Proposals to Improve the Viscosity Index Method, ASTM D2270

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Objectives

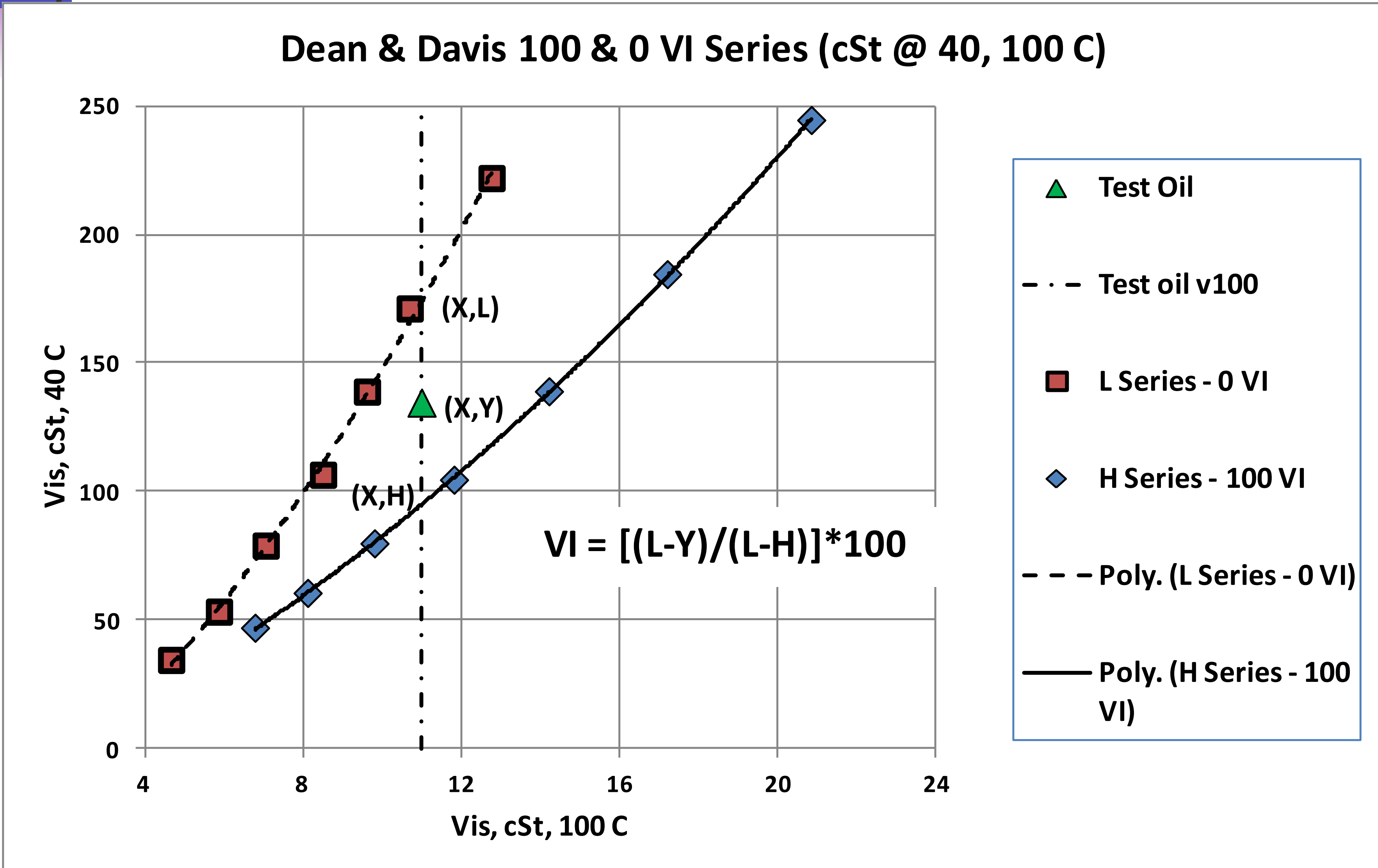
- To educate users about the limitations of the V.I. method and the potential for misapplication and misinterpretation of an oil's V.I. rating.
- To propose other, more systematic ways to define the viscosity-temperature behavior of a lubricating oil.
- To stimulate further discussion and research on ways to improve the V.I. method.

Original Definition of Viscosity Index

- Proposed by Dean & Davis, Standard Oil Development Company of New Jersey, in 1929.
- The V.I. is a single number which serves as a <u>relative ranking</u> of the rate of change of viscosity with temperature.
- The V.I. is calculated by comparing the viscosity of a candidate oil at 40°C to the viscosities of “good” and “poor” reference oils at 40°C.

Original Definition of Viscosity Index

- Dean & Davis fractionated 2 crude oils into narrow-boiling-range cuts.
- The individual fractions of crude oil from Pennsylvania were designated as the “H” Series and each assigned a V.I. of 100.
- The individual fractions of crude oil from the Louisiana Gulf Coast were designated as the “L” Series and each assigned a V.I. of 0.
- The following slide shows their original data, converted from SUS to cSt and from °F to °C.



Dean & Davis 100 & 0 VI Series (cSt @ 40, 100 C)
250
200
150
100
50
0
4
8
12
16
20
24
Vis, cSt, 40 C
Vis, cSt, 100 C
(X,L)
(X,Y)
(X,H)
VI = [(L-Y)/(L-H)]*100
Test Oil
Test oil v100
L Series - 0 VI
H Series - 100 VI
Poly. (L Series - 0 VI)
Poly. (H Series - 100 VI)

Deficiencies of Original V.I. Definition

- Reference oil data set is very limited. H Series data ranges from 6.79 to 20.85 cSt @ 100°C.
- Lower viscosity oils not commonly used as lubricants at that time. Also, SUS viscometers not accurate below about 7.3 cSt @ 98.9°C.
- The H and L Series converge tightly as the viscosity decreases. This means that very small viscosity differences will result in very large V.I. differences.
- Dean & Davis used a 2nd order polynomial to curve fit their data. For V.I.s >130, the curves of constant V.I. went through a maximum, allowing two very different oils to have the same V.I.
- The absurd results for >100 V.I. were fixed in 1964 when ASTM D567 became the current D2270. But the fix was designed to preserve the inconsistencies in the 100 V.I. series.

Inconsistencies in the V.I. Scale

Following changes in 1932 & 1940, the situation was as follows:

- The region above 7.29 cSt @ 210°F was defined by parabolic equations fitting the original 1929 data.
- The region from 2.0 – 4.2 cSt @ 210°F was defined by parabolic equations fitting a different set of data than the original 1929 data.
- The region between 4.2 – 7.29 cSt was defined by graphical interpolation of the 1929 & 1940 data.
- NOTE: The current ASTM D2270 uses 16 different 2nd order polynomial equations to describe the H & L series!

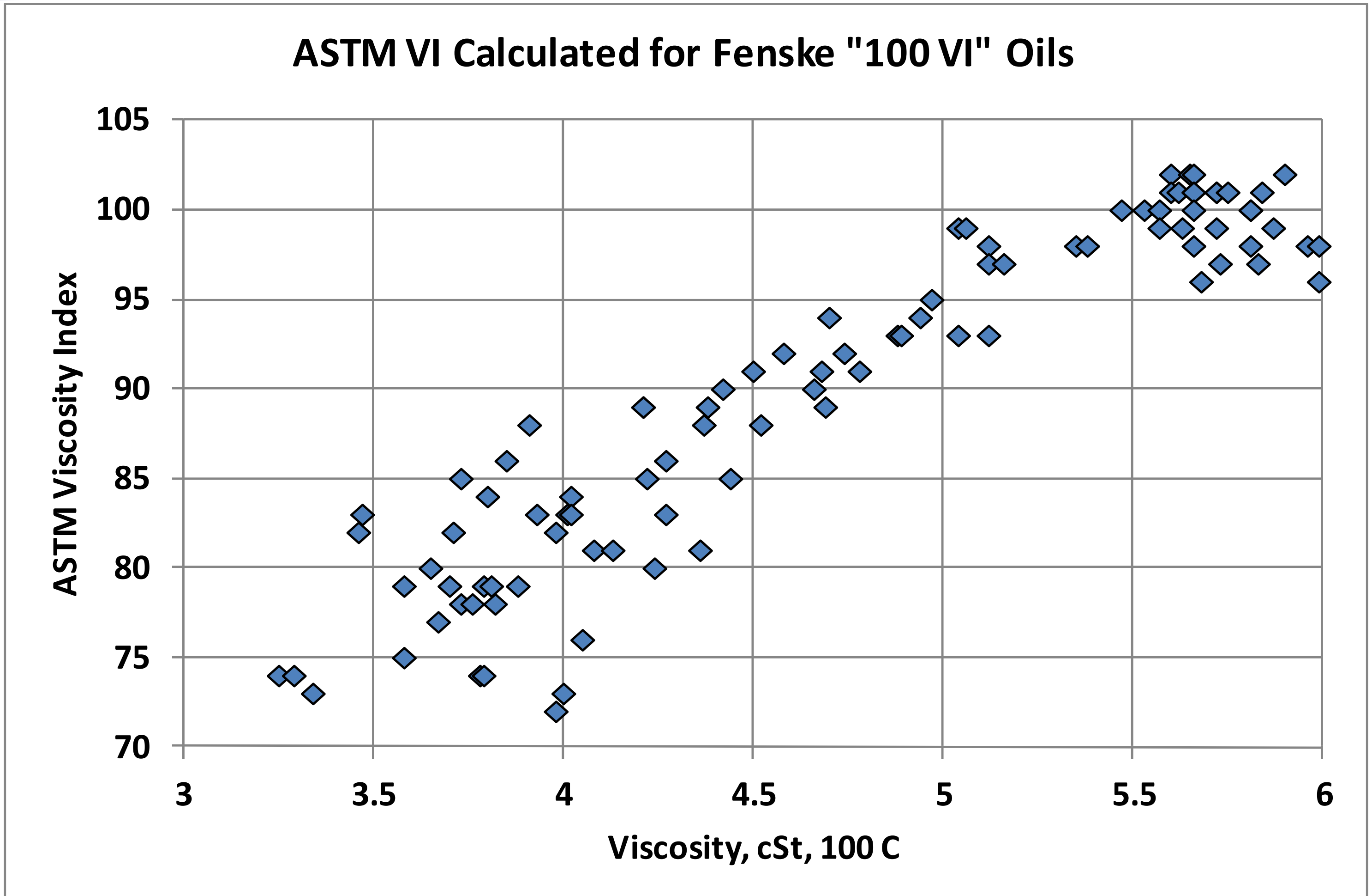
More Rational Attempts to Define a V.I. Scale

- In 1935, Fenske and coworkers at Pennsylvania State College fractionated a large number of lubricating oils from Pennsylvania sources.
- Their H Series consisted of 230 oils, ranging in viscosity from 3.31 – 181.5 cSt @ 210°F.
- Their L Series data came from a careful 19-cut fractionation and measurement of coastal oil from Sugarland crude.
- They proposed log-log equations to describe their reference oil series.

Fundamental Assumption of V.I. Scale

- The V.I. "…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". [Dean & Davis, 1929]
- The V.I.s of the Fenske L Series fractions, using the 1929 method, ranged from -33 to 28.
- The chart on the next slide shows that the fundamental assumption also does not hold for the Fenske H Series. As the viscosity decreases, the V.I. drops.

Fenske 100 V.I. H Series
(Pennsylvania Crude Fractions)



Why Does the Definition of V.I. Matter?

- V.I. is widely used and unquestionably accepted in numerous commercial transactions.
- V.I. is used as a quality indicator for base oils and finished products.
  - Previous slide shows that 4 & 6 cSt oils from the SAME reference series are given V.I. values of 83 & 100, respectively. The "quality" of lower viscosity oils is <u>dramatically underrated</u> by the current V.I. scale.
- API Group classifications, done by V.I., affect guidelines for approval testing & readacross.

Criteria for an Improved V.I. Scale

The new method should:

- Be based on an underlying principle, such as the slope of viscosity-temperature plots, or the comparison with well-defined reference oil series.
- Not <u>underrate</u> very low viscosity oils. It should also not <u>overrate</u> very high viscosity oils.
- Preferably give similar ratings as the current V.I. for oils in the range of 5.5 to 35 cSt @ 100 C.
- Correctly reclassify low viscosity oils from Group 3 refining processes as truly Group 3, not Group 2 as currently done.

Previous Proposals

- Zakarian made 3 proposals in 2012* for alternate ways to characterize viscosity-temperature behavior.
- Proposal #1 used the slope (S) from Roelands equation:
  - $\text{Log}(\log \eta + 1.2) = -S*\log(1 + t/135) + \log G$
- Proposal #2 used the Fenske H & L series to calculate V.I.. This method, used by Fenske, is termed "Kinematic V.I."
- Proposal #3 used only the H Series and calculated the "Proportional V.I." as follows:
  - PVI = (100 V.I. reference oil vis at 40°C / test oil vis at 40°C)
- Each of the 3 proposals had shortcomings in meeting the criteria on the previous slide, so this talk will provide more proposals for consideration.

*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.

Improve the Reference Series

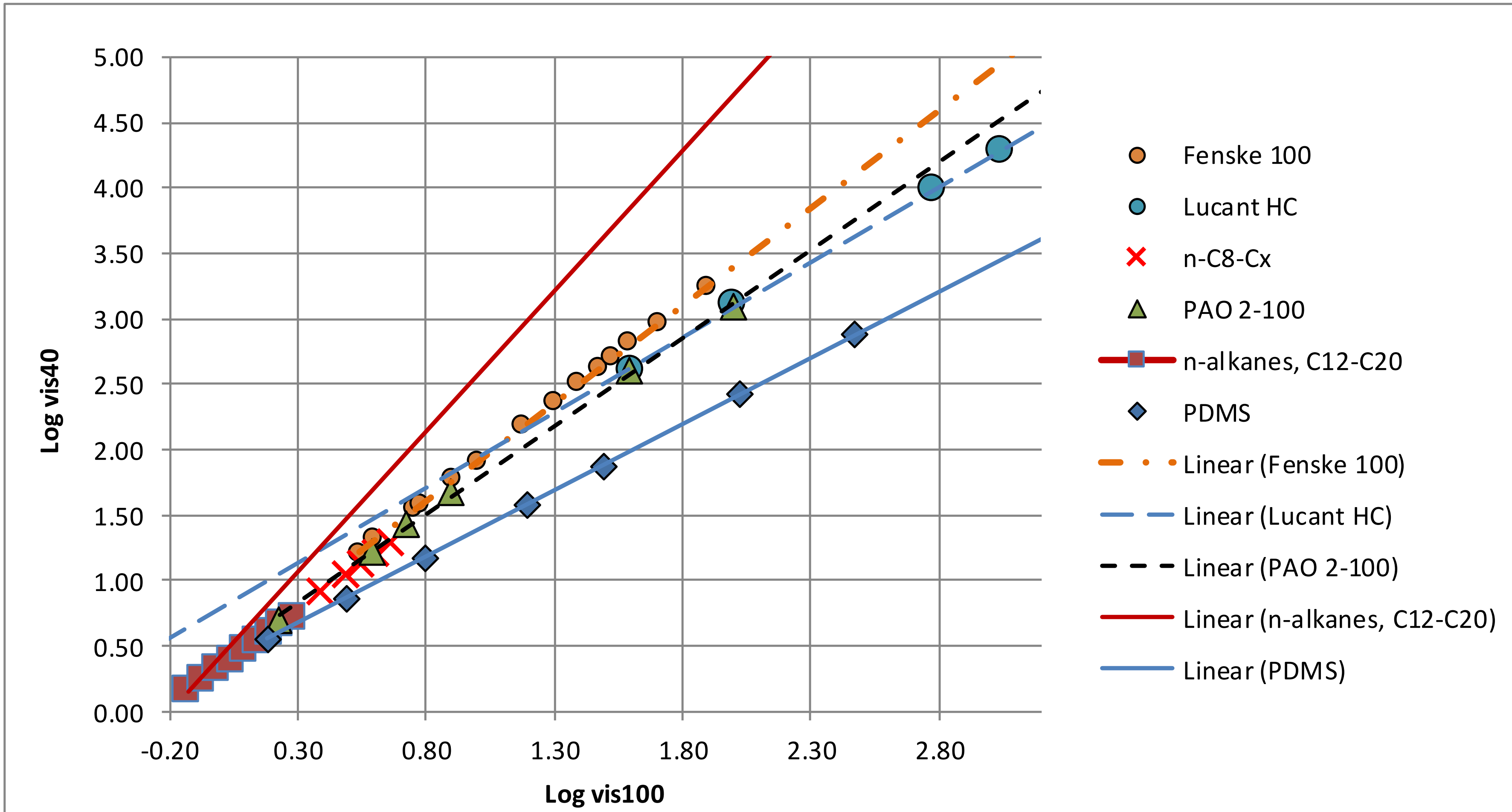
- There are 2 major ways to classify viscosity-temperature relations: (1) absolute, and (2) relative.
- Absolute methods generally use a viscosity-temperature equation and devise a way of comparing the "slopes" for different oils.
- Relative methods, such as ASTM D2270, compare a candidate oil to one or more reference oil series.
- Given the inconsistent, patchwork nature of the D2270 H & L series, one opportunity for improvement is to use more rational reference series.
- For many homologous* fluids, a plot of log(vis40) versus log(vis100) gives a straight line. Thus, such fluids could form the basis for a more rational system.

*Homologous is defined as "having the same or a similar relation; corresponding, as in relative position or structure" (www.dictionary.com)

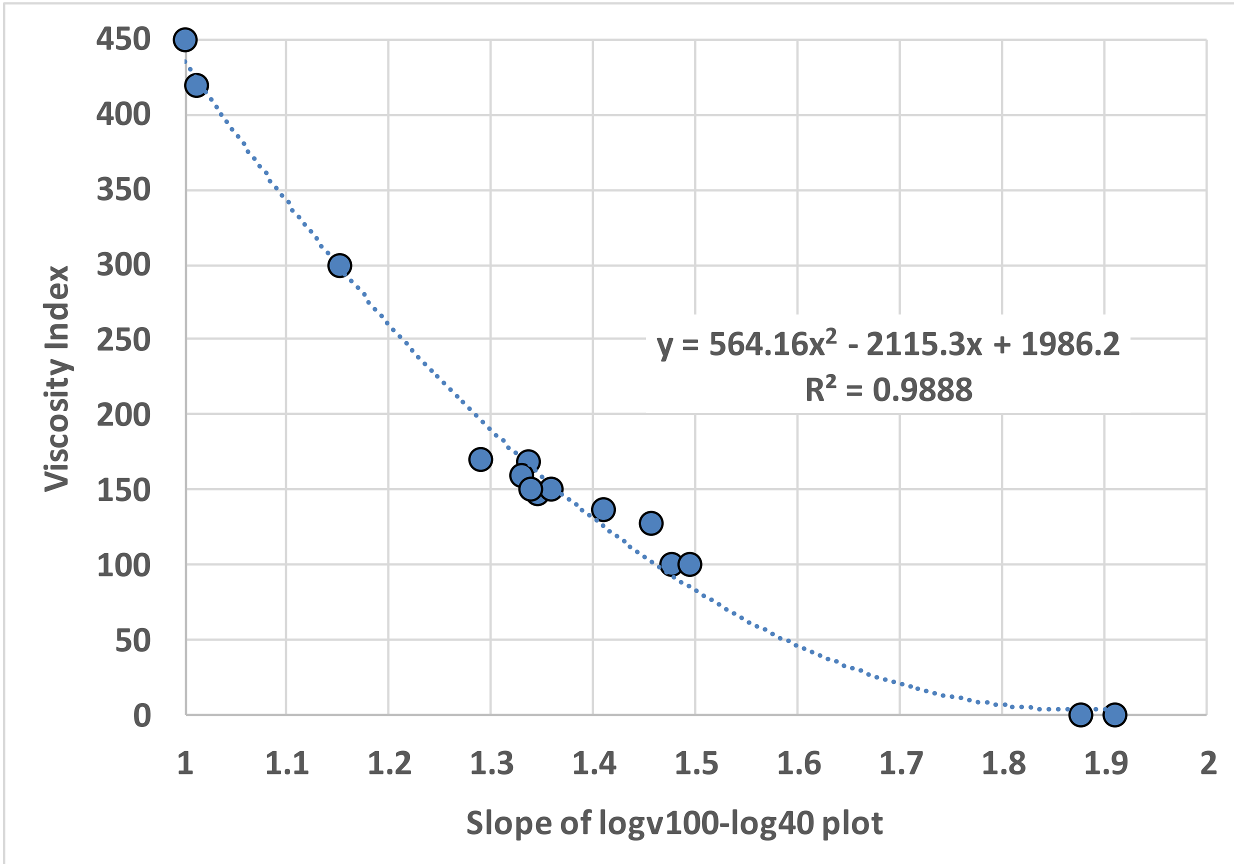
Examples of Possible Reference Series

- n-alkanes or other homologous isoparaffins.
- Distillation cuts from low- and high-VI crudes (similar to the original Dean & Davis concept)
- Polyalphaolefins, either low-viscosity only or a combined low- and high-viscosity series. (It is important that the PAOs use the same starting linear alpha olefin).
- Non-petroleum-based oils such as polydimethyl silicone fluids.
- Polymer series such as LUCANT™, an ethylene/alpha olefin oligomer.
- The next slide shows examples of log(vis40)-log(vis100) plots for the chemical families described above.

Examples of Homologous Reference Series



New Reference Series Correlate with V.I.



- If one assigns a "typical V.I." to members of a reference series, there is a good correlation of V.I. with the slope of log(vis40)-log(v100) plots.
- The "perfect" oil in this plot has an assigned V.I.=450.

Results Using Fenske's H & L Series

- The table on the right shows the effect of using Fenske's H & L series.
- The series are described by linear equations for log(vis40) versus log(vis100).
- The equations are forced to have a common intercept.
- Without a common intercept, the H & L lines converge and cross over at low viscosities.
- The crossover gives unrealistic index values at low viscosities.

Base Stock	vis 100	D2270 V.I.	KVI-18
ExxonMobil AP/E SN 90	3.7	96	111
ExxonMobil AP/E SN 100	4.04	98	109
ExxonMobil AP/E SN 150	5.25	101	101
ExxonMobil AP/E SN 600	12.1	96	95
ExxonMobil AP/E 150 BS	31.5	96	97
Chevron 100R	4.1	102	111
Chevron 220R	6.6	102	99
Chevron 600R	12.2	103	102
Nexbase 3020	2.2	90	138
Nexbase 3030	3	111	137
Nexbase 3043	4.3	123	128
Nexbase 3060	6	129	122
Nexbase 3080	7.8	130	121
Chevron Phillips mPAO 100	100	194	130
Chevron Phillips mPAO 40	40	170	133
Chevron Phillips PAO 8	7.8	137	126
Chevron Phillips PAO 6	5.9	137	128
Chevron Phillips PAO 4	3.9	124	133
Chevron Phillips PAO 2.5	2.4	104	146

Results Using C12 PAO & Fenske H Series

- The table on the right shows the effect of using C12 PAO as the "high" reference (V.I.=150) and Fenske's H series as the "low" reference (V.I.=100).
- The series are described by linear equations for log(vis40) versus log(vis100).
- Most results are fine, except for the Group 1 SN 600 & 150 bright stock, which dropped below 95 V.I. on the newer scale.

			C12 PAO
Base Stock	vis 100	D2270 V.I.	Fenske H
ExxonMobil AP/E SN 90	3.7	96	117
ExxonMobil AP/E SN 100	4.04	98	114
ExxonMobil AP/E SN 150	5.25	101	104
ExxonMobil AP/E SN 600	12.1	96	92
ExxonMobil AP/E 150 BS	31.5	96	91
Chevron 100R	4.1	102	117
Chevron 220R	6.6	102	101
Chevron 600R	12.2	103	104
Nexbase 3020	2.2	90	138
Nexbase 3030	3	111	142
Nexbase 3043	4.3	123	137
Nexbase 3060	6	129	132
Nexbase 3080	7.8	130	132
Chevron Phillips mPAO 100	100	194	181
Chevron Phillips mPAO 40	40	170	173
Chevron Phillips PAO 8	7.8	137	140
Chevron Phillips PAO 6	5.9	137	141
Chevron Phillips PAO 4	3.9	124	141
Chevron Phillips PAO 2.5	2.4	104	150

Results Using Fenske H Series Only

- The table on the right shows the effect of using Fenske's H series as the "high" reference, with no "low" reference.
- The H series is fit with 2 separate curves, one for vis100 <30 cSt and the other for vis100 >30 cSt.
- In order to assign Proportional VIs (PVIs) >120 for Group 3 oils, the H series is defined as 108 V.I.

Base Stock	vis 100	D2270 V.I.	PVI Fenske H=108
HFC Sunpar 130	7.9	96	103
HFC Sunpar 150	10.9	95	103
HFC Sunpar 160	11.6	95	103
HFC Sunpar 2170	24.2	95	102
HFC Sunpar 2280	31.2	95	94
Chevron 100R	4.1	102	115
Chevron 220R	6.3	101	108
Chevron 600R	12.0	103	110
Nexbase 3020	2.2	90	120
Nexbase 3030	3	111	124
Nexbase 3043	4.3	123	125
Nexbase 3050	5.1	127	124
Nexbase 3060	5.9	124	121
Nexbase 3080	7.9	130	127
Chevron Phillips mPAO 100	100	194	249
Chevron Phillips mPAO 40	40	170	191
Chevron Phillips Synfluid 2.5	2.4	104	124
Chevron Phillips Synfluid 4	3.9	124	126
Chevron Phillips Synfluid 6	5.9	137	129
Chevron Phillips Synfluid 8	7.8	137	131

A Simple Approach: Add More V.I. Units to Low Viscosity Oils

- The V.I. of low viscosity oils, shown in slide 10, is underrated in a linear manner.
- For oils with viscosity@100 < 5.5 cSt, the underrating is described by the following equation:

  V.I. Penalty = -12*(vis@100) + 66
- The table on the right shows the effect of adding the penalty number to the D2270 V.I.

Base Stock	vis 100	D2270 V.I.	V.I. + Penalty
ExxonMobil AP/E SN 100	4.04	98	116
ExxonMobil AP/E SN 150	5.25	101	104
ExxonMobil AP/E SN 600	12.1	96	96
Chevron 100R	4.1	102	119
Chevron 220R	6.3	101	101
Chevron 600R	12.0	103	103
Nexbase 3020	2.2	90	130
Nexbase 3030	3.0	111	141
Nexbase 3043	4.3	123	137
Nexbase 3050	5.1	127	132
Nexbase 3060	5.9	124	124
S-Oil Ultra S-2	2.2	109	149
S-Oil Ultra S-3	3.3	117	143
S-Oil Ultra S-4	4.2	123	138
S-Oil Ultra S-6	6.0	127	127
Chevron Phillips Synfluid 2.5	2.4	104	141
Chevron Phillips Synfluid 4	3.9	124	143
Chevron Phillips Synfluid 6	5.9	137	137
Chevron Phillips Synfluid 8	7.8	137	137

Summary

- This year marks the 90th birthday of the V.I. scale.
- Ever since the introduction of the scale, many in the industry have labored to improve it.
- The scale has evolved so that the most egregious flaws have been fixed, but several major problems remain.
- In this talk, I have presented more ideas about how to replace the V.I. with a more rational rating system.
- Many combinations of new reference series were tried, but all had shortcomings.
- One problem is that we are trying to design a rational system which retains the familiarity of the current irrational system.
- Future work will continue on both absolute & relative index proposals.