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The Proper Use of Substitute Test Fluids

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Liquid-measuring devices are used in many different commercial applications. The vast array of liquid products that are measured includes some products that may pose difficulties in testing. NIST Handbook 44, *Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices,* allows for substitution of fluids during testing in place of the actual fluids that will be used in commerce to mitigate some of these issues.

The most important consideration that will determine if one fluid can be used as a viable substitute for another is whether the results of the testing with the alternative fluid will accurately predict the performance of the device when measuring the fluid with which the device will normally be used. This article provides some guidance and considerations to help those who need to make decisions about whether or not to allow substitute fluids for testing.

Handbook 44 Notes on Test Liquids

Within Section 3.30. "Liquid-Measuring Devices" of NIST Handbook 44, paragraph N.1. "Test Liquid" makes the following statement: ***"The liquid used for testing of a liquid-measuring device shall be the type the device is used to measure, or another liquid with the same general physical characteristics."*** The Handbook also states that ***"Following the completion of a successful examination of a wholesale device, the weights and measures official should attach a label or tag indicating the type of liquid used during the test."***

Similar statements also appear in other sections of the Handbook. For example, Section 3.31. "Vehicle-Tank Meters" and Section 3.3. "Milk Meters" include the above statements and both of these Sections further specify that, "A milk-measuring system shall be tested with the type of milk to be measured when the accuracy of the system is affected by the characteristics of the milk (e.g., positive displacement meters)." The latter example holds the key to understanding the phrase "another liquid with the same general physical characteristics." The intent of this statement is to allow a fluid to be used as a valid substitute for another fluid during testing, so long as it is reasonable to expect that whatever differences do exist between the physical characteristics (properties) of the fluids will not have a significant impact on the meter's performance and the conclusions from the testing.

Justifications to Use a Substitute Fluid

Generally speaking, the most conclusive results can be obtained by testing with the same fluid that is to be sold commercially (hereafter referred to as the "primary fluid"). However, there

are many reasons that may make it impractical to use the primary fluid for testing. When there is good reason to justify the use of a substitute fluid for testing, the suitability of the substitution fluid must be authorized by the regulatory official, and must also comply with any restrictions made by the meter manufacturer.

- In cases where handling of the product for the purpose of testing may result in risks to safety, a substitute fluid may well be justified. Testing methods often require greater exposure of the product to people and the environment than is present during normal operation. If testing with the primary fluid poses hazards, then a substitute fluid that is safer for the testing should be considered if one is available.
- Certain products may also pose a risk of damage to the integrity of the reference standards that are needed for a test. For example, a product that might result in corrosion, erosion, or fouling of an otherwise carefully maintained and valuable field test standard would clearly be something that the official would want to avoid.
- The cost and expense of testing will often be impacted by whether the product used for test drafts can be returned to inventory for later sale or must be discarded. It may be that the testing process renders the product unsalable or that there is unacceptable risk of contamination due to the test. In such cases, substitution of an acceptable alternative fluid can help to avoid excessive costs that would be prohibitive to a reasonable maintenance cycle interval.

Other reasons may arise to justify a substitute fluid and all should be considered on a case by case basis using good judgment to decide if they warrant the substitution of an alternate fluid. In any case in which a reason is deemed to be justified, the need still remains to also confirm that the proposed substitute fluid complies with the statement that the fluid be "another liquid with the same general physical characteristics."

Substitute Fluids - The Four Key Factors

The suitability of a fluid for testing really depends on influence factors that affect the measuring device that is to be tested. If a particular fluid property (characteristic), such as density or viscosity, is known to have an influence on the performance of the device to be tested, then it is important that any proposed substitute fluid have properties (characteristics) similar to the primary fluid. Because different device technologies and designs are affected by different influence factors, the type of measuring device will determine the fluid characteristics that must be similar between the primary and the substitute fluids. For example, the performance of positive displacement meters is typically influenced by fluid viscosity, whereas conductivity of a fluid may influence the performance of a magnetic flow meter.

There are four key factors to consider while assessing the acceptability of one fluid as a substitute for another:

- the **DEVICE TYPE** to be tested,
- the difference in the **CRITICAL FLUID CHARACTERISTIC** for that device,
- whether or not the two fluids are in the same **PRODUCT CATEGORY TEST REQUIREMENT GROUP** for that device, and
- the difference in **OTHER FLUID CHARACTERISTICS IDENTIFIED BY THE MANUFACTURER** as important for that device.

Device Type. The reason that the type of device is such an important consideration is that some fluid characteristics affect different device types differently than they will other device types. A change in one particular fluid characteristic that has no effect at all on one type of device may, in contrast, have a significant effect on another type of device. For example, viscosity has two effects that are unique to a turbine flow meter. Viscosity affects the flow profile and the boundary layer thickness as the fluid flows over the turbine blades, resulting in non-linear performance. Viscosity also creates mechanical drag on the turbine bearing, which impacts the resistance of the rotor to turn freely. Comparatively, magnetic and Coriolis flow meters are less subject to viscosity changes, but instead have other unique influence factors related to other fluid characteristics.

Critical Fluid Characteristic. Device types have a single "Critical Fluid Characteristic", which is specific to each device type as defined by the policies used for National Type Evaluation Program (NTEP) evaluations. NTEP policies for grouping products according to key characteristics were developed with input from State and Federal government officials, device manufacturers, and other experts. These policies take into account meter type and the effect of the different product characteristics on performance. For example, for mass flow meters, the critical fluid characteristic is "specific gravity" because some mass flow meters use automatic density correction to correct for changes in product density. A fluid with a significantly different specific gravity or density than the primary fluid would be a poor substitute to use for testing.

National Conference on Weights and Measures (NCWM) Publication 14 for Measuring Devices contains a valuable tool to help establish whether or not one fluid should be substituted for another. The "Table of Product Families for Meters" can be found in Part C of the Technical Policy in Publication 14. This table is organized to show what fluid products share the same "Product Category" for a given type of meter. The table also shows, in the definitions of the various tests, what the critical fluid characteristic is for a meter type.

The "Critical Fluid Characteristics" for four different meter types are shown in Table 1.

Table 1.
Critical Fluid Characteristics by Meter Type
as Determined by NCWM Publication 14 for Measuring Devices

	Mass Flow Meters	Magnetic Flow Meters	Positive Displacement (PD) Meters	Turbine Meters
Critical Fluid Characteristic	Specific Gravity (Density)	Conductivity	Dynamic Viscosity	Kinematic Viscosity

The critical fluid characteristic can also be identified by consulting the NTEP Certificate of Conformance for a given meter or another meter of the same type. The "Applications" section of the Certificate of Conformance should state the range values for the critical fluid characteristic that are approved for a device based on previous NTEP testing and the application of Technical Policy C.

Product Category Test Requirement Group. Product categories are defined as groups of products that have been shown to produce similar performance results for a given meter type. These categories were developed to minimize the amount of testing required during NTEP evaluations intended to demonstrate meter performance with multiple products. Examples of product categories include fertilizers, crop chemicals, compressed gases, compressed liquids, water, chemicals, fuels, solvents, and heated products.

Product categories are combined together in NCWM Publication 14 into groupings that are defined by the type and extent of testing required. These groupings are identified by the designation of the "test requirements." There are six different test requirements named "Test A" through "Test F." Some test requirements apply only to certain device types. "Test F" requirements apply only to magnetic flow meters, "Test C" requirements apply only to positive displacement meters, "Test B" requirements apply only to mass flow meters, and "Test E" requirements apply only to turbine meters. Other test requirements apply to multiple device types. "Test D" requirements apply to all device types and "Test A" requirements apply to either turbine or positive displacement meters. The specific test requirements that apply in any given case will depend on both the device type and the product.

Each of the six test requirements explain the grouping of product categories by describing what products are covered by the test requirements. For example, "Test B" requirements state that "The Certificate of Conformance will cover all products in <u>all</u> product categories listed in the table under Test B within the specific gravity range tested." Because the coverage under "Test B" includes all products in <u>all</u> product categories under "Test B", then all "Test B" product

categories fall into the same product category test requirement group. This "Test B" product category test requirement group for mass flow meters was referred to collectively as "Normal Liquids" in 2010 and earlier editions of NCWM Publication 14. It is valid to consider all the fluids in the "Test B" set of product categories as if they were in a single product category for consideration of substitute fluids. Similarly, all the fluids in the various product categories that fall under the "Test F" requirements should be considered as being in the same product category for magnetic flow meters when considering substitute fluids. As another example, "Test E" requirements state that "The Certificate of Conformance will cover all products in the product category within the kinematic viscosity range tested." Because the coverage under "Test E" includes all products in the product category, all "Test E" product categories represent individual and separate product category test requirement groups. Product category test requirement groups are separated by double lines in the Product Families Table in NCWM Publication 14 to help readily identify these groupings. The product category test requirement groups are structured such that the performance of a meter with a given product will predict the performance and give results similar to those of the meter with other products in that same product category test requirement group.

A product category test requirement group for one meter type will not necessarily contain all the same fluids as it would for another meter type because, as noted in "*Device Type*" above, different meter types are affected by different fluid characteristics. The relationships between different fluids that determine whether they are in the same product category for a given meter type or not are complex because they depend on similarities and differences in one or in many secondary characteristics. These secondary characteristics are other fluid properties, in addition to the critical fluid characteristic, that can potentially impact test results for a given meter type. Examples of secondary properties that help define product categories include temperature range (as in the case of heated and cryogenic products), lubricity, phase stability, coefficient of thermal expansion, vapor pressure, and solids content. The best way to ensure that test results will not be impacted by a secondary characteristic of a substitute fluid is to verify, using NCWM Publication 14, whether or not the two fluids share a common product category test requirement group for a particular device.

Consider as an example a case where water is proposed as a substitute fluid for testing a device that has been installed to meter xylene. The owner of the device is reluctant to run xylene for the start-up tests because it is highly flammable and the testing arrangement will result in greater exposure and risk to safety than the normal system operation. NCWM Publication 14 reveals in the Product Families Table that xylene is in the product category known as "Solvents General." The "Solvents General" product category includes hexane, toluene, acetone, and some other solvents, but it does not include water. Water would not be a good substitute for xylene if the meter is either a positive displacement meter or a turbine meter because it is not

in the same product category test requirement group as xylene. Although xylene is a "Test F" fluid for magnetic flow meters, water is not a "Test F" fluid, so water would also not be a good substitute for a magnetic flow meter. For a mass flow meter, both xylene and water are fluids in the same "Test B" product category test requirement group (formerly known as "Normal Liquids"), so they can be considered as if they were in the same product category, but only if the device were a mass flow meter. The critical fluid characteristic for mass flow meters is specific gravity (density). The specific gravity of xylene is typically 0.89 and that of water is 1.0, which are somewhat close together. If the NTEP certificate for the device confirms in the "Applications" section that the meter approval already covers a range of specific gravities that includes both 0.89 and 1.0, then the substitution may still be considered after consulting the manufacturer for their input.

Other Fluid Characteristics Identified by the Manufacturer. Some device designs have additional influence factors, identified by the meter manufacturer, that are related to certain particular fluid properties. In cases where the meter manufacturer has identified influence factors related to fluid characteristics beyond the critical fluid characteristic for that device type, these other fluid characteristics must also be considered when evaluating a fluid to use as a substitute for testing of that particular device.

Once the fluid characteristics that can potentially influence the particular device type are identified, the next task is to determine the degree to which each of those characteristics may impact test results. The ideal scenario is for a substitute fluid to be equivalent to the primary fluid in every characteristic that is known to have an influence on the device performance, but in many cases, small differences will arise that will make it necessary to determine if the magnitude of that difference is likely to influence the outcome of the test.

An example of this would be the case where a device manufacturer has published a secondary influence factor relating to pressure. To determine if the effect of pressure on the device is likely to influence the outcome of the test, first ascertain whether the substitute fluid would be measured at a different pressure than the primary fluid. If this is the case, then use the formula stated by the manufacturer to estimate the magnitude of the effect based on the expected difference in pressure between the substitute fluid and the primary fluid. If the magnitude of this effect under the proposed test conditions with the substitute fluid would be significant in comparison with the allowed tolerance, then the proposed fluid would be a poor substitute.

Consult Device Manufacturers

Whenever possible, the manufacturer of the device should be consulted before approving a substitute test fluid. This can sometimes be achieved simply by referring to their published specifications. It is not uncommon for the published specifications of a measuring device to contain quantified influence factors of field effects. Unfortunately, these effects are not always

published or even well understood by all manufacturers, so the absence of these types of specifications cannot be interpreted as an absence of any influence factors.

Ideally, the manufacturer should be contacted directly. If the manufacturer believes that the substitute fluid may have an effect on your test results, or is not sure of what the effects might be, then you should only proceed with extreme caution. In order to avoid any misunderstanding and possible wrong conclusions, the manufacturer should be provided with the names and known properties of both the substitute fluid and the primary fluid. Additionally, you should provide the manufacturer with as much information as is known about the test conditions and the normal operating conditions (e.g., pressure, temperature, flow, etc.) since some of these conditions may impact the characteristics of one or both of the fluids differently in a way that affects performance of the device.

One other valuable piece of information that either the equipment owner or the manufacturer may be able to provide is data from prior controlled testing with the primary fluid. If the device model has been proven to perform within tolerances using the primary fluid at least once, then confidence in future testing using a qualified substitute fluid is higher than if there is no historical data available involving the primary fluid.

Automatic Temperature-Compensating Systems

In certain applications, automatic temperature compensation may be in use. Automatic temperature compensation adjusts the indication and registration of a measured volume to the volume that the particular product would occupy if it were at a specified reference temperature, typically 15 °C or 60 °F for petroleum products.

Substitution of another fluid in the testing of systems that include automatic temperature compensation is generally not recommended. The ultimate measurement accuracy of these types of systems depends on both the accuracy of the primary flow measurement and the accuracy of the automatic temperature compensation system and its associated calculations. Because the automatic temperature compensation system and its calculations are directly linked to the coefficient of thermal expansion (CTE) of the primary fluid, it is highly likely that a substituted fluid with a different CTE will have a significant impact on test results.

Substitutions for Gaseous Products

The same reasons that might exist to justify substitution of one liquid for another during testing might also arise when metering gases. Since gases are more difficult to contain and control than liquids, this can be especially evident when the primary gas represents a safety hazard because it is either toxic or flammable.

As in the case of liquids, NIST Handbook 44 also recognizes the substitution of gases for testing. In both Section 3.33. “Hydrocarbon Gas Vapor-Measuring Devices,” paragraph N.1. “Test

Medium," and in Section 3.37. "Mass Flow Meters," paragraph N.2., the Handbook states that "The device shall be tested with air or the product to be measured."

As more high pressure gaseous fueling applications (e.g., hydrogen) emerge, further attention needs to be given when considering substitution of different gases during testing, primarily because of the highly dynamic nature of flows, pressures, and temperatures that are seen during high pressure gas fueling. The Joule-Thompson coefficient is a gas property that indicates whether and by how much a gas will heat up or cool down as pressure changes and it can have dramatic impacts on the temperature of a gas during test drafts. Different gases can behave entirely differently under otherwise similar conditions.

The Bottom Line – Who determines the suitability of a substitute liquid?

In the case of installation, start-up, and maintenance verifications of individual devices used in legal trade, the weights and measures official has full jurisdictional authority and the final decision on whether a certain substitute fluid can be used or not at their discretion. For Type Evaluation, any substitution of fluids is subject to the approval of the NTEP laboratories and the NTEP administrator.

For questions about this article or further information on product substitutions during testing of commercial measuring devices, contact Marc Buttler by e-mail at marc.buttler@nist.gov or by phone at (301) 975-4615.