Designation: D7937 – 15

Standard Test Method for In-situ Determination of Turbidity Above 1 Turbidity Unit (TU) in Surface Water[1]

This standard is issued under the fixed designation D7937; 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 in-situ field measurements of turbidity in surface water. The measurement range is greater than 1 TU and the lesser of 10 000 TU or the maximum measurable TU value specified by the turbidimeter manufacturer.

1.1.1 Precision data was conducted on both real world and surrogate turbidity samples up to about 1000 TU. Many of the technologies listed in this test method are capable of measuring above that provided in the precision section (see Section 16).

1.2 "In-situ measurement" refers in this test method to applications where the turbidimeter sensor is placed directly in the surface water in the field and does not require transport of a sample to or from the sensor. Surface water refers to springs, lakes, reservoirs, settling ponds, streams and rivers, estuaries, and the ocean.

1.3 Many of the turbidity units and instrument designs covered in this test method are numerically equivalent in calibration when a common calibration standard is applied across those designs listed in Table 1. Measurement of a common calibration standard of a defined value will also produce equivalent results across these technologies. This test method prescribes the assignment of a determined turbidity values to the technology used to determine those values. Numerical equivalence to turbidity standards is observed between different technologies but is not expected across a common sample. Improved traceability beyond the scope of this test method may be practiced and would include the listing of the make and model number of the instrument used to determine the turbidity values.

1.4 In this test method, calibration standards are often defined in NTU values, but the other assigned turbidity units, such as those in Table 1 are equivalent. For example, a 1 NTU formazin standard is also a 1 FNU, a 1 FAU, a 1 BU, and so forth.

1.5 This test method was tested on different natural waters and with standards that served as surrogates for samples. It is recommended to validate the method response for waters of untested matrices.

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

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D1129 Terminology Relating to Water
D1193 Specification for Reagent Water
D2777 Practice for Determination of Precision and Bias of Applicable Test Methods of Committee D19 on Water
D3864 Guide for On-Line Monitoring Systems for Water Analysis
D4411 Guide for Sampling Fluvial Sediment in Motion
D7315 Test Method for Determination of Turbidity Above 1 Turbidity Unit (TU) in Static Mode
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

[1] This test method is under the jurisdiction of ASTM Committee D19 on Water and is the direct responsibility of Subcommittee D19.07 on Sediments, Geomorphology, and Open-Channel Flow.

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[2] 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.

TABLE 1 Summary of Known in-situ Instrument Designs, Applications, Ranges, and Reporting Units

Design and Reporting Unit	Prominent Application	Key Design Features	Typical Instrument Range	Suggested Application Ranges
Nephelometric Non-Ratio (NTU)	White light turbidimeters Comply with EPA 180.1 for low level turbidity monitoring.	Detector centered at 90° relative to the incident light beam. Uses a white light spectral source.	0.0–40	0.0–40 Regulatory
Ratio White Light Turbidimeters (NTRU)	Complies with U.S. EPA regulations and EPA 2130B. Can be used for both low and high level measurement.	Used a white light spectral source. Primary detector centered at 90°. Other detectors located at other angles. An instrument algorithm uses a combination of detector readings to generate the turbidity reading.	0–10 000	0–40 Regulatory 0–10 000 other
Nephelometric, Near-IR Turbidimeters, Non- Ratiometric (FNU)	Complies with ISO 7027. The wavelength is less susceptible to color interferences. Applicable for samples with color and good for low level monitoring.	Detector centered at 90° relative to the incident light beam. Uses a near-IR (780-900 nm) monochromatic light source.	0–1 000	0–40 Regulatory (non-US) 0–1 000 other
Nephelometric Near-IR Turbidimeters, Ratio Metric (FNRU)	Complies with ISO 7027. Applicable for samples with high levels of color and for monitoring to high turbidity levels.	Uses a near-IR monochromatic light source (780–900 nm). Primary detector centered at 90°. Other detectors located at other angles. An instrument algorithm uses a combination of detector readings to generate the turbidity reading.	0–10 000	0–40 Regulatory 0–10 000 other
Formazin Back Scatter (FBU)	Not applicable for regulatory purposes. Best applied to high turbidity samples. Backscatter is common probe technology and is best applied in higher turbidity samples.	Uses a near-IR monochromatic light source in the 780–900 nm range. Detector geometry is 30 ± 15° relative to the incident light beam.	100–10 000+	100–10 000
Backscatter Unit (BU)	Not applicable for regulatory purposes. Best applied for samples with high level turbidity.	Uses a white light spectral source (400–680 nm range). Detector geometry is 30 ± 15° relative to the incident light beam.	10–10 000+	100–10 000+
Formazin Attenuation Unit (FAU)	May be applicable for some regulatory purposes. This is commonly applied with spectrophotometers. Best applied for samples with high level turbidity.	Detector is geometrically centered at 180° relative to incident beam (attenuation) Wavelength is 780–900 nm.	20–1 000	20–1 000 Regulatory
Light Attenuation Unit (AU)	Not applicable for some regulatory purposes. This is commonly applied with spectrophotometers.	Detector is geometrically centered at 180° relative to incident beam (attenuation). Wavelength is 400–680 nm.	20–1 000	20–1 000
Nephelometric Turbidity Multibeam Unit (FNMU)	Is applicable to EPA regulatory method GLI Method 2. Applicable to drinking water and wastewater monitoring applications.	Detectors are geometrically centered at 90° and 180°. An instrument algorithm uses a combination of detector readings, which may differ for turbidities varying magnitude.	0.02–4000	0–40 Regulatory 0–4 000 other
Forward Scatter Ratio Unit (FSRU)	The technology encompasses a single, light source and two detectors. Light sources can vary from single wavelength to polychromatic sources. The detection angle for the forward scatter detector is between 0 and 90° relative to the centerline of the incident light beam.	The technology is sensitive to turbidities as low as 1 TU. The ratio technology helps to compensate for color interference and fouling.	1-800 FSRU The measurement of ambient waters such as streams, lakes, rivers.	Forward Scatter Ratio Unit (FSRU)
Forward Scatter Unit (FSU)	The technology encompasses a single, light source and one detector between 0 and 90° relative to the centerline of the incident light beam.	The technology is sensitive to turbidities as low as 1 TU. The ratio technology helps to compensate for color interference and fouling.	1-1000 FSU The measurement of ambient waters such as streams, lakes, rivers and process waters.	Forward Scatter Unit (FSU)

2.2 *Other Referenced Standards:*
EPA 180.1 Determination of Turbidity by Nephelometry[3]
EPA 2130B Analytical Method For Turbidity Measurement[3]
ISO 7027 (International Organization for Standardization) Water Quality for the Determination of Turbidity[4]
GLI Method 2 Turbidity[3]

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*—Unless otherwise noted, the term 'light' means visible light or near-infrared (NIR) radiation or both.

3.2.1 *ambient light, n*—light or optical path or both that does not originate from the light source of a turbidimeter.

3.2.2 *attenuation, n*—the amount of incident light that is scattered and absorbed before reaching a detector, which is geometrically centered at 180° relative to the centerline of the incident light beam.

3.2.2.1 *Discussion*—Attenuation is inversely proportional to transmitted signal.

Attenuated Turbidity = Absorbed Light + Scattered Light

3.2.2.2 *Discussion*—The application of attenuation in this test method is as a distinct means of measuring turbidity. When measured in the FAU or AU mode, the turbidity value is a combination of scattered (attenuated) light plus absorbed light. The scattered light is affected by particle size and is a positive response. The absorption due to color is a negative response. The sum of these two responses results in the turbidity value in the appropriate unit.

3.2.3 *automatic power control (APC), n*—the regulation of light power from a source such that illumination of the sample remains constant with time and temperature.

3.2.4 *broadband, white-light source, n*—a visible-light source that has a full bandwidth at half of the source's maximum intensity (FWHM) located at wavelengths greater than 200 nm.

3.2.4.1 *Discussion*—Tungsten-filament lamps (TFLs) and white LEDs are examples of broadband sources.

3.2.5 *calibration turbidity standard, n*—a turbidity standard that is traceable and equivalent to the reference turbidity standard to within defined accuracy; commercially prepared 4000 NTU Formazin, stabilized formazin, and styrenedivinylbenzene (SDVB) are calibration turbidity standards.

3.2.5.1 *Discussion*—These standards may be used to calibrate the instrument. All meters should read equivalent values for formazin standards. SDVB-standard readings are instrument specific and should not be used on meters that do not have defined values specified for that instrument. Calibration standards that exceed 10 000 turbidity units are commercially available.

3.2.6 *calibration-verification standards, n*—defined standards used to verify the instrument performance in the measurement range of interest.

3.2.6.1 *Discussion*—Calibration-verification standards may not be used to adjust instrument calibration, but only to check that the instrument measurements are in the expected range. Examples of calibration-verification standards are opto-mechanical light-scatter devices, gel-like standards, or any other type of stable liquid standard. Calibration-verification standards may be instrument-design specific.

3.2.7 *color, n*—the hue (red, yellow, blue, etc.) of a water sample produced by the combination of: the selective absorption of visible light, the spectral reflectivity, and the degree of darkness or blackness of suspended matter.

3.2.7.1 *Discussion*—The combination above is defined by the Munsell (**1**)[5] color-classification scheme.

3.2.8 *detector, n*—a solid-state device that converts light into electrical current or voltage.

3.2.9 *detector angle, n*—the angle between the axis of the detector acceptance cone and the axis of the source light or NIR beam.

3.2.9.1 *Discussion*—The detector angle equals 180° – θ (θ is the scattering angle).

3.2.10 *narrow-band source, n*—a light source with a full bandwidth (at half of the source's maximum intensity) (FWHM) located at wavelengths less than 5 nm.

3.2.11 *operating spectrum, n*—the wavelength-by-wavelength products of source intensity, filter transmittance, and detector sensitivity.

3.2.11.1 *Discussion*—The operating spectrum determines the relative contributions of wavelengths in the light-to-current conversions made by a turbidimeter.

3.2.12 *ratio turbidity measurement, n*—the measurement derived through the use of a primary detector and one or more other detectors to compensate for variation in incident-light intensity, stray light, sample color, window transmittance, and dissolved NIR-absorbing matter.

3.2.13 *reference turbidity standard, n*—a standard that is synthesized reproducibly from traceable raw materials by a skilled analyst.

3.2.13.1 *Discussion*—All other standards are traced back to this standard. The reference standard for turbidity is formazin.

3.2.14 *sample volume, n*—the water-sample volume wherein light from a turbidimeter source interacts with suspended particles and is subsequently detected.

3.2.15 *scattering (also referred to as scatter), n*—light interaction that alters the direction of light transport through a sample without changing the wavelength.

3.2.15.1 *Discussion*—The light interaction can be with suspended particles, water molecules, and variations in the sample's refractive index.

3.2.16 *scattering angle (θ), n*—the angle between a source light or NIR beam, and the scattered beam.

[3] Available from United States Environmental Protection Agency (EPA), William Jefferson Clinton Bldg., 1200 Pennsylvania Ave., NW, Washington, DC 20004, http://www.epa.gov.

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[5] The boldface numbers in parentheses refer to the list of references at the end of this standard.

3.2.17 *forward-scattered radiation, n*—the scattered incident light that is detected at an angle between 0-degrees and less than 90-degrees, relative to the direction of the projected incident-light beam.

3.2.17.1 *Discussion*—Most designs will have an angle between 0-degrees and 45-degrees.

3.2.18 *stray light, n*—all light reaching the detector(s) other than light that is scattered by the sample.

3.2.18.1 *Discussion*—Stray light could be ambient-light leakage, internal reflections, and divergent light in optical systems. For this test method, stray light is likely to be negligible. The instrument design is intended to reduce or eliminate stray light.

3.2.19 *transmittance, n*—the ratio of light power transmitted through a sample to the light power incident upon the sample.

3.2.20 *turbidimeter design, n*—an arrangement of optical (lenses, windows, filters, apertures, etc.) and optoelectronic (light sources and detectors, etc.) components, mechanical components, and electrical circuits for determining the turbidity of water.

3.2.21 *turbidity, n*—an expression of a sample's optical properties that cause light rays to be scattered and absorbed rather than transmitted in straight lines through the sample.

3.2.21.1 *Discussion*—Turbidity of water is caused by the presence of suspended and dissolved matter such as clay, silt, finely divided organic matter, plankton, other microscopic organisms, organic acids, and dyes.

3.3 *Symbols:*

A = amperes
b = scattering coefficient
θ = scattering angle
W = Watts

3.4 *Acronyms:*

3.4.1 *APC, n*—automatic power control

3.4.2 *AU, n*—attenuation unit

3.4.3 *BU, n*—backscatter unit

3.4.4 *FAU, n*—formazin attenuation unit

3.4.5 *FBU, n*—formazin backscatter unit

3.4.6 *FNMU, n*—nephelometric turbidity multi-beam unit

3.4.7 *FNRU, n*—formazin nephelometric ratio unit

3.4.8 *FNU, n*—formazin nephelometric unit

3.4.9 *FSU, n*—forward scatter unit

3.4.10 *FSRU, n*—forward scatter ratio unit

3.4.11 *FWHM, n*—full bandwidth at half of the source's maximum intensity

3.4.12 *IRED, n*—infrared-emitting diode

3.4.13 *LED, n*—light-emitting diode

3.4.14 *NIR, adj*—near infrared

3.4.15 *NTRU, n*—nephelometric

3.4.16 *NTU, n*—nephelometric turbidity unit

3.4.17 *SDVB, n*—styrenedivinylbenzene

3.4.18 *SSC, n*—suspended sediment concentration

3.4.19 *TFL, n*—tungsten-filament lamp

3.4.20 *TU, n*—turbidity unit

NOTE 1—See Table 1 for description of all acronyms related to turbidity reporting units.

4. Summary of Test Method

4.1 Turbidity is a numerical expression, in relative units, of the optical properties that cause light to be scattered and absorbed rather than transmitted straight through a water sample. It is measured with a turbidimeter, which in simplest form has a light source to illuminate the water sample and light detectors to measure the relative intensity of light scattered from the sample (**2**). In some meter designs, a second detector is positioned to respond to transmitted light and to give a relative measure of attenuation resulting from light absorption in the beam and the scattering of light from the beam.

4.2 The area of illuminated particles, particle-volume concentration and the sample turbidity are directly proportional to one another in the linear range of a turbidimeter. Depending on meter design, the range can be as little as 40 TU or as large as 10 000 TU. As the concentration of light-scattering particles increases, the relative intensity of scattered light will increase linearly whereas the intensity of transmitted light will decrease exponentially. Beyond the linear range, the indicated turbidity value will be a nonlinear function of concentration. The linear range is larger for turbidimeters with closely spaced sources and detectors than for meters with wider source-detector spacing.

4.3 The method is based upon a comparison of the intensity of light scattered from and transmitted by a surface water sample with the intensity of light scattered from and transmitted by a reference light-scattering suspension (turbidity calibration or reference turbidity standard) using an in-situ turbidimeter. Unlike static measurements for which sample vials are placed in a bench-top or portable turbidimeter, in-situ measurements allow the meter to be placed in the water. A recent ASTM precision and bias study (see Test Method D7315) and independent research have demonstrated that different turbidimeters indicate different TU values for the same water sample even when calibrated with the same turbidity calibration standards. For some suspended matter, the indicated values can differ by a factor of ten. These differences are caused by a number of factors including the instrument design, light source, detector orientation, sediment color and grain size characteristics. It is therefore recommended that metadata, in the form of reporting units and appended model numbers in certain cases, be used when reporting TU values. In this way, data can be traced to the type of meter used, data compatibility will be enhanced, and long-term surface-water quality trends may be more apparent.

5. Significance and Use

5.1 Turbidity is monitored to help control processes, monitor the health and biology of aquatic environments and to determine the impact of environmental events such as storms, floods, runoff, etc. Turbidity is undesirable in drinking water, plant-effluent waters, water for food and beverage production, and for a large number of other water-dependent manufacturing processes. Turbidity is often reduced by coagulation, sedimentation and water filtration. The measurement of turbidity may indicate the presence of particle-bound contaminants and is vital for monitoring the completion of a particle-waste settling process. Significant uses of turbidity measurements include:

5.1.1 Compliance with permits, water-quality guidelines, and regulations;

5.1.2 Determination of transport and fate of particles and associated contaminants in aquatic systems;

5.1.3 Conservation, protection and restoration of surface waters;

5.1.4 Measure performance of water and land-use management;

5.1.5 Monitor waterside construction, mining, and dredging operations;

5.1.6 Characterization of wastewater and energy-production effluents;

5.1.7 Tracking water-well completion including development and use; and

5.1.8 As a surrogate for other constituents in water including sediment and sediment-associated constituents.

5.2 The calibration range of a turbidimeter shall exceed the expected range of TU values for an application but shall not exceed the measurement range specified by the manufacturer.

5.3 Designs described in this standard detect and respond to a combination of relative absorption, intensity of light scattering, and transmittance. However, they do not measure these absolute physical units as defined in 3.2.15 and 3.2.19.

5.4 Several different turbidimeter designs may be used for this test method and one design may be better suited for a specific type of sample or monitoring application than another. The selection flowchart in Annex A1 provides guidance for the selection of an appropriate turbidimeter design for a specific application.

5.5 Report turbidity in units that reflect the design of the turbidimeter used as recommended in 4.3. See Table 1 and Section 7 for a discussion of the design criteria and derivation of reporting units.

5.6 Table 1 and Section 7 lists the turbidimeter designs currently used for in-situ measurements. Future revisions of the method may include additional designs.

6. Interferences

6.1 Bubbles may interfere with turbidity determined by this test method. Bubbles cause turbidity values to be higher than they would be in bubble-free water and result in a positive interference.

6.2 Depending on the application color may or may not be considered as an interference. Color is characterized by absorption of specific wavelengths of light. If the wavelengths of incident light are significantly absorbed, a lower turbidity reading will result unless the instrument has special compensating features.

6.2.1 Color has less effect on a turbidimeter with an NIR operating spectrum, however, particle and water color may indicate the presence of NIR-absorbing matter as well as NIR reflectivity that can cause interferences. Particle reflectivity is considered an intrinsic turbidity factor. Those designs where color effects can be reduced or eliminated include nephelometric-based designs with incident light sources in the 780–900 nm range. Those designs that have additional detectors, such as ratioing instruments also help to reduce the effects of color regardless of the light source. Single detector systems with light sources below 780 nm will be more impacted by the effects of color in the sample, that is color visible to the naked eye. Color can have a significant impact on attenuation-based instruments if it has absorption spectrum that overlaps the spectral output of the incident light source. In some applications, the spectral reflectivity or color of suspended matter and light-absorbing dissolved matter are considered to be part of a turbidity measurement and not an interference.

NOTE 2—The user should not automatically assume that sample color will interfere with turbidity measurements. The only way to reliably determine whether or not it can is to filter the samples with 0.2-micron membrane filters and measure the absorbance spectra in the operating band of the turbidimeter with a spectrophotometer. If the integral of absorbance differs by more than 10 % from the integral of absorbance for turbidity-free water in the same band, then measurable negative interferences from dissolved color can be expected.

NOTE 3—Particle color becomes an interference when it changes in an application while other factors remain constant, that is, particle size, shape, and composition. This can occur, for instance, during dredging operations and re-suspension events in settling ponds when light-colored oxidized sediment overlies dark-colored anoxic material of similar size and composition. In this situation, a turbidity spike occurs while light-colored sediment is re-suspended followed by a turbidity sag while anoxic material is re-suspended. The spike-sag sequence will occur even when the sediment concentration remains unchanged.

6.3 The particle-size distribution and operating spectrum will affect the relative sensitivity of turbidimeters. The intensity of light scattered from a water sample depends, among other factors, on the ratio of particle diameter to light wavelength. Since the operating wavelength of a turbidimeter is fixed, particle size is the controlling variable. Particle size can be a positive or negative interference when a user is unaware of decreases or increases in size while monitoring turbidity.

6.4 In-situ turbidimeters are intrusive devices that alter water flow and turbulence intensity near the turbidimeter. Flow disruption can change the location of light-scattering particles in the sampled water and the intensity of scattered light. The disturbed flow extends about three to five probe diameters away from the meter. Flow around a turbidimeter might cause particles to separate from the water in the sample volume and decrease the indicated TU value, or conversely, flow stagnation can concentrate particles and cause the indicated TU values to increase.

6.5 A large temperature difference between a turbidimeter and the surrounding water can result in measurement errors. In such situations, temperature can be an interference. Rapid surveys of thermal plumes or profiling in thermally stratified water can produce temperature interferences. The user should establish the magnitude of temperature interference by alternately testing water samples having the same turbidity but substantially different temperatures, ~20°C. Fixed monitoring sites in river and lakes are less susceptible to temperature fluctuations because they are gradual, typically less <1°C per hour and the probe has sufficient time to come to temperature equilibrium with the stream temperature.

NOTE 4—Ambient light is a positive interference with some sensor designs. Locate the sensor to minimize ambient light or surface reflections, or both.

7. Apparatus

7.1 The turbidimeters discussed herein can be submerged in water for extended periods (weeks to years). Many of them are stand-alone instruments containing batteries, a microcontroller, and solid-state memory for data logging, whereas others are components of multiparameter instruments or must be connected to a host device such as a data logger or current meter for power and data recording.

NOTE 5—Meters with processing capabilities may perform real-time digital filtering, signal averaging, or smoothing that could obscure real transients in surface-water turbidity of interest to a user. For example, a meter with signal averaging installed a stream to monitor waterside construction could fail to record brief turbidity spikes caused by equipment operation. See manufacturer's specifications and instruction on signal averaging or smoothing before selecting a meter for real-time monitoring.

7.1.1 There are several technologies that are capable of measuring turbidity that exceed 1.0 turbidity unit. A summary of these technologies is provided in the Table 1. Within this table, suggested reporting units, which are representative to the technology, are included.

7.1.2 Clean optics are important in applications where biofouling, chemical precipitation, or sedimentation can render a turbidimeter dysfunctional between service calls. Fouling is the biggest challenge facing users and manufacturers. Several approaches have been devised to cope with it, including: wipers, shutters, water and compressed-air jets, ultrasonic shakers, and anti-foulant coatings. In this standard, they are collectively referred to as automatic-cleaning/anti-fouling (AC/AF) features. Tests in surface waters have shown that no combination of AC/AF features performs satisfactorily in all environments for more than a few months. They can, however, prolong the time between service visits and field recalibrations from weeks to a few months, which makes them key meter-selection criteria for users who establish unattended monitoring stations. The tradeoff between increased power consumption for automatic cleaners and extended service requirements needs to be factored into the selection process.

7.1.3 Because of the variety of turbidimeter designs and manufacturers, selection of a design for a particular application is important. See 7.2 and 7.6 for a discussion of each of the designs. Annex A1 provides guidance to assist a user in the selection of a turbidimeter appropriate for a particular application. Appendix X1 provides detailed apparatus design considerations for in-situ turbidimeters. It is highly recommended that the user read these sections carefully before selecting a turbidimeter and using this test method.

7.2 *The Nephelometer:*

7.2.1 This instrument uses a light source for illuminating the sample and a single photodetector with a readout device to indicate the intensity of light scattered at right angle(s) (90°) to the centerline of the path of the incident light. The photoelectric nephelometer should be designed so that minimal stray light reaches the detector in the absence of turbidity and should be free from significant drift after a short warm-up period. The light source shall be a Tungsten lamp operated at a color temperature between 2200 and 3000 K (EPA 180.1). Light Emitting Diodes (LEDs) or laser diodes in defined wavelengths ranging from 400–680 nm and 780–900 nm may also be used if accurately characterized to be equivalent in performance to tungsten using the same type of calibration and calibration verification standards. It is important to note that new technologies may not be covered by this test method. If LEDs or laser diodes are used, then the LED or Laser diode should be coupled with a monitor detection device to achieve a constant output. LEDs and laser diodes should be characterized by a wavelength of between 400 and 900 nm with a bandwidth of less than 60 nm. The total distance traversed by incident light and scattered light within the sample is not to exceed 10 cm. The angle of light acceptance to the detector shall be centered at 90° to the centerline of the incident light path and shall not exceed ±10° from the 90° scatter path centerline. The detector must have a spectral response that is sensitive to the spectral output of the incident light used.

7.2.2 Differences in physical design of nephelometers may cause differences in measured values for turbidity even though the same suspension is used for calibrations. Comparability of measurements made using instruments differing in optical and physical designs is not recommended. To minimize initial differences, the design criteria discussed herein should be observed (see Fig. 1).

7.2.3 Report in units of NTU if a white light source was used), or in units of FNU if a 780–900 nm light source was used.

7.3 *Ratio Nephelometer:*

7.3.1 *Ratio Nephelometer* (see Fig. 2 for multiple beam design)—This instrument uses the measurement derived through the use of a nephelometric detector that serves as the primary detector and one or more other detectors used to compensate for variation in incident light fluctuation, stray light, instrument noise, or sample color. As needed by the design, additional photodetectors may be used to detect the intensity of light scattered at other angles. The signals from these additional photodetectors may be used to compensate for variations in incident light fluctuation, instrument stray light, and instrument noise and/or sample color. The ratio photoelectric nephelometer should be so designed that minimal stray light reaches the detector(s), and should be free from significant drift after a short warm-up period. The light source should be a tungsten lamp, operated at a color temperature between 2200 and 3000 K (EPA 180.1). LEDs and laser diodes in defined wavelengths ranging from 400 to 900 nm may also be used. If an LED or a laser diode is used in the single beam design, then the LED or laser diode should be coupled with a monitor detection device to achieve a consistent output. The distance traversed by incident light and scattered light within the sample is not to exceed 10 cm. The angle of light acceptance to the nephelometric detector(s) should be centered