# Standard Practice for
# Calculating Viscosity of a Blend of Petroleum Products[1]

This standard is issued under the fixed designation D7152; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ($\varepsilon$) indicates an editorial change since the last revision or reapproval.

$\varepsilon^1$ NOTE—Editorially updated Footnote 3 in February 2020.

## 1. Scope

1.1 This practice covers the procedures for calculating the estimated kinematic viscosity of a blend of two or more petroleum products, such as lubricating oil base stocks, fuel components, residua with kerosine, crude oils, and related products, from their kinematic viscosities and blend fractions.

1.2 This practice allows for the estimation of the fraction of each of two petroleum products needed to prepare a blend meeting a specific viscosity.

1.3 This practice may not be applicable to other types of products, or to materials which exhibit strong non-Newtonian properties, such as viscosity index improvers, additive packages, and products containing particulates.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 Logarithms may be either common logarithms or natural logarithms, as long as the same are used consistently. This practice uses common logarithms. If natural logarithms are used, the inverse function, $\exp(\times)$, must be used in place of the base 10 exponential function, $10^\times$, used herein.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and to determine the applicability of regulatory limitations prior to use.*

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

## 2. Referenced Documents

2.1 *ASTM Standards:*[2]

D341 Practice for Viscosity-Temperature Charts for Liquid Petroleum Products

D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)

D7042 Test Method for Dynamic Viscosity and Density of Liquids by Stabinger Viscometer (and the Calculation of Kinematic Viscosity)

2.2 *ASTM Adjuncts:*

Calculating the Viscosity of a Blend of Petroleum Products Excel Worksheet[3]

## 3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *ASTM Blending Method, n*—a blending method at constant temperature, using components in volume percent.

3.1.2 *blend fraction, n*—the ratio of the amount of a component to the total amount of the blend. Blend fraction may be expressed as mass percent or volume percent.

3.1.3 *blending method, n*—an equation for calculating the viscosity of a blend of components from the known viscosities of the components.

3.1.4 *dumbbell blend, n*—a blend made from components of widely differing viscosity.

3.1.4.1 *Example*—a blend of S100N and Bright Stock.

3.1.5 *inverse blending method, n*—an equation for calculating the predicted blending fractions of components to achieve a blend of given viscosity.

3.1.6 *mass blend fraction, n*—The ratio of the mass of a component to the total mass of the blend.

3.1.7 *McCoull-Walther-Wright Function, n*—a mathematical transformation of viscosity, generally equal to the logarithm of

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the logarithm of kinematic viscosity plus a constant, log[log($v$+0.7)]. For viscosities below 2 mm$^2$/s, additional terms are added to improve accuracy.

3.1.8 *modified ASTM Blending Method, n*—a blending method at constant temperature, using components in mass percent.

3.1.9 *modified Wright Blending Method, n*—a blending method at constant viscosity, using components in mass percent.

3.1.10 *volume blend fraction, n*—The ratio of the volume of a component to the total volume of the blend.

3.1.11 *Wright Blending Method, n*—a blending method at constant viscosity, using components in volume percent.

3.2 *Symbols:*

$f_{ij}$ = blending fraction of component $i$ calculated at temperature $t_j$. Blending fraction may be in mass percent or volume percent.

$m_i$ = slope of the viscosity-temperature line,

$$\frac{(W_{i1} - W_{i0})}{(T_{i1} - T_{i0})}$$

$m_i^{-1}$ = reciprocal of the viscosity-temperature slope, $m_i$

$t_B$ = temperature, in Celsius, at which the blend has viscosity $v_B$

$t_{ij}$ = temperature, in Celsius, at which component i has viscosity $v_{ij}$

$T_{ij}$ = transformed temperature

$$T_{ij} = log(273.15 + t_{ij}) \qquad (1)$$

$v_B$ = predicted kinematic viscosity of the blend, in mm$^2$/s, at temperature $t_B$ if component blend fractions are known, or desired viscosity of the blend if component blend fractions are being calculated

$v_{ij}$ = viscosity of component $i$ at temperature $t_j$

$W_{ij}$ = MacCoull-Walther-Wright function, a transformation of viscosity:

$$W_{ij} = log[log(v_{ij} + 0.7 + exp(-1.47 - 1.84v_{ij} - 0.51v_{ij}^2))]$$
$$\qquad (2)$$

where log is the common logarithm (base 10) and exp(x) is e (2.716...) raised to the power x.

$W_H$ = arbitrary high reference viscosity, transformed using Eq 2

$W_L$ = arbitrary low reference viscosity, transformed using Eq 2

## 4. Summary of Practice

4.1 The Wright Blending Method calculates the viscosity of a blend of components at a given temperature from the known viscosities, temperatures, and blending fractions of the components. The viscosities and temperatures of the components and the blend are mathematically transformed into MacCoull-Walther-Wright functions. The temperatures at which each component has two reference viscosities are calculated. The transformed reference temperatures are summed over all components as a weighted average, with the blend fractions as the

weighting factors. The two temperatures at which the blend has the reference viscosities are used to calculate the blend viscosity at any other temperature.

4.2 The Inverse Wright Blending Method calculates the blend fractions of components required to meet a target blend viscosity from the known viscosities and temperatures of the components. The viscosities and temperatures of the components and the blend are mathematically transformed into MacCoull-Walther-Wright functions. The temperatures at which each component has the target blend viscosity are calculated. The component transformed temperatures are summed over all components, as a weighted average, to meet the target blend transformed temperature. The weighting factors are the desired blend fractions, which are obtained by inverting the weighted summation equation.

4.3 The ASTM Blending Method calculates the viscosity of a blend of components at a given temperature from the known viscosities of the components at the same temperature and their blending fractions. The viscosities of the components and the blend are mathematically transformed into MacCoull-Walther-Wright functions. The transformed viscosities are summed over all components as a weighted average, with the blend fractions as the weighting factors. The transformed viscosity is untransformed into viscosity units.

4.4 The Inverse ASTM Blending Method calculates the blend fractions of components required to meet a target blend viscosity at a given temperature from the known viscosities of the components at the same temperature. The viscosities of the components and the blend are mathematically transformed into MacCoull-Walther-Wright functions. The component transformed viscosities are summed over all components, as a weighted average, to equal the target blend transformed viscosity. The weighting factors are the desired blend fractions, which are obtained by inverting the weighted summation equation.

## 5. Significance and Use

5.1 Predicting the viscosity of a blend of components is a common problem. Both the Wright Blending Method and the ASTM Blending Method, described in this practice, may be used to solve this problem.

5.2 The inverse problem, predicating the required blend fractions of components to meet a specified viscosity at a given temperature may also be solved using either the Inverse Wright Blending Method or the Inverse ASTM Blending Method.

5.3 The Wright Blending Methods are generally preferred since they have a firmer basis in theory, and are more accurate. The Wright Blending Methods require component viscosities to be known at two temperatures. The ASTM Blending Methods are mathematically simpler and may be used when viscosities are known at a single temperature.

5.4 Although this practice was developed using kinematic viscosity and volume fraction of each component, the dynamic viscosity or mass fraction, or both, may be used instead with minimal error if the densities of the components do not differ greatly. For fuel blends, it was found that viscosity blending

using mass fractions gave more accurate results. For base stock blends, there was no significant difference between mass fraction and volume fraction calculations.

5.5 The calculations described in this practice have been computerized as a spreadsheet and are available as an adjunct.[3]

## 6. Procedure

### Procedure A

6.1 *Calculating the Viscosity of a Blend of Components With Known Blending Fractions by the Wright Blending Method:*

6.1.1 This section describes the general procedure to predict the viscosity of a blend, given the viscosity-temperature properties of the components and their blend fractions. Any number of components may be included. If the blend fractions are in volume percent, this is known as the Wright Blending Method. If the blend fractions are in mass percent, this is known as the Modified Wright Blending Method.

6.1.2 Compile, for each component, its blend fraction, and viscosities at two temperatures. The viscosity of component $i$ at temperature $t_{ij}$ is designated $v_{ij}$, and its blend fraction is $f_i$. If the viscosities are not known, measure them using a suitable test method. The two temperatures may be the same or different for each component.

NOTE 1—Test Methods D445 and D7042 have been found suitable for this purpose.

6.1.3 Transform the viscosities and temperatures of the components as follows:

$$Z_{ij} = v_{ij} + 0.7 + \exp(-1.47 - 1.84 v_{ij} - 0.51 v_{ij}^2) \quad (3)$$

$$W_{ij} = \log[\log(Z_{ij})] \quad (4)$$

$$T_{ij} = \log[t_{ij} + 273.15] \quad (5)$$

where $v_{ij}$ is the kinematic viscosity, in mm²/s, of component $i$ at temperature $t_{ij}$ in degrees Celsius, exp() is e (2.716) raised to the power x, and log is the common logarithm (base 10).

6.1.3.1 If the kinematic viscosity is greater than 2 mm²/s, the exponential term in Eq 3 is insignificant and may be omitted.

6.1.3.2 Transform the temperature at which the blend viscosity is desired using Eq 5. This transformed temperature is designated $T_B$.

6.1.4 Calculate the inverse slope for each component, as follows:

$$m_i^{-1} = \frac{(T_{i1} - T_{i0})}{(W_{i1} - W_{i0})} \quad (6)$$

6.1.5 Calculate the predicted transformed viscosity, $W_B$, of the blend at temperature $T_B$, as follows:

$$W_B = \frac{T_B + \sum f_i (m_i^{-1} W_{i0} - T_{i0})}{\sum (f_i m_i^{-1})} \quad (7)$$

where the sum is over all components.

6.1.6 Calculate the untransformed viscosity of the blend, $v_B$, at the given temperature:

$$Z'_B = 10^{W_B} \quad (8)$$

$$Z_B = 10^{Z'_B} - 0.7 \quad (9)$$

$$v_B = Z_B - \exp[-0.7487 - 3.295 Z_B + 0.6119 Z_B^2 - 0.3193 Z_B^3] \quad (10)$$

where $Z'_B$ and $Z_B$ are the results of intermediate calculation steps with no physical meaning.

NOTE 2—For viscosities between 0.12 and 1000 mm²/s, the transforming Eq 3 and Eq 4 and the untransforming equations Eq 9 and Eq 10 have a discrepancy less than 0.0004 mm²/s.

NOTE 3—See the worked example in Appendix X3.

### Procedure B

6.2 *Calculating the Blend Fractions of Components to Give a Target Viscosity Using the Inverse Wright Blending Method:*

6.2.1 This section describes the general procedure to predict the required blending fractions of two components to meet a target blend viscosity at a given temperature, given the viscosity-temperature properties of the components. This is known as the Inverse Wright Blending Method.

6.2.1.1 In principle, the blend fractions may be calculated for more than two blending components, if additional constraints are specified for the final blend. Such calculations are beyond the scope of this practice.

6.2.2 Compile the viscosities of the components at two temperatures each. The viscosity of component $i$ at temperature $t_{ij}$ is designated $v_{ij}$. If the viscosities are not known, measure them using a suitable test method. The two temperatures do not have to be the same for both components, nor do they have to be the same as the temperature at which the target viscosity is specified.

NOTE 4—Test Methods D445 and D7042 have been found suitable for this purpose.

6.2.3 Transform the viscosities and temperatures of the components using Eq 3, Eq 4, and Eq 5.

6.2.4 Use the target blend viscosity, $v_B$, as a reference viscosity. Transform $v_B$ to $W_B$ using equations Eq 3 and Eq 4.

6.2.5 Calculate the transformed temperatures at which each component has that viscosity:

$$T_{iL} = \frac{(T_{i1} - T_{i0})}{(W_{i1} - W_{i0})}(W_L - W_{i0}) + T_{i0} \quad (11)$$

6.2.6 Calculate the predicted blend fraction of the first component:

$$f_1 = \frac{(T_B - T_{0L})}{(T_{1A} - T_{0L})} \quad (12)$$

and the fraction of the second component is $f_2 = (1 - f_1)$ because the total of the two components is 100 %.

NOTE 5—See the worked example in Appendix X4.

### Procedure C

6.3 *Calculating the Viscosity of a Blend of Components With Known Blending Fractions Using the ASTM Blending Method:*

6.3.1 This section describes the general procedure to predict the viscosity of a blend at a given temperature, given the viscosities of the components at the same temperature and their blend fractions. Any number of components may be included. If the blend fractions are in volume percent, this is known as the ASTM Blending Method. If the blend fractions are in mass percent, this is known as the Modified ASTM Blending Method.

6.3.2 Compile the viscosities of the components at a single temperature (the reference temperature). The viscosity of component $i$ at that temperature is designated $v_i$. If the viscosities are not known, measure them using a suitable test method.

NOTE 6—Test Methods D445 and D7042 have been found suitable for this purpose.

6.3.2.1 If the viscosity of a component is not known at the reference temperature, but is known at two other temperatures, use Viscosity-Temperature Charts D341 or Eq 10 to calculate its viscosity at the reference temperature.

6.3.3 Transform the viscosities of the components using Eq 2.

6.3.4 Calculate the transformed viscosity of the blend as a weighted average of the component transformed viscosities, using the blend fractions as the weighting factors:

$$W_B = \frac{\sum [f_i W_i]}{\sum [f_i]} \qquad (13)$$

where $W_B$ is the transformed viscosity of the blend, $f_i$ is the blend fraction of component $i$, and $W_i$ is the transformed viscosity of component $i$.

6.3.4.1 Normally, the sum of blend fractions is 100 %:

$$\sum (f_i) = 1 \qquad (14)$$

and the denominator in Eq 12 may be omitted. However, the more general formula may be used when more convenient, for example to save re-normalizing the base stock fractions in an oil containing other components (for example, additives).

6.3.5 Calculate the predicted (untransformed) viscosity of the blend at the reference temperature:

$$v_B = (Z_B - 0.7) - \exp[-0.7487 - 3.295(Z_B - 0.7) + 0.6119(Z_B - 0.7)^2 - 0.3193(Z_B - 0.7)^3] \qquad (15)$$

NOTE 7—See the worked example in Appendix X5.

### Procedure D

6.4 —Calculating the Blend Fractions of Components to Give a Target Viscosity using the Inverse ASTM Blending Method

6.4.1 This section describes the general procedure to predict the required blending fractions of two components to meet a target blend viscosity at a given temperature, given the viscosity of the components at the same temperature. This is known as the Inverse ASTM Blending Method.

6.4.1.1 In principle, the blend fractions may be calculated for more than two blending components, if additional constraints are specified for the final blend. Such calculations are beyond the scope of this practice.

6.4.2 Compile the viscosities of the components at the temperature at which the target blend viscosity is specified. The viscosity of component $i$ at this temperature is designated $v_i$. If the viscosities are not known, measure them using a suitable test method. If the viscosity of a component is not known at the reference temperature, but is known at two other temperatures, calculate the viscosity at the reference temperature using Viscosity-Temperature Charts D341 or Eq 10.

NOTE 8—Test Methods D445 and D7042 have been found suitable for this purpose.

6.4.3 Transform the viscosities of the components and the target blend using Eq 4.

6.4.4 Calculate the blend fraction of the first component:

$$f_1 = \frac{(W_B - W_2)}{(W_1 - W_2)} \qquad (16)$$

where $W_i$ is the transformed viscosity of component $i$ at the given temperature and $f_1$ is the blending fraction of component 1. The blending fraction of the second component is $f_2 = (1 - f_1)$ because the total of the two components is 100 %.

NOTE 9—See the worked example in Appendix X6.

### 7. Report

7.1 Report the predicted viscosity of the blend at the given temperature, if known blending fractions were given.

7.2 Report the calculated blending fractions, if a target blend viscosity was given.

7.3 Report which procedure was used for the calculation.

### 8. Measurement Uncertainty

8.1 The calculations in this practice are exact, given the input data.

8.2 Measuring or compiling the input data can introduce sources of variation. For example, the measured viscosities of the components will vary according the precision of Test Methods D445 or D7042, and will lead to variation in calculated results using this practice. For the Wright Blending Methods, measuring viscosities at narrowly-spaced temperatures is expected to lead to greater variability than using widely spaced temperatures, due to the increased uncertainty in the slope of the fitted viscosity-temperature equations.

8.3 Agreement between the methods in this practice and experimental results were determined in two studies.

8.3.1 The agreements between calculated and predicted results were compared for 37 fuel blends.[4] The fuel components included light gas oil, heavy gas oil, light cat cracked cycle oil, bright stock furfural extract, kerosine, and short residue. For fuel blends, the agreement is close to the precision of the experimental data and viscosity blending using mass fractions is preferred to volume fractions. Using mass fractions, all blend combinations show a positive bias (calculated higher than actual). The bias is dependent on blending ratio and clearly indicates that viscosity blending is nonlinear. The magnitude of the bias seems to be correlated with the absolute density difference and the viscosity difference between the blend components.

8.3.1.1 For fuels, the difference between calculated and measured blend viscosities is expected to exceed the following values only one time in twenty:

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[4] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1573.