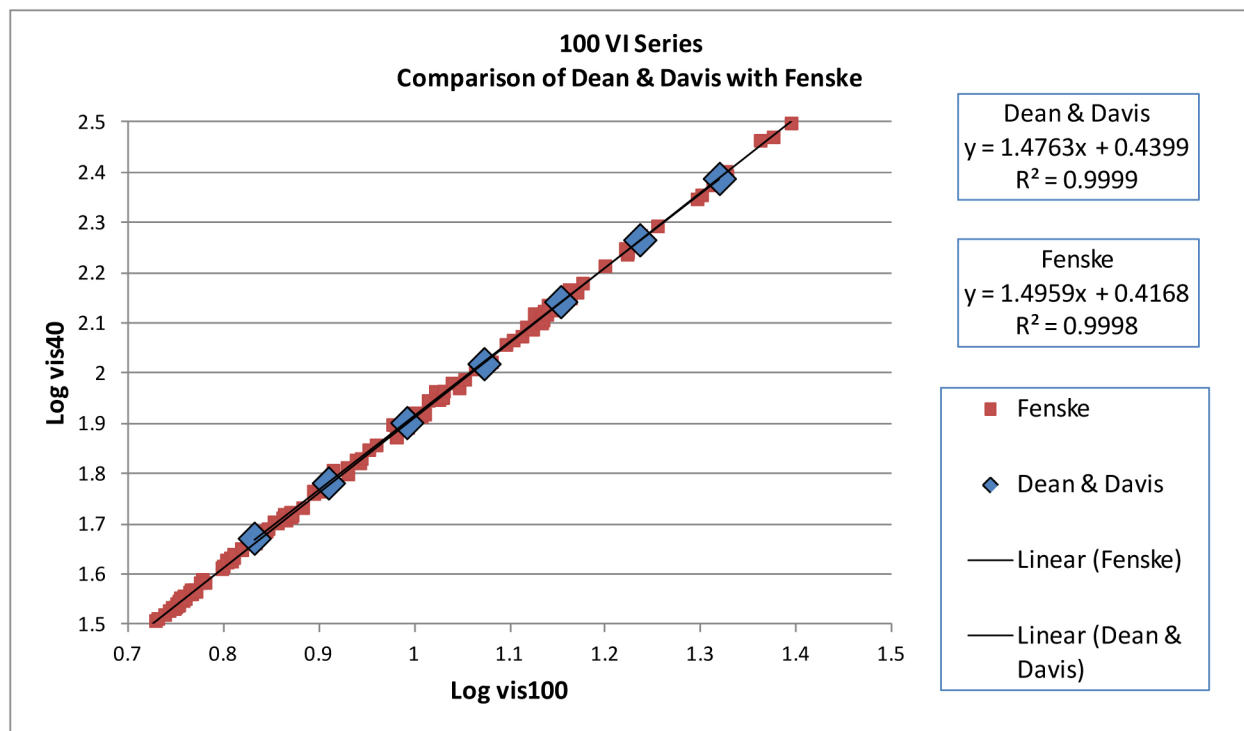


**Figure 2. Comparison of Dean & Davis 1929 data with Fenske H Series.**

Fenske also proposed a new data set for the L Series oils, which were believed originally derived from Gulf Coast crude. His team did a careful fractionation and viscosity measurement of coastal oil from Sugarland crude. [Figure 3](#) compares the Fenske data for the 0 VI Series with the original Dean & Davis data. Again, the log-log plot shows a linear relation.

Fenske et. al. proposed the concept of a “Kinematic Viscosity Index” using their H Series for the 100 VI reference line. Curiously, they did not use their own data for the L Series - preferring instead to use the original Dean & Davis data. This is because the VIs of the Fenske L Series, calculated for each fraction using the 1929 method, ranged from -33 to +28. A fundamental assumption of Viscosity Index is that the VI “...is independent of the actual viscosity of the oil in question and has the nature of a constitutive property: in other words, the viscosity indexes of all lubricating fractions, separated or refined by conventional methods from any given crude, ordinarily are approximately constant” [1]. It is the present author's view that the underlying assumption of VI is not correct and that Fenske's data confirmed the assumption was not valid. Nevertheless, Fenske et. al. rejected their own L Series data with the following explanation: “In view of the fact that a material change in the slope of the 0 VI curve would incorporate serious differences in the calculated viscosity indexes of oils, it was thought inadvisable to use the experimental data, for a zero VI oil is undoubtedly a less definite thing than the 100 VI oils...” [4].

The 1940 paper by Dean et. al. [3] did not cite or discuss Fenske's work, although the authors were well aware of it. [Table 1](#) of their paper includes a column which compares Fenske's Kinematic VI to their new proposed VI and in each instance there was a large disagreement between the two rating methods.

Zakarian [5] presented a critical analysis of the basis of the VI scale and noted that the approach adopted by Dean et. al. resulted in serious inconsistencies between different viscosity ranges. Oils with viscosity above 7.2 cSt at 210°F were described by the 1929 data set. Oils with viscosity from 2.0 to 4.2 cSt at 210°F were described by the 1940 data set. And oils with viscosity between 4.2 and 7.2 cSt were described by smoothing and extrapolation of the first two data sets. When the different data sets were compared on log-log plots, it was readily apparent that the data were discontinuous. Even though [Figures 2 & 3](#) show that the 1929 data sets agreed with the more detailed data generated by Fenske and coworkers, the extension of the VI scale to the lower viscosity ranges did not agree at all with the Fenske data. The extension into the lower viscosity region was arbitrary and inconsistent with log-log relation demonstrated by Fenske. Second-order polynomial fits proved unsuitable to describe the H & L Series. In fact, the polynomials proposed by Dean & Davis actually resulted in negative values of the H & L viscosities at 100°F when the viscosity at 210°F fell below the range of 34-36 SUS.

Another major undesirable characteristic of the 1940 VI scale was a reverse curvature noted for oils in the region