



Standard Test Method for On-Line Measurement of Residue After Evaporation of High-Purity Water¹

This standard is issued under the fixed designation D5544; 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 (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of dissolved organic and inorganic matter and colloidal material found in high-purity water used in the semiconductor, and related industries. This material is referred to as residue after evaporation (RAE). The range of the test method is from 0.001 $\mu\text{g/L}$ (ppb) to 60 $\mu\text{g/L}$ (ppb).

1.2 This test method uses a continuous, real time monitoring technique to measure the concentration of RAE. A pressurized sample of high-purity water is supplied to the test method's apparatus continuously through ultra-clean fittings and tubing. Contaminants from the atmosphere are therefore prevented from entering the sample. General information on the test method and a literature review on the continuous measurement of RAE has been published.²

1.3 The values stated in SI units are to be regarded as standard. The values given in parentheses are mathematical conversions to inch-pound units that are provided for information only and are not considered standard.

1.4 *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 and health practices and determine the applicability of regulatory limitations prior to use.* For specific hazards statements, see Section 8.

2. Referenced Documents

2.1 ASTM Standards:³

[D1129 Terminology Relating to Water](#)

¹ This test method is under the jurisdiction of ASTM Committee D19 on Water and is the direct responsibility of Subcommittee D19.03 on Sampling Water and Water-Formed Deposits, Analysis of Water for Power Generation and Process Use, On-Line Water Analysis, and Surveillance of Water.

Current edition approved June 1, 2016. Published June 2016. Originally approved in 1994. Last previous edition approved in 2011 as D5544 – 11. DOI: 10.1520/D5544-16.

² Blackford, D. B., "Use of Nonvolatile Residue Monitoring in Semiconductor Water Applications" *Ultrapure Water Journal*, Tall Oaks Publishing, November 2008, pp. 16–23.

³ For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[D2777 Practice for Determination of Precision and Bias of Applicable Test Methods of Committee D19 on Water](#)
[D3370 Practices for Sampling Water from Closed Conduits](#)
[D3864 Guide for On-Line Monitoring Systems for Water Analysis](#)
[D3919 Practice for Measuring Trace Elements in Water by Graphite Furnace Atomic Absorption Spectrophotometry](#)
[D5127 Guide for Ultra-Pure Water Used in the Electronics and Semiconductor Industries](#)
[E1184 Practice for Determination of Elements by Graphite Furnace Atomic Absorption Spectrometry](#)

3. Terminology

3.1 *Definitions*—For definitions of terms used in this test method, refer to Terminology [D1129](#).

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *aerosol, n*—any solid or liquid particles, with a nominal size range from 10 nm to 100 μm , suspended in a gas (usually air).

3.2.2 *colloidal suspension, n*—any material in suspension (for example, silica) with a nominal particle size less than 100 nm.

3.2.3 *Water-based condensation particle counter (WCPC), n*—instrument for detecting very small aerosol particles in a size range from approximately 7 nm to 2 to 3 μm .

3.2.3.1 *Discussion*—The WCPC cannot differentiate among particles of varying size within this size range; the counter reports the number of particles with a size greater than that defined by the detection-efficiency curve. Detection is independent of particle composition.

3.2.4 *detection efficiency, n*—in this test method, detection efficiency represents a curve relating particle size to a counter's ability to detect that size.

3.2.5 *polydisperse, adj*—a type of size population, in this case of aerosol particles, composed of many different sizes; the opposite of monodisperse, which is a type of size distribution of just one size.

3.2.6 *realtime, n*—the time that an event is occurring plus the response time.

3.2.6.1 *Discussion*—In this case, the response time is 3 to 5 min, therefore, contamination is recorded 3 to 5 min after it occurs.

3.2.7 *residue after evaporation, n*—contaminants remaining after all water is evaporated; sometimes known as nonvolatile residue or total dissolved and suspended solids.

4. Summary of Test Method

4.1 This test method consists of continuously removing a representative sample of high-purity water from a pressurized supply line (refer to Practices D3370, Practice C on Continual Sampling, and Practice D3864). The temperature of the incoming high-purity water should ideally be at room temperature, but not more than 50°C. A nebulizer is supplied with the high-purity water at a constant flow rate, and a source of compressed air, or nitrogen, at a constant flow rate and pressure, to generate a stable aerosol of high-purity water droplets. Under these conditions, the nebulizer produces a polydisperse size distribution of droplets with a median size of approximately 1 μm, and a concentration of approximately 10⁷ droplets/s, or 10¹² droplets/mL

4.2 The droplets are heated at 120°C. After the heating, additional compressed air or nitrogen is introduced from the supply to prevent re-condensation and to quickly move the residue particles to the Water-based Condensation Particle Counter (WCPC).

4.3 The WCPC works as follows: Residue particles pass through a region called the Saturator (see Fig. 1) where the residue particles are saturated with water vapor and temperature equilibrated. The residue particles and water vapor then pass into a region called the Growth Tube, where the wetted walls of the porous media are heated to raise vapor pressure. The high diffusivity of the vapor allows it to reach the center of the sample stream at a faster rate than the thermal diffusivity of the vapor can equilibrate to the higher temperatures near the walls, resulting in a supersaturated condition along the radius of the flow stream. Residue particles in the flow stream act as nuclei for condensation. Water condenses on the residue particles to form large droplets with only one residue particle at the center of each droplet. Droplets can then be counted with a relatively simple optical particle counter. A more elaborate

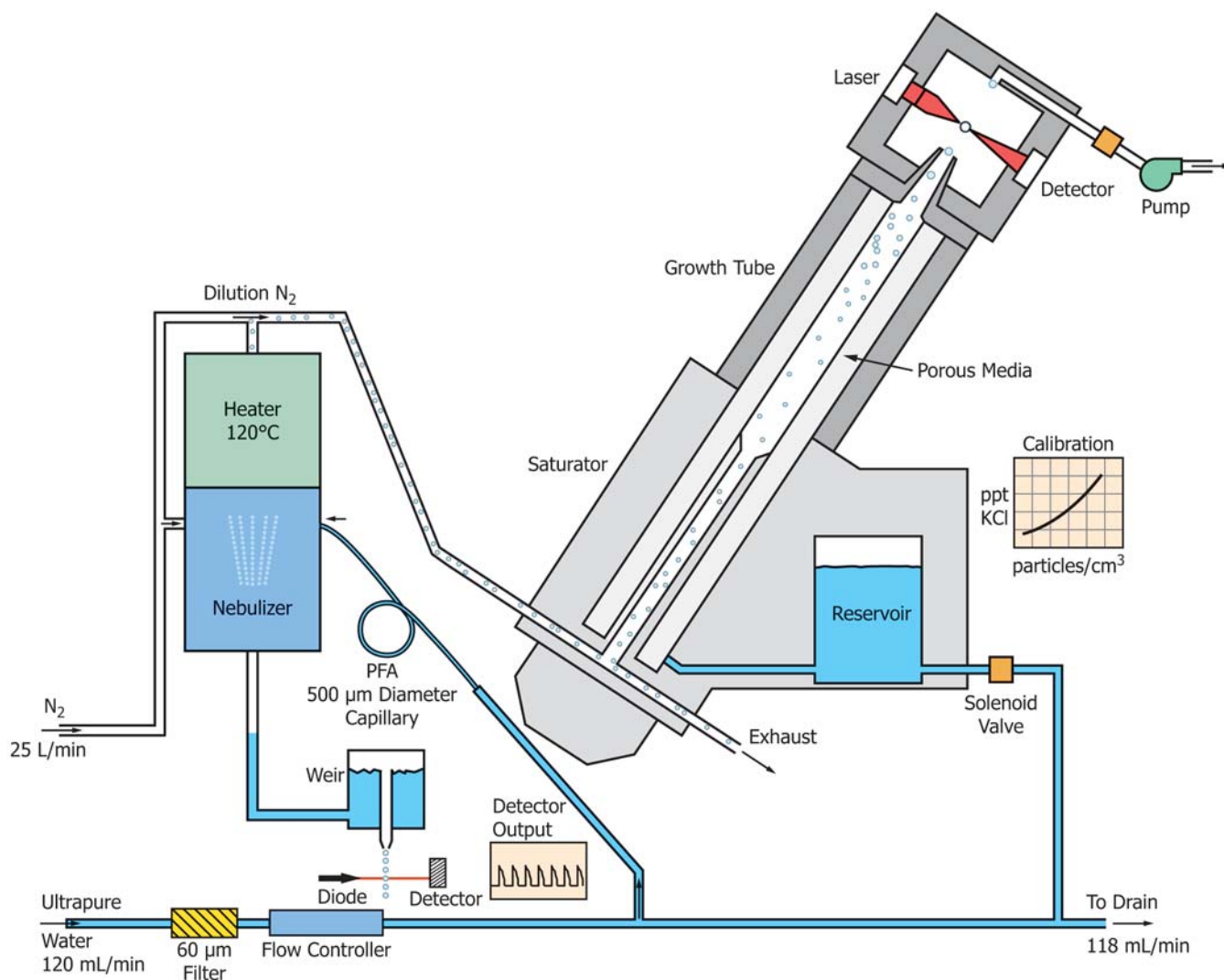


FIG. 1 Schematic Diagram of Apparatus Required for This Test Method

description of the WCPC's method for distinguishing between clean and dirty water is described in [Appendix X1](#).

4.4 A calibration technique (described in detail in Section 10) uses concentration standards of high-purity potassium chloride (KCl) to convert the WCPC count concentration in particles per cubic centimetre into RAE concentration in micrograms per litre or milligrams per litre. A graphite furnace atomic absorption spectrometer (GFAAS), or equivalent method, can be used to check the concentration of KCl in this test method standard (see Practices [D3919](#) and [E1184](#)).

5. Significance and Use

5.1 Even so-called high-purity water will contain contaminants. While not always present, these contaminants may contribute one or more of the following: dissolved active ionic substances such as calcium, magnesium, sodium, potassium, manganese, ammonium, bicarbonates, sulfates, nitrates, chloride and fluoride ions, ferric and ferrous ions, and silicates; dissolved organic substances such as pesticides, herbicides, plasticizers, styrene monomers, deionization resin material; and colloidal suspensions such as silica. While this test method facilitates the monitoring of these contaminants in high-purity water, in real time, with one instrument, this test method is not capable of identifying the various sources of residue contamination or detecting dissolved gases or suspended particles.

5.2 This test method is calibrated using weighed amounts of an artificial contaminant (potassium chloride). The density of potassium chloride is reasonably typical of contaminants found in high-purity water; however, the response of this test method is clearly based on a response to potassium chloride. The response to actual contaminants found in high-purity water may differ from the test method's calibration. This test method is not different from many other analytical test methods in this respect.

5.3 Together with other monitoring methods, this test method is useful for diagnosing sources of RAE in ultra-pure water systems. In particular, this test method can be used to detect leakages such as colloidal silica breakthrough from the effluent of a primary anion or mixed-bed deionizer. In addition, this test method has been used to measure the rinse-up time for new liquid filters and has been adapted for batch-type sampling (this adaptation is not described in this test method).

5.4 Obtaining an immediate indication of contamination in high-purity water has significance to those industries using high-purity water for manufacturing components; production can be halted immediately to correct a contamination problem. The emerging nano-particle technology industry will also benefit from this information.

6. Apparatus

6.1 The schematic arrangement of the system is shown in [Fig. 1](#). The apparatus is available as a complete instrument.⁴

6.2 *60 μm Filter*, high purity water flows into the apparatus at approximately 120 mL/min and immediately passes through a 60 μm sintered stainless filter that removes any large debris and then flows to flow controller.

6.3 *Flow Controller*, made of a non-contaminating material such as perfluoroalkoxy (PFA), necessary to supply the nebulizer with high-purity water at the desired flow rate. The flow controller must contain an air actuated pressure regulator to ensure that water is delivered to the nebulizer at a stable flow rate, despite external fluctuations. High-purity water must be delivered to the flow controller and nebulizer through ultra-clean tubes and fittings made from PFA. Nebulizers usually require a very low flow rate, approximately 1 mL/min, for efficient operation. However, such a low flow rate is inadequate for routine monitoring because it results in a long response time. This test method is designed to overcome the problem of long response times by using a flow controller to deliver approximately 120 mL/min of high-purity water to the monitoring site and then to divert approximately 1 mL/min of the flow to the nebulizer through a short tube. This short tube facilitates a short response time. From the pressure regulator, the water flows to the nebulizer through a tee fitting and a section of PFA 500μm capillary tubing. The PFA tubing gradually lowers the water pressure and prevents any out-gassing of dissolved gases in the incoming water.

6.4 *Measuring the Flow Rate*, the flow rate of water flowing through the nebulizer is used as an indicator that the NRM 8000 is set up and operating correctly. Instead of using a conventional flow meter, the NRM 8000 incorporates a new, patented method of measuring the flow rate. Of the water flowing through the nebulizer, 95% leaves it as part of a waste stream. The waste water is collected by a weir and stand-pipe system and then delivered as a steady stream of water droplets of identical size. These droplets fall through a simple light beam. As each droplet breaks the beam, a detector senses a scattered light signal, or pulse, and a counter keeps track of the pulses. An algorithm converts the pulse count to a flowrate (in mL/min.) which is shown on the front panel display.

6.5 *Nebulizer*, required to produce a polydisperse size distribution of droplets with a median size of approximately 1 μm and a concentration of approximately 10⁷ droplets/s. Within the customized designed nebulizer, the water and compressed air/nitrogen (supplied at a constant flow rate and pressure) combine to form the required stable, poly-dispersed aerosol of ultrapure water droplets. The nebulizer must be supplied with clean, dried filtered compressed air or nitrogen and must be machined from a material that will not contaminate the high-purity water. Passivated 316L stainless steel has been

⁴ The sole source of supply of the apparatus known to the committee at this time is Fluid Measurement Technologies, 4106 Hoffman Road, White Bear Lake, MN 55110. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee¹, which you may attend.