Viscosity Index Enhancement Through Dumb-Bell Blending of Lubricants

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1. Introduction

Viscosity index is an arbitray number used to characterize the variation of lubricant viscosity with respect to temperature. It is well recognized in the oil industry that as refining severity increases, lubricant VI increases. Consequently, VI is often perceived as a measure of lubricant quality. Futhermore, a 95 VI minimum specification is commonly imposed in marketing base stocks. These factors provide the incentitive for this study to carefully analyze VI definition and two component viscosity blending techniques to investigate how they affect VI change, and finally to examine possible avenues to produce 95+VI base stocks by blending sub-95 VI base stocks.

2. Results and Discussion

2-1. Definition of Viscosity Index

The viscosity index of lubricant is not a measured property, rather it is calculated according to ASTMD2270(1) as follows:

Procedure A-For oils of viscosity index up to and including 100,

$$\text{Viscosity index} = [\mu_1 - \mu_0/\mu_1 - \mu_2] \times 100 \quad (1)$$

where

μ_0 = kinematic viscosity at 40℃ of the oil whose viscosity index to be calculated.

μ_1 = kinematic viscosity at 40℃ of an oil of O viscosity index having the same viscosity at 100℃ as the oil whose viscosity index is to be calculated.

μ_2 = kinematic viscosity 40℃ of an oil of 100 viscosity index having the same kinematic viscosity at 100℃ as the oil whose viscosity index is to be calculated.

Procedure B-for oils of viscosity index of 100 and greater

$$\text{Viscosity index} = [\text{antilog } N\text{-}1/0.00715] + 100 \quad (2)$$

where

$N = \log \mu_2 - \log \mu_0 / \log \mu'$

μ' = kinematic viscosity at 100℃ of the oil whose kinematic viscosity is to be calculated

Eq. (1) is a linear interpolation to establish VI between 0 and 100 for lubricants having VI up to and including 100. But, for lubricants of VI of 100 and greater, Eq. (2) assumes an expenential form.

Since VI is a calculation, repeatability and reproducibility are controlled by the accuracy of kinematic viscosity measurements. VI reproducibility is shown in Fig. 1(1). The constant kinematic viscosity at 100℃ contours show that the lubricant viscosity decreases, VI reproducibility improves. For a 4 cSt, 100 VI lubricant, a maximum VI difference of 6 is possible. As VI increases, VI precision increases for VI's of below 100 and decreases for above 100 VI. This contrasting behavior is caused by the difference in VI calculations using Eq. (1) for below 100 VI and Eq. (2) for above 100 VI.

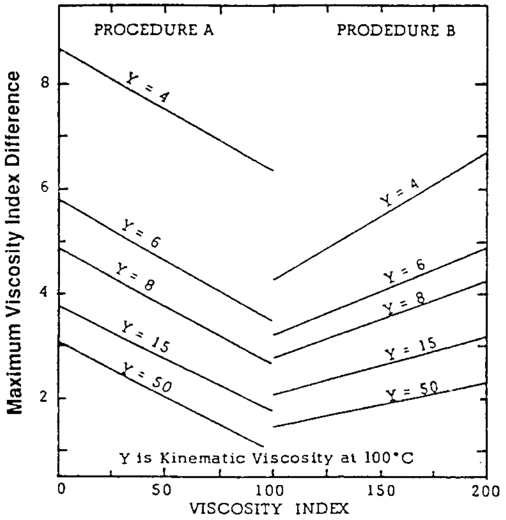


Fig. 1. Reproducibility of viscosity index (Ref. 1) viscosity index.

2-2. Two Component Viscosity Blending

Estimating the volume fractions of two given lubricants when blending to meet a specified kinematic viscosity at a given temperature is a common problem for the lubricant blenders. Although a number of blending calculation techniques have been applied, the most widely accepted one is the Wright method described in ASTMD341(2). The method includes a graphical method which uses an ASTM viscosity-temperature chart by plotting the known viscosity data for each component and carefully draw straight lines through the points. The volume fraction of low viscosity oil or high viscosity oil can be estimated by carefully measuring the distance between the straight lines for the two oils where they cross the line of the desired blend kinematic viscosity. The required blend may also be calculated using a calculator or computer. The mathematical relationships to be used are:

$$[\text{Volume fraction}]_{H(40)} = [(\log\cdot\log \mu_H - \log\cdot\log \mu_B)(\log\cdot\log \mu_L - \log\cdot\log \mu_L')/(\log\cdot\log \mu_H - \log\cdot\log \mu_H')(\log\cdot\log \mu_B - \log\cdot\log \mu_L) + 1]^{-1} \quad (3)$$

$$[\text{Volume fraction}]_{H(100)} = [(\log\cdot\log \mu_H' - \log\cdot\log \mu_B')(\log\cdot\log \mu_L - \log\cdot\log \mu_L')/(\log\cdot\log \mu_H - \log\cdot\log \mu_H')(\log\cdot\log \mu_B' - \log\cdot\log \mu_L') + 1]^{-1} \quad (4)$$

where

μ = kinematic viscosity at 40℃

μ' = kinematic viscosity at 100℃

subscripts:

B = blend

H = high viscosity oil

L = low viscosity oil

(40) = 40℃

(100) = 100℃

Either Eq. (3) or Eq. (4) can be used to calculate the volume fraction of high viscosity oil at 40℃ or 100℃ respectively, with the known viscosity data for each component and a desired blend viscosity.

Both the graphical and computational methods provide a desired blend with sufficient accuracy of viscosity values. If, however, the kinematic viscosity-temperature data must be extrapolated to temperature for above or below the data, the accuracy of the methods may suffer significantly.

2-3. Analysis Procedure

VI enhancement through dumb-bell blending was studied by calculating blend kinematic viscosities using Eq. (3) and (4) for lubrications at 40 and 100℃, respectively. then calculating the VI using Eq. (1) or (2) whichever is appropriate for a given case.

Along with this study, a series of base stocks was blended in various combinations to produce blended base stocks in ISO viscosity grades 46, 68, 100, 150, 220 and 320 with a minimum of 95 VI to investigate the predictability of VI. Table 1 lists viscometric properties for these base stocks. Fig. 2 shows the

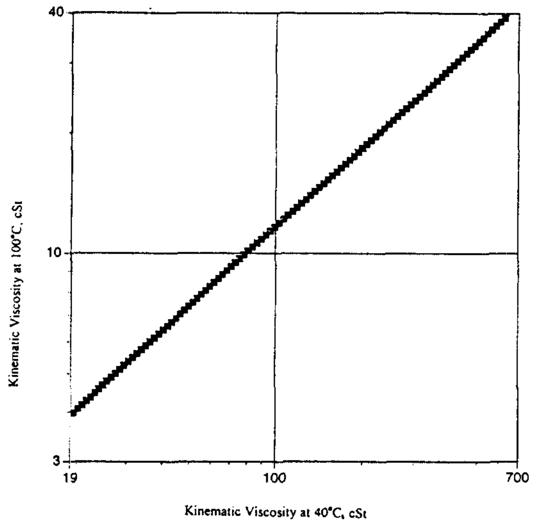


Fig. 2. Kinematic viscosity variation for blending a 100 SUS neutral and bright stock with 100 VI using ASTM D341.

Table 1. Viscometrics of Base Stocks used to Produce ISO VG 46, 68, 100, 220 and 320 Blends with 95+ VI

Kinematic Viscosity, cSt		VI
40℃	100℃	
19.95	4.01	95
29.86	5.24	106
31.89	5.28	95
91.67	10.62	98
107.42	11.46	93
111.30	11.64	91
496.52	31.94	95

VI calculated from predicted blend kinematic viscosities plotted against the calculated VI for the measured kinematic viscosity of blended base stocks. Despite some scatterings, the plot shows that they are in good agreement, indicating that VI can be accureately calculated using ASTMD341. Deviations between the measured and predicted VI may be attributable in most part to measurement error in viscosity.

2-4. Viscosity Index Enhancement

When two lubricats with vastly differing vis-

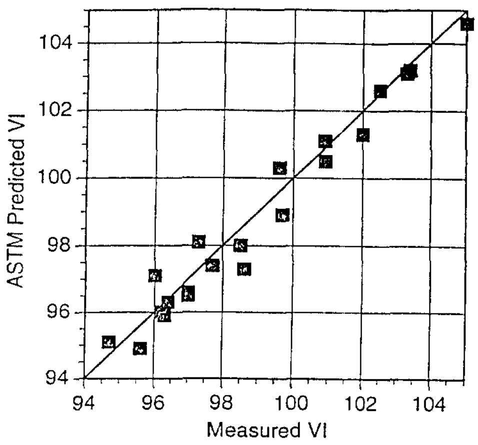


Fig. 3. Predicted VI using ASTM D341 blending calculations.

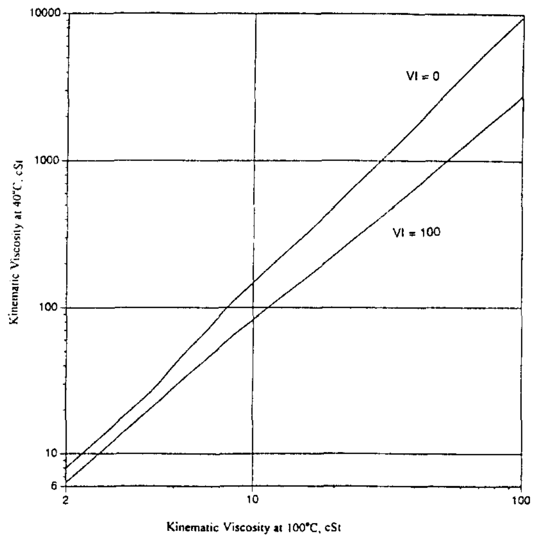
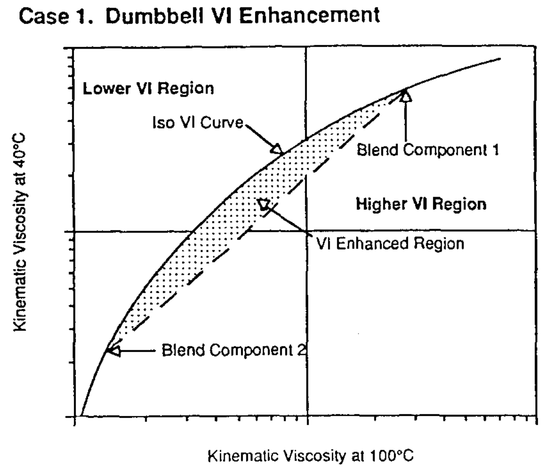


Fig. 4. Kinematic viscosity data defining 0 and 100 viscosity index.

cosities are blended at different volume ratios, the kinematic viscosity of blends can be easily calculated by using Eq. (3) and (4), or ASTM D341 graphical method. Viscosity variation is a logarithmic function and a straight line results when the log kinematic viscosity at 40℃ is plotted against the log kinematic viscosity at 100℃ for various combinations of the two lubricants, as shown in Fig. 3. Similarily, when kinematic viscosity data defining 0 VI and 100



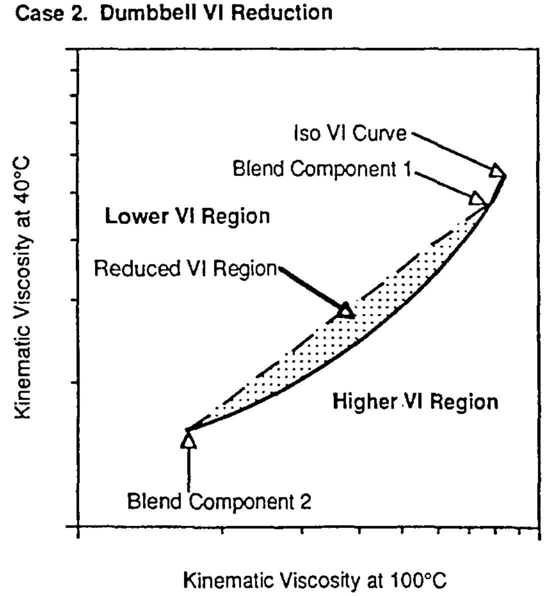


Fig. 5. Illustration for VI enhancement possibility from dumb-bell blending.

VI are plotted on a log-log chart, the curves dipicted in Fig. 4 are not straight, rather showing kinks (non-linearity) at about 4.2 and 7.3 cSt at 100℃. This non-linear nature of the curves is the foundation which makes VI enhancements through dumb-bell blending possible.

The VI change through blending is determined by the relationship between the linear line of two component kinematic viscosity and the 0 and 100 VI curves. Fig. 5 illustrates two possible cases: As shown in Fig. 3, when blending two lubricants having the same VI, the final VI is found along a straight line conecting the lubricant kinematic viscosity on the log-log plot. When the chord connecting the kinematic viscosity of blending components subtends the constant VI curve, the final blend will be located on a different constant VI curve. This new curve is located in the higher VI region, thus, VI enhancement will occur. When, however, the chord connecting the two blending component viscosities is above the constant VI curve, VI reduction will result. Fortunately, VI reduction is less common than VI enhancement and the magnitude is much less.

2-5. VI Enhancement Calculation Through Dumb-bell Blending

In order to illustrate the blending effect, calculated VI enhancement values are plotted in Fig. 6 for a case of blending a light base stock and a heavy base stock both having the same (iso) VI. VI's of 60, 80 and 100 are chosen for this illustration. It can be seen from the curves that a maxinum VI enhancement is observed for each iso-VI combination at approximately 16% heavy base stock. The maximum VI enhancement rises from 9 to 14 as VI drops from 100 to 60. Because of the discontinuous regions in the VI reference data sets, the VI enhancement curves are not smooth.

Similar curves are presented in Fig. 7 for blending light and heavy base stocks with VI values of from 100 to 140. Again, a VI enhancement is noted for each iso-VI combination. Unlike to the previous case, the VI enhancement increases from 9 to 13 as VI increases from 100 to 140. This is opposite from the behavior observed for iso-VI blends from 100 to 60. This VI blending anomaly occurs because the VI function takes a different form above and below 100 VI, as indicated by Eqs. (1) and (2).

To further investigate the viscosity effect

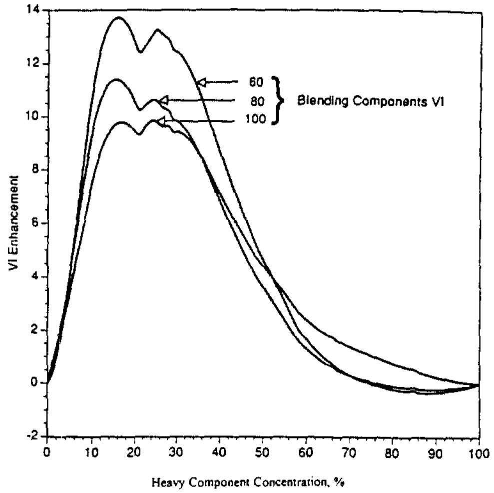


Fig. 6. VI enhancement from dumb-bell blending 100 SUS neutral and bright stock having iso-VIs.

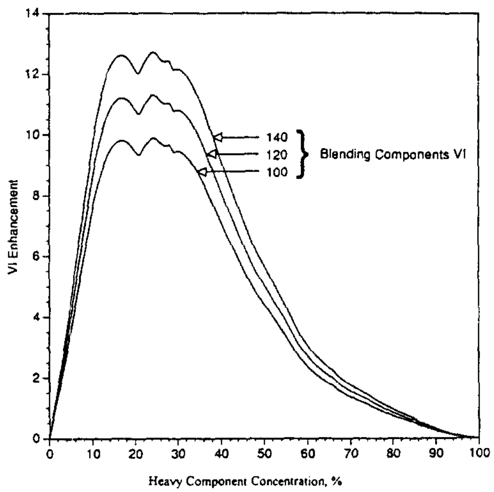


Fig. 7. VI enhancement from dumb-bell blending 100 SUS neutral and bright stock having iso-Vis.

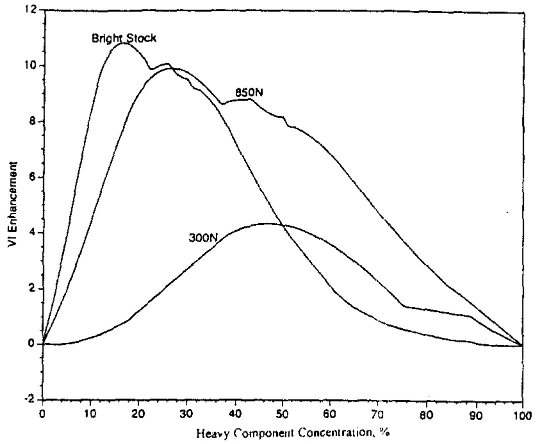


Fig. 8. VI enhancement from blending 100 SUS neutral and heavy stock having 90 VI.

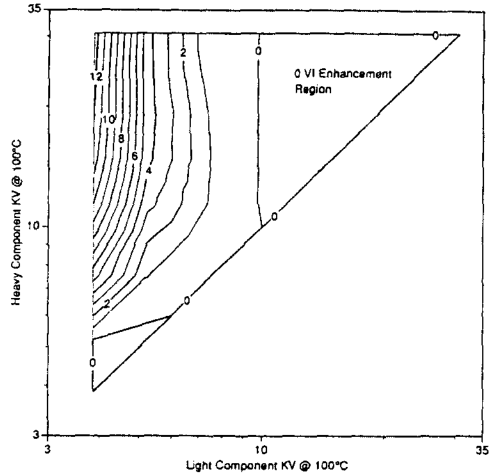


Fig. 9. Maximum Vi enhancement for combinations of 90 VI lubricants.

of heavy blending component, the calculated VI enhancement for blending a light base stock (100 SUS) with 300 and 850 SUS neutrals and a bright stock is plotted in Fig. 8. All base stocks have a VI of 90. The resulting plot shows that as the viscosity difference between blending components increases, the maximum boost achievable increases. The maximum VI boost is 4 for 300 SUS neutral base stock, 10 for the 850 SUS neutral and 11 for the bright stock.

Fig. 9 presents a contour plot of calculated maximum VI enhancement possible through dumb-bell blending combinations of 90 VI lubricants. VI enhancements of 10 and greater are possible when blending two 90 VI lubricants. Once again, the contour plot clearly indicates that the VI enhancement increases as the viscosity difference between the two blending components increases and it is particularly strong when the kinematic viscosity of li-

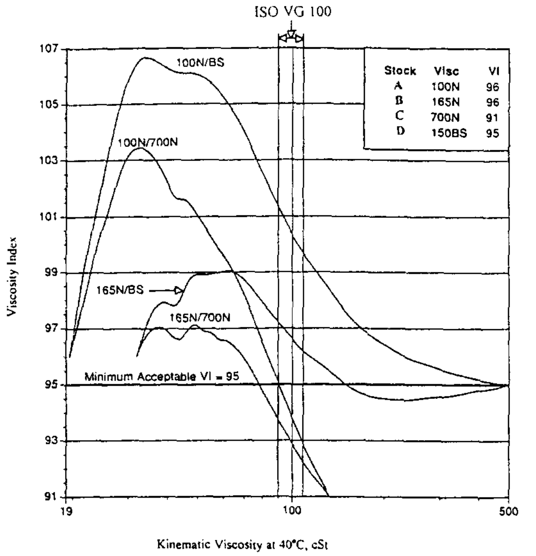


Fig. 10. Dumb-bell blends using commercial base stocks.

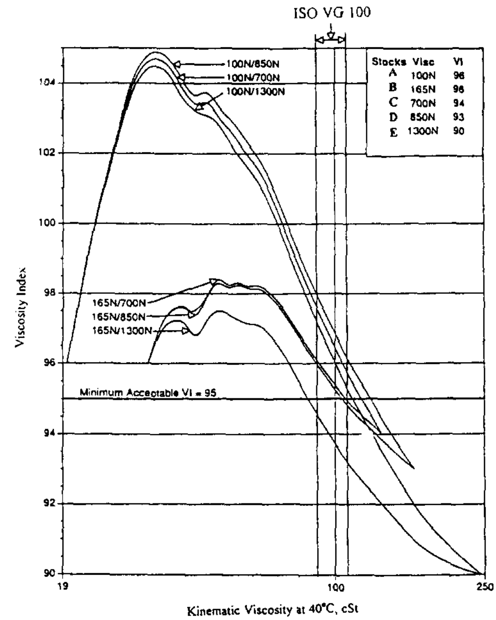


Fig. 11. Dumb-bell blends using commerical base stocks.

ght component is less than 5 cSt at 100℃. When both blending components have a kinematic viscosity of above 9.5 cSt at 100℃, no VI enhancement is observed; rather a mild (less than one) VI reduction is shown in this region.

2-6. Dumb-bell Blending Applications

Let's assume that a lube refiner's current manufacturing slate of base stocks only includes a 96 VI 100 SUS neutral a 96 VI 165 SUS neutral, a 91 VI 700 SUS neutral and a 95 VI 150 SUS bright stock. Also, assume that the refiner must make available a base stock meeting 95 VI minimum specification for external sales. Although this refiner does not produce a heavy neutral base stock with 95 +VI, dumb-bell blending makes this possible.

Fig. 10 presents dumb-bell blends which result from the base stocks currently produced by the refiner. ISO viscosity grade 100 is chosen to define the target viscosity for discussion. Using the current base stock slate, a 95 VI, ISO viscosity grade 100 base stock can be produced by blending the 100 or 165 SUS neutrals with the bright stock, but not with 700 SUS neutral. Unfortunately, greater than 40% bright stock is required at the target viscosity. This high usage of bright stock would probably not be acceptable in the market place for sale because of quality concerns of the blended base stocks. Accordingly, a marketable 95 VI, ISO viscosity grade 100 base stock can not be produced using the current base stock slate.

Other options for producing such a base stock (ISO viscosity grade 100 with 95 VI) are possible if the refiner additionally produce the heavy neutrals of 700 SUS with 94 VI, 850 SUS with 93 VI and 1300 SUS with 90 VI. Fig. 11 illustrates such options which include the combinations of 100/850N, 100N/700N, 100 N/300N, 165N/700N and 165N/850N. A combination of 165N/1300N unexpectedly fails to meet the production target. It is also interesting to note that the 850 SUS neutral with 93 VI and the 700 SUS neutral with 94 VI essentially produce equivalent VI enhancing blends with the 165 SUS neutral base stock.

Therefore, there may be a processing economic incentive for producing the 850 SUS neutral, instead of the 700 SUS neutral, for dubmbell blending use.

While dumb-bell blending can producee ISO viscosity grade 100 base stock with VI 95+, other important properties such as volatility and low temperature may suffer. The volatility of dumb-bell blended base stocks may be controlled by the amount and volatility of the light component. Although low temperature fluidity may still be less than desirable, this in many cases is not considered as a specification property for the ISO viscosity grade 100 base stocks intended for commercial engine oil application.

3. Concluding Remarks

Viscosity index is often perceived as a measure of quality and used as such in marketing lubricants. But, a lubricant with an enhanced VI can be resulted from a dumb-bell blending efffect when two lubricants having the same VI, but different viscosities are blended together. This VI enhancement is unrelated to the measure of lubricant quality. This study provides details of the dumb-bell blending effect and other related results. Key findings include.

(1) VI enhancements of 10 and greater are possible over a limited viscosity range for dumb-bell blending combinations of 100 SUS neutral and 150 SUS bright stock.

(2) The VI enhancement through dumb-bell blending increases as the difference in component viscosity increases.

(3) No VI enhancement is observed if both blending components have a kinematic viscosity at 100℃ of greater than 9.5 cSt.

(4) Dumb-bell blending can be used to produce an ISO viscosity grade 100 base stock with a minimum VI of 95 if high-treated heavy neutral base stocks become available.

References

1. ASTM D2270, "Standard Practice for Calculating Viscosity Index From Kinematic Viscosity at 40 and 100℃", 1992 Annual Book of ASTM Standards, Vol. 5.02, p. 114-119 (1992).
2. ASTM D341, "Standard Viscosity-Temperature Charts for Liquid Petroleum Products", 1992 Annual Book of ASTM Standards, Vol. 5.01, p. 137-141 (1992).