To: API Lubricants Group
Cc: Lubricants Group Mailing List
API

**Ballot for Revised Annex R - API Guidelines for Use of Single Technology Matrix**

On Nov. 14, 2018 the Lubricants Standards Group (LSG) discussed the BOI/VGRA, Annex R/STM Work Group proposed revision of **Annex R - API Guidelines for Use of Single Technology Matrix**.

The Discussion was a summary of significant changes with a copy of the Revised Annex R.

The significant revisions to Annex R were summarized in a presentation: **API 1509 Annex R Document Clarification - November 2018 Overview** (Attachment 1).

The Revised Annex R was provided in document: **Annex R - Edits Made After June 28 Meeting API Guidelines for Use of Single Technology Matrix** (Attachment 2)

After review and discussion, the LSG agreed by voice vote to **Ballot Revised Annex R - API Guidelines for Use of Single Technology Matrix.**

**Motion**

Ballot the revised version of Annex R as explained in Attachment.

Motion by: Dan Pridemore

Second by: Muibat Gbadamosi/Calumet

Voice Vote:

- For: 14
- Against: 0
- Abstain: 0

**Motion Passed**

Lubricants Group Members should use the API Ballot System to cast their vote and make comments. The Ballot Link is: http://Ballots.api.org. The Lubricants Group Member votes will be counted, and all received comments reviewed and considered before the ballot results are final.

Non-Lubricants Group Members should comment on the Ballot Motion using the Ballot system. The Ballot Link is: http://Ballots.api.org. All comments on the Ballot Motion will be reviewed before the ballot results are final.

Due to the complexity of the Revised Annex R - API Guidelines for Use of Single Technology Matrix this ballot will be open for approximately 60 days. Ballot will close on February 11, 2019. All Votes and/or Comments must be finalized by the close date.

# Attachment 1

# API 1509 Annex R Document Clarification - November 2018 Overview

## Communication to API Lubricants Standards Group

B W Schwab

November 14, 2018

# Annex R : API Guidelines for Use of Single Technology Matrix

- Revised document was the result of numerous companies who actively participated in the work group :
  - Afton Chemical
  - API
  - Chevron
  - ExxonMobil
  - Infineum
  - Lubrizol
  - KleenPerformance
  - Neste Oil
  - Oronite
  - Petro-Canada
  - Shell
  - SK
  - Total
  - Valvoline

# Annex R : Clarification Activity

- BOI/VGRA Task Force commissioned the STM Work Group in 2013 to review and update Annex R
  - WG members are active users of Annex R
- STM WG has met regularly throughout the past 5 years and methodically worked through Annex R to:
  - Clarify the original intent
  - Improve readability for all users
- After thorough review, the WG shared the final draft on July 18 and informed the BOI/VGRA TF at August 29 meeting that the clarification document is ready for balloting

# Annex R : API Guidelines for Use of Single Technology Matrix

- Work Group has revised Annex R to make it a more readable document
- Draft is intended to clarify, it is not intended to change the original intent of the document
- Cannot be compared line by line

**API Guidelines for Use of a Single Technology Matrix**

**R.1 General**

~~A~~**Principles**

The Single Technology Matrix (STM) approach ~~may be used in addition to the Base Oil Interchangeability (BOI) and SAE Viscosity Grade Testing (VGRA) Guidelines included in Annexes E and F. The STM approach must follow the guidelines outlined in R.2 and any engine-test-specific amendments listed in R.6.~~

~~**R.1.1 Introduction**~~

~~The BOI/VGRA guidelines in API 1509 are developed through industry consensus. Each guideline is generally derived using the 'minimum quality and quantity of data' rule. This rule requires that three technologies from at least two companies agree~~is based on ~~the characteristic behavior of the base oil and/or SAE viscosity grade. This process has the benefit of industry consensus and public display of data, but it is not without limitations: reaching consensus on guidelines is often slow, over-testing in some areas occurs, and the type of data that can be viewed is limited.~~

~~The STM approach encompasses a~~ a single technology ~~or family of technologies~~ from a single supplier ~~in lieu of at least three technologies from different suppliers. The purpose of this approach is to offer an alternate, cost-effective, and technically valid process to demonstrate the performance capability of an additive technology. The matrix can be~~

# Annex R : STM – July 2018 Draft

- Recommend to read the draft document for meaning
  - Does it tell you what you already know?
  - Does it support your understanding of STMs?
- Reorganized the sections to have general information up front
  - Tests covered by STM had been listed in the back in R.6
  - Multiple Technology Matrix left out; build with Modified Technologies
  - Added additional definitions
- The statistics information was kept in section R.2
  - R.2.1 presents clearer scope for STM
  - Added more details on the analysis requirements
- Sections R.3 through R.6 were reordered for better flow
- Expanded the Summary of Requirements to include Guidelines and Uses (now R.4)
- Added more details to the examples in R.5 and R.6
-

# Annex R : Highlights of Clarifications to Accompany Ballot

- Document contents are reordered to have general information at the front of the document and the statistics language and examples at the back of the document
- Multiple Technology Matrix was removed from the language of Annex R
  - Work Group felt it was not being used; removing it did not change the way STM is practiced
- The minimum number of tests required for an STM is based on the number of identified Base Oil Properties of Interest + 2 additional tests. Currently Annex R identifies 5 properties for accepted STM tests. It was agreed that for the current accepted STM test types, Base Oil Saturates and Base Oil Sulfur would be dropped as Base Oil Properties of Interest when the STM contain only Group II and/or Group III base oils, thus reducing the number of Base Oil Properties of Interest to 3 and the minimum number of tests required for those STMs to 5 tests.
  - This reflects a change for some companies that had been using either 6 or 7 tests depending on the interpretation of the original Annex R
  - The change does not impact STM validity

# Annex R : Objectives of Clarified Annex R

- Intended to make Annex R more understandable to the general user
- Trying to improve the readability of the document for the statistician and non-statistician user
- Provide guidance to the new statistician being asked to construct and/or extract data for an STM
- Have Industry feel comfortable with Annex R to consider applying the STM approach for other test types such as the Sequence IIIH

# Annex R : STM – July 2018 Draft – Next Steps

- Motion: Issue a ballot with this accompanying information to adopt the edits to API 1509 Annex R, July 2018 draft document

# Motion to Ballot

Ballot the revised version of Annex R as explained in Attachment.

- Motion by: Dan Pridemore
- Second by: Muibat Gbadamosi/Royal Purple

Hand Vote Results: For = 14 | Against = 0 | Abstain = 0

# Attachment 2

# Annex R - Edits Made After June 28 Meeting

# API Guidelines for Use of a Single Technology Matrix

## R.1 General

### Principles

The Single Technology Matrix (STM) approach is based on a specific technology from a single supplier; the **statistical model** developed from a Single Technology Matrix applies only to the technology used in that STM.[1]

Currently STM is only applicable to select Sequence III tests (Sequence IIIF, IIIFHD, IIIG, and IIIGA) but could be adapted for other engine tests if the industry agreed to do so. To incorporate future tests, it would be necessary to understand the key physical and chemical properties that influence a test so the defining Base Oil Properties of Interest could be determined. Please refer to section R.1.2.6.

### R.1.1 Introduction

The STM refers to the set of test results on a specific technology for a specific API Performance Category generated on test oils with Base Oil and Finished Oil properties that span an operative range. The tested oil properties and engine test results are analyzed to establish a predictive model for that range of Base Oil and Finished Oil properties. The model is used to generate a Predicted Test Result for a Candidate Oil. If the prediction meets the statistical requirements as outlined in Section R.2.2, the Predicted Test Result is used in lieu of an engine test result to support API license claims for the Candidate Oil. An STM Predicted Test Result should not be used to override an actual failing test result on a Base Oil with this technology.

The Predicted Test Result and STM support documentation are reported in the Candidate Data Package. The set of tests that are currently covered by the STM include the following:

- IIIF
- IIIFHD
- IIIG
- IIIGA

### R.1.2 Definitions

In order to better understand the development and application of an STM, these key terms are required.

**R.1.2.1** A *Single Technology* as designed for use in an STM is a single additive package (DI) at a constant treat rate, with a single viscosity modifier, and in a single viscosity grade.

[1]The Base Oil Interchange/Viscosity Grade Read Across (BOI/VGRA) guidelines in API 1509 are developed through industry consensus. Each guideline is generally derived using the 'minimum quality and quantity of data' principle. This principle requires that three technologies from at least two companies agree on the characteristic behavior of the base stock slates and/or SAE viscosity grade(s). This process has the benefit of industry consensus and public display of data.

Prior to the adoption of API Guidelines for use of a Single Technology Matrix (STM) in 2002, Base Oil Interchange (BOI) for the Sequence III test had been proposed. This proposal was based on industry experience and extensive data in a large variety of Base Oils. Discussions at the Administrative Guidance Panel (AGP) level indicated that the Sequence III test would not be accepted as a candidate for typical BOI but would adopt STM for the Sequence III test.

**R.1.2.2** A *Modified Technology* used in building an STM is a formulation containing a modification. The allowed modifications are described in 1.2.9 and 1.2.10. For each Modified Technology in the STM, one additional passing test is required by adding one unique Base Oil. This concept is different than that of a minor formulation modification as defined by ACC Code of Practice Appendix H.

**R.1.2.3** A *Single Technology Matrix* consists of a group of data meeting the criteria outlined in Annex R, Section R.2. The test results in the matrix are based on a Single Technology as described in R.1.2.1 and, if necessary, a Modified Technology as described in R.1.2.2.

**R.1.2.4** A *Base Stock* is defined in Annex E, Section E.1.2.1.

**R.1.2.5** A *Base Oil* is defined in Annex E, Section E.1.2.3. A *Base Oil* used in an STM can consist of a single base stock or a blend of base stocks. The *Base Oil* can be comprised of base stocks from one or more base stock slates. The *Base Oil* used in a Single Technology Matrix (in addition to the definition in E.1.2.3) is also defined by the relevant Base Oil Properties of Interest.

A *Base Stock Slate* is defined in Annex E, Section E.1.2.2.

**R.1.2.6** The *Base Oil Properties of Interest* are Base Oil or Finished Oil properties decided by the API BOI/VGRA Task Force to be meaningful and influential to engine test performance for the test covered by STM.

The *Base Oil Properties of Interest* are test type specific, defined in section R.5, and consist of one or more of the following:

- Base Oil Saturates (ASTM D2007)
- Base Oil Sulfur (API Approved Tests from Annex E, Table E-1)
- Base Oil Viscosity at 100°C (ASTM D445)
- Base Oil Viscosity Index (ASTM D2270)
- Finished Oil Noack Volatility (ASTM D5800)

**R.1.2.7** A *Spread Requirement* is a stipulation on the Base Oil Properties of Interest in the STM that facilitates a symmetric spread in those properties. For each Base Oil Property of Interest that has to meet the spread requirement (refer to table R.5.0), the number of Base Oils on either side of the mean of all Base Oils in the matrix must be within 1 of equal in order to satisfy the spread requirements. The Base Oils at the mean should be counted as zero.

The guiding principle for the spread requirement for the selection of Base Oils in the STM is to avoid skewing the analysis by clustering the data at an extreme or at the mean. The number of Base Oils at the mean needs to be equal to or less than the number of Base Oils on either side of the mean.

For the Sequence IIIF, IIIFHD, IIIG, and IIIGA tests, the Spread Requirement is only applied to Base Oil saturates and viscosity index (VI), unless the Spread Requirement Waiver for Saturates (per section R.1.2.8) applies and then only VI needs to meet the Spread Requirement.

When performing the spread calculations for an STM, all raw data and data means must be properly formatted according to the specific ASTM test procedure listed in R.1.2.6 and using the ASTM E29 standard practice for rounding.

For saturates, there is no formal statement in the ASTM D2007 standard on the number of significant figures/rounding. As a result, the recommended practice is to round saturates to the nearest tenths place.

VI is rounded to whole numbers. The rounding for VI is applied to each Base Oil in the matrix and the overall mean of the Base Oils in the matrix.

A Base Oil may be repeated but the Base Oil Properties of Interest only count once in the Spread Requirement calculations. A Base Oil repeat may be the result of MTEP, outliers, etc. Given that rounding is involved, when counting the number of Base Oils on either side of the mean, a Base Oil Property of Interest equal to the mean should be counted as zero.

The Base Oil Properties of Interest reported and used in the STM / spread requirement analysis should accurately reflect the batches of Base Stocks used in the STM. This can be accomplished by one of three ways and the selected

method should be documented. The first is by a direct analysis of the Base Oil Properties of Interest for the blended Base Oil. The second is by calculation of the Base Oil Properties of Interest from values associated with the individual base stocks comprising the Base Oil. The third method applies if one is relying on historical Base Oil/stock data to create an STM with missing properties. With the third method, an effort should be made to accurately reflect the properties used with an explanation provided.

**R.1.2.8** The *Spread Requirement Waiver for Saturates* allows for the elimination of any spread requirement for saturates, if, and only if, every Base Oil in the matrix is comprised of base stocks belonging to API Group II, Group III, and/or Group IV, because saturates is not considered an important property of interest for these groups of base stocks. The Spread Requirement Waiver for Saturates currently applies only to the Sequence IIIF, IIIFHD, IIIG, and IIIGA tests.

**R.1.2.9** *Formulation Modifications* are described in the American Chemistry Council (ACC) Code of Practice. Modifications are allowed in the development of an STM but require an additional Base Oil and test result for a given modification. These modified formulations are called *Modified Technologies*.

**R.1.2.10** A *Viscosity-Grade Change* is allowed within an STM in the direction of previously approved API 1509 Viscosity Grade Read Across Guidelines. Such a change is allowed in the development of an STM but requires an additional Base Oil and test result. The STM can then only support the least difficult viscosity grade tested in the STM as defined by API 1509 Viscosity Grade Read Across Guidelines (Annex F).

**R.1.2.11** The *Predicted Test Result* from the STM model can be used in lieu of an actual engine test result provided that all STM requirements outlined in Annex R are met. The Predicted Test Result should not be used to override a failing test result. The Predicted Test Result shall be comprised of the maximum treat level of all Modified Technologies in the least difficult viscosity-grade tested in the STM. The least difficult viscosity-grade is as defined in API 1509 Annex F. The predicted result and STM documentation is provided to the Marketer in the Candidate Data Package (CDP).

**R.1.2.12** A *Passing Test Result* used to build the STM can be obtained from a single test or by using the appropriate Multiple Test Evaluation Procedures (MTEP) outlined in ACC Code of Practice Appendix F.

**R.1.2.13** A *Sequence IIIGA Matrix Requirement* is that the fresh oil MRV of the candidate oil, blended to the same viscosity grade, is equal to or less than the fresh oil MRV of at least one of the passing oils in the matrix, within the precision of the test.

**R.1.2.14** An *Outlier* is a test result in which the absolute value of the Studentized Residual for that observation from the analysis is at the one-sided 97.5$^{th}$ percentile, or beyond, on a Student *t* distribution. Outliers must be shown, but may be removed from the STM analysis and Spread Requirements. See section R.2.4.

**R.1.2.15** A *Candidate Oil* is a Base Oil blended with the final technology in a specific viscosity grade for a specific performance test in a specific API performance category whose performance is being predicted by an existing STM model. The Candidate Oil's relevant *Base Oil Properties of Interest* shall fall within the defined ranges of the STM.

## R.2 Scope and Criteria for a Single Technology Matrix

### R.2.1 Scope and Criteria for STM Data and Matrix

The STM approach is used to establish a Predicted Test Result for a Candidate Oil blended with a specific technology in a specific viscosity-grade for a specific performance test in a specific API performance category. A predicted result from the STM that meets the requirements of Annex R can be used in lieu of an engine test result. It is possible that the prediction model may be applicable to more than one API performance category and different limits may apply depending on the category. Therefore, a separate STM analysis must be performed and documented for each performance category in which a Predicted Test Result is desired.

The STM matrix data must be developed using a Single Technology as described in R.1.2.1, and, if necessary, a Modified Technology as described in R.1.2.2. The STM approach only covers Group I, II, III and IV base stock groups. The Predicted Test Result must be for the final Modified Technology from the STM matrix data.

All tests documented in an STM shall be ASTM operationally valid ACC registered tests.

In an STM, the minimum number of unique passing Base Oils is determined by the number of Base Oil Properties of Interest relevant to the model plus 2. For each Modified Technology the number of unique Base Oils increases by 1. For the tests for which STM application has been defined (IIIF, IIIFHD, IIIG, IIIGA), the default number of Properties of Interest is 5 and the minimum number of Base Oils is equal to 7. If the Base Oils are comprised of API Group II, III, IV, then the number of Properties of Interest is 3 (excludes saturates and sulfur) and the minimum number of Base Oils is equal to 5. The minimum number of unique passing Base Oils shall not be less than five.

Base Oil Properties of Interest are determined by the API BOI/VGRA Task Force on a per test-type basis; Base Oil Properties of Interest are listed in R.1.2.6. The range of Base Oil Properties of Interest, defined by the maximum and minimum of the data used to develop the STM model, must encompass the Base Oil Properties of Interest of the Candidate Base Oil. To extend to a Candidate Base Oil outside this range would require at least one added test on an oil with Base Oil Properties of Interest at or beyond the Candidate Base Oil. A new STM would then be developed to include the new test result.

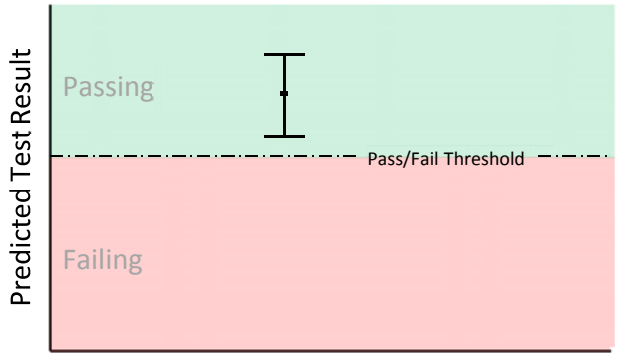
Once a Predicted Test Result has been established minor formulation modifications as per American Chemistry Council Product Approval Code of Practice (Appendix H and I) and VGRA as per API 1509 Viscosity Grade Read Across Guidelines (Annex F) may be applied.

### R.2.2 STM Analysis Requirements

An empirical model for the test results must be developed from the STM data. If the data set includes one or more Modified Technologies, the data can be coded as categorical and/or continuous variable data. The final form of the data for analysis and model is at the discretion of the organization developing the STM. Based on the empirical model, the Predicted Test Result for the Candidate Oil must meet the performance specification of interest and a confidence interval requirement for the Predicted Test Result must be met as described in R.2.2.1 and R.2.2.2.

#### R.2.2.1 Primary Test

The Primary Test is to determine if the entire 95% confidence interval for the predicted mean performance (R.2.3.2) is within the performance specification of interest, i.e., the confidence interval of the Predicted Test Result, which is based on the data set used in the analysis, does not extend beyond the pass limit into the fail region of the specification.

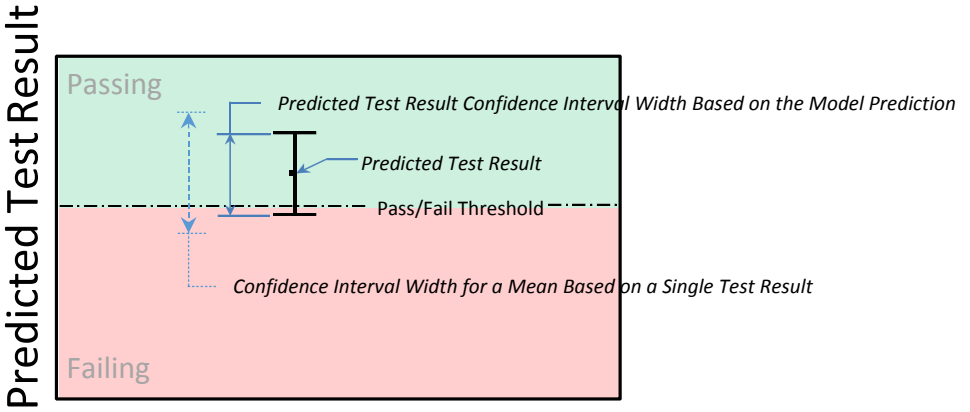



Predicted 95% Confidence Interval above Pass/Fail Limit Threshold

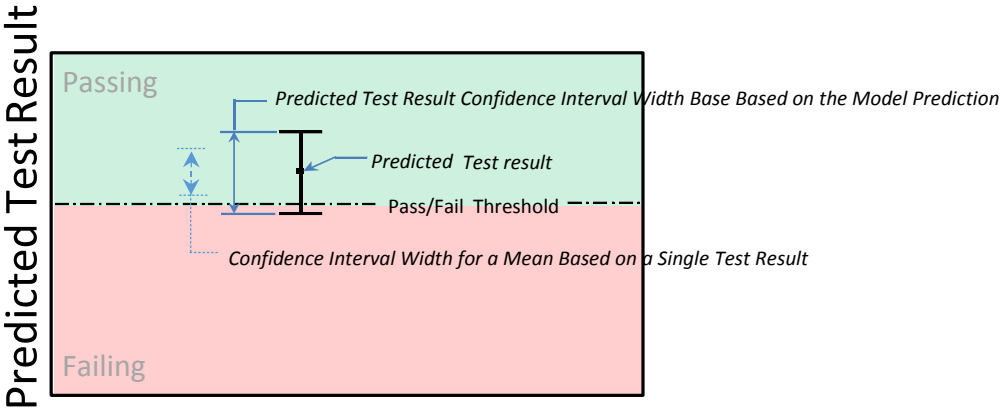
#### R.2.2.2 Secondary Test

If the Predicted Test Result meets the performance requirement, but the Predicted Test Result Confidence Interval (R.2.3.2) crosses the pass/fail threshold into the fail region, then and only then can the Secondary Test be applied. The Secondary Test evaluates the width of the Predicted Test Result Confidence Interval and compares it to the Confidence Interval for a Mean Based on a Single Test Result (R.2.3.1), which is based on the Normal Frequency Distribution and the current standard deviation of the test used in the calculation of severity adjustments as defined in ASTM Test Monitoring Center Technical Memorandum 94-200, Annex C of the LTMS Manual. The width calculated in R.2.3.2 cannot be greater than the width calculated in R.2.3.1 Although the confidence intervals must be calculated in the appropriate transformed units, the comparison must be made in original units.

Predicted Engine Test can be used in lieu of an actual engine test.
(R.2.3.2 Width < R.2.3.1 Width)




Predicted Engine Test CANNOT be used in lieu of an actual engine test.
(R.2.3.2 Width ≥ R.2.3.1 Width)




**R.2.3 Calculation of Width of 95% Confidence Interval**

**R.2.3.1 Industry Confidence Interval Width for a Mean Based on a Single Test Result ($CIW_1$)**

$$CIW_1 = 2 \times Z_{0.05} \times \sigma$$

Where:

$Z_{0.05}$ = 1.96

$\sigma$ = current standard deviation of the test used in the calculation of severity adjustments as defined in ASTM Test Monitoring Center Technical Memorandum 94-200, Annex C, of the LTMS Manual.

This is the shortcut method for calculating the width of the method 1 confidence interval. If a transformation is required, the shortcut method cannot be used. The actual confidence interval must be calculated for the predicted result for the oil on the transformed scale. This is done by adding and subtracting $Z_{0.05} \times \sigma$ from the Predicted Test Result, transforming the confidence limits back, and then subtracting the limits on the original scale.

**R.2.3.2 Predicted Test Result Predicted Confidence Interval Width based on the Model Prediction ($CIW_2$)**

$$CIW_2 = 2 \times t_{0.05,df} \times S \times \sqrt{h_i}$$

Where:

$t_{0.05,df}$ = Student T distribution at the 95% Confidence Level with degrees of freedom equal to the degrees of freedom used in the estimate of the Root Mean Squared Error (RMSE)

S = Root Mean Squared Error from the analysis

$h_i$ = $x_i (X'X)^{-1} x_i^1$

X = the factor matrix

$x_i$ = a particular factor setting

This is the shortcut method for calculating the width of the method 2 confidence interval. If a transformation is required, the shortcut method cannot be used. The actual confidence interval must be calculated for the predicted result for the oil on the transformed scale. This is done by adding and subtracting $t_{0.05,df} \times S \times \sqrt{h_i}$ from the transformed predicted result, transforming the confidence limits back, and then subtracting the limits on the original scale.

**R.2.4 Calculation of the Studentized Residual and Outlier Test**

Outliers **<u>may</u>** be removed from the STM analysis as long as both the spread requirement and minimum number of Base Oils requirement are satisfied upon re-evaluation with the Outlier removed. If an Outlier is removed, then all test related data for that observation must be removed from the analysis. However, Outliers must still be included in the STM documentation. Note: while observations may be dropped according to the Multiple Test Evaluation Procedure (MTEP) to determine pass/fail, those observations may not be dropped from the STM analysis unless declared an Outlier according to R.2.4.

$$e^*_i = e_i / (S(i) \times (\sqrt{1-h_1}))$$

Where:

$e^*_i$ = the Studentized Residual, which is distributed closely to the Student T distribution. In this application, the ith observation for a test parameter may be declared as an outlier and removed from the analysis if $e^*_i$ is greater than the one sided $t_{0.025,df}$ with degrees of freedom equal to the degrees of freedom used in the estimate of the Root Mean Squared Error.

$e_i$ = the residual from the analysis, the actual test result for the ith observation for a parameter minus the predicted test result for the ith observation for a parameter.

S(i) = Root Mean Squared Error from the analysis with the ith observation removed from the analysis

$h_i$ = $x_i (X'X)^{-1} x_i'$

X = the factor matrix

$x_i$ = a particular factor setting

**R.3 Notification of Single Technology Matrix Use to API**

The Matrix data and analysis must be shown to the Oil Marketer within the Candidate Data Package. Oil Marketers must notify API on the EOLCS Application for Licensure whenever STM data is used to qualify an oil formulation for API licensing. The on-line license application asks the question if STM has been used or not.


When asked to provide a Formulation/Stand Code on the licensing form, any one of the actual test stand codes from the STM can be listed on the licensing form.

## R.4 Summary of Requirements, Guidelines and Uses for the Single Technology Matrix

The requirements, principals and guidelines for the STM are summarized below:

a. STM is used to establish a Predicted Test Result for a Candidate Base Oil for a specific technology (see R.1.2.1) in a specific viscosity-grade. Applicable VGRA may be applied to the Predicted Test Result.
b. A Predicted Test Result is used in lieu of an engine test result and can be treated as an actual test result in the execution of a program.
c. The STM approach only covers Base Oils comprised of base stocks belonging to API Groups I, II, III, and IV.
d. The API BOI/VGRA Task Force reviews performance engine tests for STM use, defines the Base Oil Properties of Interest, and recommends use of the STM to the Lubricants Group.
e. The API Lubricants Group approves the Base Oil Properties of Interest and use of the STM for performance engine tests recommended by the API BOI/VGRA Trask Force.
f. The Matrix Data Criteria must be met as defined in R.2.1.
g. All tests in the development of the STM dataset and analysis must be registered according to the ACC Code of Practice.
h. The single technology must pass within a single test result or by using the appropriate Multiple Test Evaluation Procedures (MTEP) outlined in ACC Code of Practice Appendix F for each Base Oil in the STM for all relevant test parameters. If not, a formulation adjustment or a Viscosity Grade Change may be made to the Single Technology to create a Modified Technology within the STM. The Modified Technology must then pass all remaining Base Oils not passed using the Single Technology, within a single test result or by using the appropriate MTEP for all relevant test parameters. The minimum number of unique Base Oils in the STM MUST increase by one (1) for every Modified Technology used to demonstrate an acceptable STM.
i. Data may not be dropped from the STM analysis unless declared an Outlier according to R.2.4. Test results dropped for evaluation in an MTEP procedure may not be dropped from the STM analysis unless declared an Outlier according to R.2.4. Outliers must be shown in the STM documentation, but may be removed from the STM analysis and Spread Requirements.
j. The width of the 95% confidence interval (based on the Student *t* distribution) for the predicted mean performance based on the STM model cannot be greater than the width of the 95% confidence interval (based on the Normal Frequency Distribution and the current standard deviation of the test used in the calculation of severity adjustments as defined in ASTM Test Monitoring Center Technical Memorandum 94-200, Annex C, of the LTMS Manual) for the mean based on a single test result at the predicted performance level UNLESS the 95% confidence interval for the predicted mean performance (based on the Student *t* distribution) is within the performance specification of interest (see R.2.2).
k. API will survey additive companies on a regular basis for STM data
l. STM should not be used to over-ride a failing test.
m. The engine test and the applicable API performance category in which the test is used must be defined and identified in any organization's STM analysis and documentation. A separate STM analysis must be performed and documented for every single performance category in which a Predicted Test Result is desired for the technology.
n. STM results must be included in ACC Candidate Data Packages. Notification of use of STM data for API licensure will be present on an Oil Marketer's API License application and must be checked if used. An example is provided in R.3.
o. Future engine test data do not affect previously established STMs.

p. *Once an STM is established, minor formulation modifications are per American Chemistry Council Product Approval Code of Practice (Appendix H) and VGRA as per API 1509 Viscosity Grade Read Across Guidelines (Annex F) may be applied.*

## R.5 Engine Tests Approved for STM

The following table summarizes the Base Oil properties of Interest for each test type approved for STMs. As stated previously in Section R.1.2.7, certain Base Oil Properties are subjected to the Spread Requirement. In Table R.5.0, those Base Oil Properties are identified with an "X". Note: The Spread Requirement for Base Oil Saturates can be waived if every Base Oil in the STM is comprised of base tocks belonging to API Group II, Group III, and/or Group IV.

***Table R.5.0 Base Oil Properties of Interest***

| | Base Oil Saturates | Base Oil Sulfur | Base Oil Viscosity at 100 °C | Base Oil Viscosity Index | Noack Volatility of the fully formulated oil |
|---|---|---|---|---|---|
| IIIF | X | | | X | |
| IIIF-HD | X | | | X | |
| IIIG | X | | | X | |
| IIIGB | X | | | X | |

Passenger car motor oil (PCMO) technologies cannot be used with heavy duty diesel engine oil (HDEO) technologies in the same STM. An STM must consist of either all PCMO technology or HDEO technology.

### R.5.1 Sequence IIIF

If any of the Base Oils in the matrix is Group I, the STM must consist of at least 7 different Base Oils and the Base Oil Properties of Interest (R.1.2.6) include:

- Base Oil Saturates (ASTM D2007)
- Base Oil Sulfur (except when Base Oil sulfur level is less than or equal to 0.03%) (API approved tests from Annex E, Table E-1)
- Base Oil Viscosity at 100°C (ASTM D445)
- Base Oil Viscosity Index (ASTM D2270)
- Noack Volatility of the fully formulated oil (Finished Oil) (ASTM D5800)

For a matrix and Candidate Oil including only Group II, Group III, and/or Group IV Base Oils, the STM must consist of at least 5 different Base Oils and the Base Oil Properties of Interest are:

- Base Oil Viscosity at 100°C (ASTM D445)
- Base Oil Viscosity Index (ASTM D2270)
- Noack Volatility of the fully formulated oil (Finished Oil) (ASTM D5800)

The relevant test results are:

- Percent Viscosity Increase at 80 Hours
- Weighted Piston Deposits

- Average Piston Varnish
- Average Camshaft plus Lifter Wear
- Stuck Rings

The STM must consist of a minimum number of Base Oils consistent with Section R.2.1. Each technology in the STM must pass each relevant test parameter (individual passing tests or by MTEP) for the given API category in each Base Oil.

Confidence intervals are applicable to each relevant test parameter except Average Camshaft plus Lifter Wear and Stuck Rings.

The table shown in R-5.1 summarizes the Base Oil Properties of Interest that must satisfy the spread requirement (R.1.2.7).

***Table R-5.1 – Base Oil Properties That Must Satisfy Spread Requirement***

| Base Oils | Saturates | Sulfur | VI | VIS100 | (Finished Oil) Noack |
|---|---|---|---|---|---|
| Group I | Yes | No | Yes | No | No |
| Group II, III, IV | No | No | Yes | No | No |

### R.5.1.1 Detailed Example Using the Sequence IIIF with Group I Base Oils for API Service Category SL

Can we obtain a passing Predicted Test Result that meets the requirements of the STM for Technology 1 shown in Table R-6.2 in a Candidate Oil that is within the ranges for Base Oil saturates, sulfur, viscosity, viscosity index and finished oil Noack volatility in the IIIF?

**Table R-5.2—Sequence IIIF Properties for Example Using STM**

| Base Oil | Base Oil Saturates D 2007 | Base Oil Sulfur D 4294 | Finished Oil Noack Volatility D 5800 | Base Oil Viscosity @ 100°C D 445 | Base Oil Viscosity Index D 2270 | IIIF Percent Viscosity Increase | IIIF Weighted Piston Deposits | IIIF Average Piston Varnish | IIIF Average Cam plus Lifter Wear | IIIF Stuck Rings |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 75.4 | 0.205 | 16.9 | 5.610 | 105 | 311.2 | 4.92 | 9.1 | 10.8 | 0 |
| 1 | 75.4 | 0.205 | 16.9 | 5.610 | 105 | 190.0 | 4.44 | 9.4 | 7.0 | 0 |
| 2 | 68.3 | 0.306 | 18.2 | 4.460 | 100 | 270.4 | 4.17 | 9.1 | 7.9 | 0 |
| 3 | 70.7 | 0.313 | 15.8 | 4.390 | 102 | 108.3 | 3.76 | 8.9 | 6.8 | 0 |
| 3 | 70.7 | 0.313 | 15.8 | 4.390 | 102 | 268.0 | 4.44 | 9.1 | 8.2 | 0 |
| 4 | 66.7 | 0.217 | 16.6 | 4.860 | 104 | 111.4 | 5.20 | 9.2 | 7.7 | 0 |
| 5 | 73.9 | 0.342 | 13.9 | 5.100 | 103 | 162.1 | 4.32 | 9.2 | 5.6 | 0 |
| 6 | 84.1 | 0.074 | 14.7 | 5.470 | 102 | 67.0 | 4.2 | 9.4 | 5.1 | 0 |
| 7 | 61.2 | 0.364 | 16.0 | 4.310 | 96 | 311.1 | 3.95 | 9.5 | 8.7 | 0 |
| 7 | 61.2 | 0.364 | 16.0 | 4.310 | 96 | 212.0 | 3.97 | 9.5 | 5.7 | 0 |
| New | 71.5 | 0.250 | 16.2 | 5.000 | 102 | | | | | |

Step 1: Do we have enough Base Oils in the Matrix?

Yes. We have 7 Base Oils in the Matrix. The minimum number of passing Base Oils is the number of Base Oil Properties of Interest (saturates, sulfur, viscosity at 100°C, viscosity index, and Noack volatility of the fully formulated oil) plus two.

Step 2: Do we satisfy the spread requirement for both saturates and Base Oil viscosity index?

Yes. There are four Base Oils with saturates below the mean saturates of all Base Oils of 71.5 and three Base Oils above this mean. There are two Base Oils with a Base Oil viscosity index below, three Base Oils above, and two Base Oils equal to the mean Base Oil viscosity index mean of 102.

Step 3: Do we pass Technology 1 in every Base Oil in the Matrix?

Yes. Some pass with one test and some pass by MTEP. (MTEP is applied to oils 1 [PVIS], 3 [WPD], and 7 [PVIS].)

Step 4: Do we predict a pass for Technology 1 in the Candidate Oil based on the analysis of the Matrix?

Yes. The prediction for the Candidate Oil is based on a very simple model (see Table R-5.3), the average over all other Base Oils since no Base Oil effects were evident with this technology over the range tested.

**Table R-5.3 - Step 4: Model Prediction for a New Group I Base Oil**

| Base Oil | Base Oil Saturates D 2007 | Base Oil Sulfur D 4294 | Finished Oil Noack Volatility D 5800 | Base Oil Viscosity @ 100°C D 445 | Base Oil Viscosity Index D 2270 | Model Predicted | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | IIIF Percent Viscosity Increase | IIIF Weighted Piston Deposits | IIIF Average Piston Varnish | IIIF Average Cam plus Lifter Wear | IIIF Stuck Rings |
| New | 71.5 | 0.250 | 16.2 | 5.00 | 102 | 201 | 4.3 | 9.2 | 7.4 | 0 |

Step 5: Are there any outliers?

Possible outliers would include test results in which the Studentized residuals exceed the Student T distribution at the one-sided 0.025 percentile with degrees of freedom being equal to 9.

$$t_{0.05,9} = 2.262$$

According to the calculations in R.2.4, there are two possible outliers (see Table R-5.4). These outliers should be investigated as to their possible cause. Given that an investigation has not yet taken place, the outliers are not removed in this example. After future investigation, the test sponsor may remove these identified outliers on a parameter-by-parameter basis. However, please note that the outlier of 2.65 identified for Weighted Piston Deposits CANNOT be removed unless another test is run on this Technology to bring the number of Passing Base Oils in the Matrix for Weighted Piston Deposits back to seven.

**Table R-5.4—Step 5: Studentized Residuals**

| Test Number | IIIF Percent Viscosity Increase | IIIF Weighted Piston Deposits | IIIF Average Piston Varnish | IIIF Average Cam plus Lifter Wear | IIIF Stuck Rings |
|---|---|---|---|---|---|
| 1 | 1.38 | 1.47 | -0.71 | *2.86* | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 2 | -0.13 | 0.23 | 0.82 | -0.20 | 0 |
| 3 | 0.81 | -0.38 | -0.71 | 0.32 | 0 |
| 4 | -1.13 | -1.45 | -2.09 | -0.32 | 0 |
| 5 | 0.78 | 0.23 | -0.71 | 0.50 | 0 |
| 6 | -1.08 | *2.65* | -0.20 | 0.20 | 0 |
| 7 | -0.45 | -0.04 | -0.20 | -1.09 | 0 |
| 8 | -1.79 | -0.31 | 0.82 | -1.48 | 0 |
| 9 | 1.38 | -0.91 | 1.44 | 0.82 | 0 |
| 10 | 0.12 | -0.86 | 1.44 | -1.02 | 0 |

Step 6: Is the entire 95% confidence interval (base d on the Student T distribution) for the predicted mean performance based on the STM model within the pass region for all relevant test properties?

If not, is the width of the 95% confidence interval (based on the Student T distribution) for the predicted mean performance based on the STM model less than or equal to the width of the 95% confidence interval (based on the Normal Frequency Distribution and the current standard deviation of the test used in the calculation of severity adjustments as defined in ASTM Test Monitoring Center Technical Memorandum 94-200, Annex C, of the LTMS Manual) for the mean based on a single test result at the predicted performance level for all relevant test properties?

Yes. Calculations are presented below for Percent Viscosity Increase and summarized for all other test properties.

Confidence Interval for the Mean Based on a Single Test Result

$$\text{Transform(Result)} + (Z_{0.05} \times \sigma) \text{ to } \text{Transform(Result)} - (Z_{0.05} \times \sigma)$$

Where:

Result = Predicted Test Result for the Candidate Oil based on the STM analysis

Transform = Industry transformation for this test; the inverse square root

$\sigma$ = current standard deviation of the test used in the calculation of severity adjustments as defined in ASTM Test Monitoring Center Technical Memorandum 94-200, Annex C, of the LTMS Manual.

$$1/(\text{Result})^{1/2} + (1.96 \times 0.0129546) \text{ to } 1/(\text{Result})^{1/2} - (1.96 \times 0.0129546)$$

$$1/(201)^{1/2} + (1.96 \times 0.0129546) \text{ to } 1/(201)^{1/2} - (1.96 \times 0.0129546)$$

0.0959 to 0.0451 in transformed units

95% confidence interval for the true mean of Percent Viscosity Increase based on a single test result using the industry-published standard deviation equals 109 to 491

The width of the confidence interval in original units equals 491 – 109 = 382

Predicted Test Result Confidence Interval Width

$$\text{Transform(Result)} + (t_{0.05,df} \times S \times \sqrt{h_i}) \text{ to } \text{Transform(Result)} - (t_{0.05,df} \times S \times \sqrt{h_i})$$

Where:

| | | |
|---|---|---|
| Result | = | Predicted Test Result for the Candidate Oil based on the STM analysis |
| Transform | = | transformation used in this STM analysis: none |
| S | = | Root Mean Squared Error (RMSE) from this STM analysis |
| df | = | degrees of freedom used in calculating the RMSE |

(Result) – (2.262 x 88.13112 x 0.3162) to (Result) + (2.262 x 88.13112 x 0.3162)

(201) – (63.0353) to (201) + (63.0353)

95% confidence interval for the true mean of Percent Viscosity Increase based on the data and analysis of the STM equals 138 to 264.

The width of the confidence interval in original units equals 264 – 138 = 126. A summary of the confidence interval widths is shown in Table R-5.5.

**Table R-5.5 - Summary of Confidence Interval Widths**

| IIIF Parameter | Confidence Interval Width for a Mean Based on a Single Test Result | Predicted Test Result Confidence Interval Width | Predicted Test Result Confidence Interval Width Smaller? |
|---|---|---|---|
| Percent Viscosity Increase | 382 | 126 | YES |
| Weighted Piston Deposits | 2.58 | 0.63 | YES |
| Average Piston Varnish | 0.86 | 0.29 | YES |

Step 7: Can we obtain a Predicted Test Result for Technology 1 in a Candidate Oil that is within the ranges for Base Oil saturates, sulfur, viscosity, viscosity index, and finished oil Noack volatility in the Sequence IIIF?

Answer: Yes

**R.5.2 Sequence IIIFHD**

If any of the Base Oils in the matrix is Group I, the STM must consist of at least 7 different Base Oils and\ the Base Oil Properties of Interest are:

- Base Oil Saturates (ASTM D2007)
- Base Oil Sulfur (except when Base Oil sulfur level is less than or equal to 0.03%) (API approved tests from Annex E, Table E-1)
- Base Oil Viscosity at 100°C (ASTM D445)
- Base Oil Viscosity Index (ASTM D2270)
- Noack Volatility of the fully formulated oil (Finished Oil) (ASTM D5800)

For a matrix and Candidate Oil including only Group II, Group III, and/or Group IV Base Oils, the STM must consist of at least 5 different Base Oils and the Base Oil Properties of Interest are:

- Base Oil Viscosity at 100°C (ASTM D445)
- Base Oil Viscosity Index (ASTM D2270)

- Noack Volatility of the fully formulated oil (Finished Oil) (ASTM D5800)

The relevant test result is:

- Percent Viscosity Increase at 60 Hours

The STM must consist of a minimum number of Base Oils consistent with Section R.2.1. Each technology in the STM must pass each relevant test parameter (individual passing tests or by MTEP) in each Base Oil.

Confidence intervals are applicable to each relevant test parameter except Hot Stuck Piston Rings.

The table shown in R-5.6 summarizes the Base Oil Properties of Interest that must satisfy the spread requirement (R.1.2.7).

***Table R-5.6 – Base Oil Properties That Must Satisfy Spread Requirement***

| Base Oils | Saturates | Sulfur | VI | VIS100 | (Finished Oil) Noack |
|---|---|---|---|---|---|
| Group I | Yes | No | Yes | No | No |
| Group II, III, IV | No | No | Yes | No | No |

**R.5.3 Sequence IIIG**

If any of the Base Oils in the matrix is Group I, the STM must consist of at least 7 different Base Oils and the Base Oil Properties of Interest are:

- Base Oil Saturates (ASTM D2007)
- Base Oil Sulfur (except when Base Oil sulfur level is less than or equal to 0.03%) (API approved tests from Annex E, Table E-1)
- Base Oil Viscosity at 100°C (ASTM D445)
- Base Oil Viscosity Index (ASTM D2270)
- Noack Volatility of the fully formulated oil (Finished Oil) (ASTM D5800)

For a matrix and Candidate Oil including only Group II, Group III, and/or Group IV Base Oils, the STM must consist of at least 5 different Base Oils and the Base Oil Properties of Interest are:

- Base Oil Viscosity at 100°C (ASTM D445)
- Base Oil Viscosity Index (ASTM D2270)
- Noack Volatility of the fully formulated oil (Finished Oil) (ASTM D5800)

The relevant test results are:

- Percent Viscosity Increase at 100 Hours
- Weighted Piston Deposits
- Average Cam plus Lifter Wear
- Hot Stuck Piston Rings

The STM must consist of a minimum number of Base Oils consistent with Section R.2.1. Each technology in the STM must pass each relevant test parameter (individual passing tests or by MTEP) in each Base Oil.
Confidence intervals are applicable to each relevant test parameter except Hot Stuck Piston Rings.

The table shown in R-5.7 summarizes the Base Oil Properties of Interest that must satisfy the spread requirement (R.1.2.7).

***Table R-5.7 – Base Oil Properties That Must Satisfy Spread Requirement***

| Base Oils | Saturates | Sulfur | VI | VIS100 | (Finished Oil) Noack |
|---|---|---|---|---|---|
| Group I | Yes | No | Yes | No | No |
| Group II, III, IV | No | No | Yes | No | No |

### R.5.3.1 Detailed Example Using the Sequence IIIG with Group II Base Oils for API Service Category SN

Can we obtain a passing Predicted Test Result that meets the requirements of the STM for Technology 1 shown in Table R-5.8 in a Candidate Oil that is within the ranges for Base Oil viscosity, viscosity index and finished oil Noack volatility in the IIIG?

**Table R-5.8—Sequence IIIG Properties for Example Using STM**

| Base Oil | Base Oil Saturates D 2007 | Base Oil[2] Sulfur D 4294 | Finished Oil Noack Volatility D 5800 | Base Oil Viscosity @ 100°C D 445 | Base Oil Viscosity Index D 2270 | IIIG Percent Viscosity Increase | IIIG Weighted Piston Deposits | IIIG Average Cam & Lifter Wear | IIIG Number of Hot Stuck Rings |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 98.9 | 0.008 | 14.9 | 4.460 | 100 | 135.0 | 5.1 | 20.0 | 0 |
| 2 | 90.9 | 0.001 | 12.6 | 4.390 | 102 | 81.0 | 5.0 | 22.3 | 0 |
| 3 | 90.8 | 0.001 | 10.8 | 5.100 | 103 | 58.4 | 4.6 | 28.8 | 0 |
| 4 | 93.6 | 0.002 | 10.0 | 5.400 | 102 | 50.4 | 4.5 | 34.0 | 0 |
| 5 | 96.1 | 0.005 | 14.0 | 4.600 | 96 | 116.2 | 4.8 | 18.7 | 0 |
| 6 | 92.4 | 0.003 | 13.0 | 5.000 | 102 | . | . | . | . |

Step 1: Do we have enough Base Oils in the Matrix?

Yes. We have 5 Base Oils in the Matrix. The minimum number of passing Base Oils is the number of Base Oil Properties of Interest (viscosity at 100°C, viscosity index, and Noack volatility of the fully formulated oil) plus two.

Step 2: Do we satisfy the spread requirement for Base Oil viscosity index?

Yes. There are three Base Oils with VI above the mean of 101 and two Base Oils below this mean.

Step 3: Do we pass Technology 1 in every Base Oil in the Matrix?

Yes.

Step 4: Do we predict a pass for Technology 1 in the Candidate Oil based on the analysis of the Matrix?

Yes. The prediction for the Candidate Oil is based on a BOV100 model for WPD, Noack for TPVIS, and a very simple model for TACLW (see Table R-5.9), the average over all other Base Oils since no Base Oil effects were evident with this technology over the range tested. A summary of the prediction models are provided below.

$$\widehat{WPD} = 7.43 - 0.55 * BOV100$$

$$\widehat{PVIS} = e^{1.86+0.20*Noack}$$

$$\widehat{ACLW} = e^{3.18}$$

**Table R-5.9 - Step 4: Model Predicted**

| Base Oil | Base Oil Saturates D 2007 | Base Oil Sulfur D 4294 | Finished Oil Noack Volatility D 5800 | Base Oil Viscosity @ 100°C D 445 | Base Oil Viscosity Index D 2270 | Model Predicted | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | IIIG Percent Viscosity Increase | IIIG Weighted Piston Deposits | IIIG Average Cam & Lifter Wear |
| NEW | 92.4 | 0.003 | 13.0 | 5.000 | 102 | 91.7 | 4.7 | 24.0 |

Step 5: Are there any outliers?

Possible outliers would include test results in which the Studentized residuals exceed the Student T distribution at the one-sided 0.025 percentile with the degrees of freedom being equal to 3 for the WPD and TPVIS models. (The WPD and TPVIS models include 1 Base Oil parameter in the model.) The critical t value for the TPVIS and WPD parameters is shown below.

$$t_{0.05,3} = 3.182 \text{ (for WPD and TPVIS models)}$$

TACLW prediction model has no Base Oil parameter in the model. As a result, there are 4 degrees of freedom in this model. This critical t value for the TACLW parameter is shown below.

$$t_{0.05,4} = 2.776 \text{ (for TACLW Model)}$$

According to the calculations in R.2.4, there are no outliers.

**Table R-5.10—Step 5: Studentized Residuals**

| Test Number | IIIG Percent Viscosity Increase (TPVIS) | IIIG Weighted Piston Deposits | IIIG Average Cam plus Lifter Wear (TACLW) |
|---|---|---|---|
| 1 | -0.10874 | 2.67827 | -0.78913 |
| 2 | -2.42546 | -0.2168 | -0.3056 |
| 3 | -0.03909 | -0.31917 | 0.73848 |
| 4 | 0.64168 | 0.56079 | 2.022 |
| 5 | 1.38654 | -1.48438 | -1.18085 |

Step 6: The 95% confidence intervals (based on the Student T distribution) for the Candidate Oil are within the pass region for all relevant test properties. No additional tests for the confidence interval width are required.

Step 7: Can we obtain a Predicted Test Result for Technology 1 in a Candidate Oil that is within the ranges for Base Oil saturates, sulfur, viscosity, viscosity index, and finished oil Noack volatility in the Sequence IIIG?

Yes

**R.5.4 Sequence IIIGA**

If any of the Base Oils in the matrix is Group I, the STM must consist of at least 7 different Base Oils and the Base Oil Properties of Interest are:

- Base Oil Saturates (ASTM D2007)
- Base Oil Sulfur (except when Base Oil sulfur level is less than or equal to 0.03%) (API approved tests from Annex E, Table E-1)
- Base Oil Viscosity at 100°C (ASTM D445)
- Base Oil Viscosity Index (ASTM D2270)
- Noack Volatility of the fully formulated oil (Finished Oil) (ASTM D5800)

For a matrix and Candidate Oil including only Group II, Group III, and/or Group IV Base Oils, the STM must consist of at least 5 different Base Oils and the Base Oil Properties of Interest are:

- Base Oil Viscosity at 100°C (ASTM D445)
- Base Oil Viscosity Index (ASTM D2270)
- Noack Volatility of the fully formulated oil (Finished Oil) (ASTM D5800)

The relevant test results are:

- MRV TP-1

The STM must consist of a minimum number of Base Oils consistent with Section R.2.1. Each technology in the STM must pass the relevant test parameter (MTEP is not applicable) in each Base Oil.

Confidence intervals are not applicable to MRV TP-1 due to the nature of test result distribution and extraordinary size of the test variability.

The table shown in R-5.11 summarizes the Base Oil Properties of Interest that must satisfy the spread requirement (R.1.2.7).

***Table R-5.11 – Base Oil Properties That Must Satisfy Spread Requirement***

| Base Oils | Saturates | Sulfur | VI | VIS100 | (Finished Oil) Noack |
|---|---|---|---|---|---|
| Group I | Yes | No | Yes | No | No |
| Group II, III, IV | No | No | Yes | No | No |

An additional requirement for use of the Sequence IIIGA matrix is that the fresh oil MRV of the candidate oil, blended to the same viscosity grade, is equal to or less than the fresh oil MRV of at least one of the passing oils in the matrix, within the precision of the test. ASTM D4684 MRV testing is to be carried out at the appropriate temperature as defined in SAE J300.

**R.6 Single Technology Matrix Examples**

***The form of the model or the modeling technique is at the discretion of the organization developing the STM. Examples of different modeling techniques may include a simple mean with confidence intervals, generalized linear models, etc.***

**R.6.1 Failure to Meet Spread Requirement**

Can we obtain a passing Predicted Test Result that meets the STM requirements for Technology 1 shown in Table R-6.1.1 in a Candidate Oil that is 75.0% saturates in a test where the pass limit is a minimum of 8.0? For illustrative purposes, this simplified example considers Base Oil saturates as the only property of interest.

**Table R-6.1.1 - Test Results**

| Technology | Base Oil | Saturates | Test Result |
|---|---|---|---|
| 1 | 1 | 60.0 | 8.6 |
| 1 | 2 | 91.0 | 8.4 |
| 1 | 3 | 93.0 | 9.2 |
| 1 | 4 | 96.0 | 8.1 |
| 1 | 5 | 100.0 | 8.9 |

Step 1: Do we have enough Base Oils in the Matrix?

Yes. We have 5 passing Base Oils in the STM which meet the minimum number of Base Oils Requirement.

Step 2: Do we satisfy the Spread Requirement for saturates?

No. The mean Saturates of all the Base Oils = 88.0. There are four Base Oils above the mean and only one Base Oil below the mean. Therefore, the spread requirement is not satisfied, and we cannot analyze this Matrix as an STM.

Step 3: Do we pass Technology 1 in every Base Oil in the Matrix?

N/A

Step 4: Are there any Outliers?

N/A

Step 5: Do we predict a pass for Technology 1 in the Candidate Oil based on the analysis of the Matrix?

N/A

Step 6: Is the entire 95% Confidence Interval (based upon the Student T distribution) for the predicted mean performance based on the Single Technology Matrix model within the pass region of the test or shorter than the width based on the ASTM standard deviation?

N/A

Step 7: Can we obtain a Predicted Test Result for Technology 1 in a Candidate Oil that is within the ranges for Base Oil saturates, sulfur, viscosity, viscosity index, and finished oil Noack volatility in the Sequence IIIF?

No. The Spread Requirement has not been met.

**R.6.2 Failing Base Oil Resulting in Insufficient Number of Base Oils for the STM**

Can we obtain a passing Predicted Test Result that meets the requirements of STM for Technology 1 shown in Table R-6.2.1 in a Candidate Oil that is 75.0% saturates in a test where the pass limit is a minimum of 8.0? For this example, let's assume the only Base Oil Property of Interest is Base Oil Saturates.

**Table R-6.2.1 – Test Results**

| Technology | Base Oil | Saturates | Test Result |
|---|---|---|---|
| 1 | 1 | 60.0 | 9.8 |
| 1 | 2 | 70.0 | 7.1 |
| 1 | 2 | 70.0 | 8.0 |

| | | | |
|---|---|---|---|
| 1 | 3 | 80.0 | 8.9 |
| 1 | 4 | 90.0 | 5.0 |
| 1 | 4 | 90.0 | 7.9 |
| 1 | 4 | 90.0 | 8.1 |
| 1 | 5 | 100.0 | 9.4 |

Step 1: Do we have enough Base Oils in the Matrix?

No. We have 5 Base Oils in the STM. The minimum number of passing Base Oils is five. Base Oil 2 does not pass; Base Oil 4 is a Passing Test Result as it is an MTAC pass. Thus, with only 4 Base Oils that pass in this technology, we do not have a sufficient number of tests.

Step 2: Do we satisfy the Spread Requirement for saturates and viscosity index?

Yes. The mean Saturates of the 5 Base Oils = 80.0. There are two Base Oils with saturates above the mean, two Base Oils with saturates below the mean, and one equal to the mean. Therefore, the spread requirement for saturates is satisfied.

Step 3: Do we pass Technology 1 in every Base Oil in the Matrix?

No. We do not have a pass in Base Oil 2.

Step 4: Are there any Outliers?

N/A

Step 5: Do we predict a pass for Technology 1 in the Candidate Oil based on the analysis of the Matrix?

N/A

Step 6: Is the entire 95% Confidence Interval (based upon the Student T distribution) for the predicted mean performance based on the Single Technology Matrix model within the pass region of the test or shorter than the width based on the ASTM standard deviation?

N/A

Step 7: Can we obtain a Predicted Test Result for Technology 1 in a Candidate Oil that is within the ranges for Base Oil saturates, sulfur, viscosity, viscosity index, and finished oil Noack volatility in the Sequence IIIF?

No. There are an insufficient number of passing Base Oils in this STM.

**R.6.3 Modified Technologies Result in Insufficient Data for STM**

***Question:***

Do we have a passing Predicted Test Result that meets the requirements of STM for Technology 1 shown in Table R-6.3.1 in a Candidate Oil that is 75.0% saturates in a test where the pass limit is a minimum of 8.0?

**Table R-6.3.1— Test Results**

*(In this hypothetical example, the number of Base Oil Properties of Interest is Equal to 3)*

| Technology | Base Oil | Saturates | Test Result | Comments |
|---|---|---|---|---|
| 1 | 1 | 60.0 | 8.5 | |
| *1* | *2* | *70.0* | *7.1* | *Failing – Need Tech Mod* |

| | | | | |
|---|---|---|---|---|
| 1A | 2 | 70.0 | 8.6 | |
| 1A | 3 | 80.0 | 8.9 | |
| *1A* | *4* | *90.0* | *6.8* | *MTEP Failing – Need Tech Mod* |
| *1A* | *4* | *90.0* | *8.1* | *MTEP Failing – Need Tech Mod* |
| 1B | 4 | 90.0 | 8.8 | |
| 1B | 5 | 100.0 | 9.0 | |

Step 1: Do we have enough Base Oils in the Matrix?

No. Since we have two Modified Technologies and there are 3 Base Oil Properties of Interest, we need a t total of 7 passing Base Oil test results (3 Base Oil Properties of Interest + 2 + 2 Modified Technologies). In this example, there are only 5 passing Base Oil test results. As such, we would need test results in two additional Base Oils. If the 2 additional Base Oils are passing results and no other Modified Technology is introduced, then the Predicted Test Result must include Technology 1B.

Step 2: Do we satisfy the Spread Requirement for saturates and viscosity index?

N/A

Step 3: Do we pass Technology 1 in every Base Oil in the Matrix?

N/A

Step 4: Are there any Outliers?

N/A

Step 5: Do we predict a pass for Technology 1 in the Candidate Oil based on the analysis of the Matrix?

N/A

Step 6: Is the entire 95% Confidence Interval (based upon the Student T distribution) for the predicted mean performance based on the Single Technology Matrix model within the pass region of the test or shorter than the width based on the ASTM standard deviation?

N/A

Step 7: Can we obtain a Predicted Test Result for Technology 1 in a Candidate Oil that is within the ranges for Base Oil saturates, sulfur, viscosity, viscosity index, and finished oil Noack volatility in the Sequence IIIF?

No. There are an insufficient number of Base Oils in this STM.

**R.6.4 Confidence Interval Requirement Not Met**

Can we obtain a passing Predicted Test Result that meets the requirements of STM for Technology 1 shown in Table R-6.4.1 in a Candidate Oil that is 75.0% saturates in a test where the pass limit is a minimum of 8.0? For illustrative purposes, this simplified example considers Base Oil saturates as the only property of interest.

**Table R-6.4.1 – Test Results**

| Technology | Base Oil | Saturates | Test Result |
|---|---|---|---|
| 1 | 1 | 60.0 | 9.8 |
| 1 | 2 | 70.0 | 7.1 |
| 1 | 2 | 70.0 | 8.9 |

| | | | |
|---|---|---|---|
| 1 | 3 | 80.0 | 8.9 |
| 1 | 4 | 90.0 | 5.0 |
| 1 | 4 | 90.0 | 7.9 |
| 1 | 4 | 90.0 | 8.1 |
| 1 | 5 | 100.0 | 9.4 |

Step 1: Do we have enough Base Oils in the Matrix?

Yes. Of the 8 test results, there are 5 passing Base Oils in the matrix.

Step 2: Do we satisfy the Spread Requirement for saturates?

Yes. The mean Saturates of all the Base Oils = 80.0. There are two Base Oils above the mean and two Base Oils below the mean. Therefore, the Spread Requirement is satisfied.

Step 3: Do we pass Technology 1 in every Base Oil in the Matrix?

Yes. Note Step 4. The result of 5.0 is identified as an outlier according to R.2.4. The average result of Base Oil 4 becomes 8.0.

Step 4: Are there any Outliers?

Yes. The result of 5.0 on Base Oil 4 is identified as an Outlier. The Studentized Residual for this observation is 3.6, which is greater than the one sided $t_{0.025,7}$ of 2.36. The observation is removed from the analysis. Steps 1 and 2 are reevaluated and are still satisfied. A follow-on analysis of the data with the 5.0 result removed indicates that no other observation exceeds the outlier limit ($t_{0.025,6}$) of 2.45.

Step 5: Do we predict a pass for Technology 1 in the Candidate Oil based on the analysis of the Matrix?

Yes. The model is simply the mean of the data (8.6) with a RMSE of 0.9353 and 6 degrees of freedom for error. The Predicted Test Result is larger than the pass/fail limit.

Step 6: Is the entire 95% Confidence Interval (based upon the Student T distribution) for the predicted mean performance based on the Single Technology Matrix model within the pass region of the test or shorter than the width based on the ASTM standard deviation?

No. As shown in the below Table R-6.2.2, the Predicted Test Result Confidence Interval based on the Model Prediction is 7.7 to 9.5. The entirety of this interval is not within the pass region of the test. Therefore, we need to compare the width of this interval (9.5 – 7.7 = 1.8) to the Confidence Interval Width for a Mean Based on a Single Test Result.

The Industry standard deviation for the test is 0.25. The width of the Confidence Interval for a Mean Based on a Single Test Result is 0.98 (2 x 1.96 x 0.25).

Therefore, the width of the Predicted Test Result Confidence Interval based on the Model Prediction is not shorter than the Confidence Interval Width for a Mean Based on a Single Test Result.

**Table R-6.2.2 - Prediction Summary**

| Technology | Base Oil | Saturates | Pred Value | 95% CI for Mean | | CI Width |
|---|---|---|---|---|---|---|
| 1 | 6 | 75.0 | 8.6 | 7.7 | 9.5 | 1.8 |

Step 7: Can we obtain a Predicted Test Result for Technology 1 in a Candidate Oil that is within the ranges for Base Oil saturates, sulfur, viscosity, viscosity index, and finished oil Noack volatility in the Sequence IIIF?

No. The confidence interval requirement has not been met.