



Standard Test Method for the Continuous Measurement of Turbidity Above 1 Turbidity Unit (TU)¹

This standard is issued under the fixed designation D7725; 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 online and inline determination of high-level turbidity in water that is greater than 1.0 turbidity units (TU) in municipal, industrial and environmental usage.

1.2 In principle there are three basic applications for on-line measurement set ups. This first is the slipstream (bypass) sample technique. For the slipstream sample technique a portion of sample is transported out of the process and through the measurement apparatus. It is then either transported back to the process or to waste. The second is the in-line measurement where the sensor is brought directly into the process (see Figure 8). The third basic method is for in-situ monitoring of sample waters. This principle is based on the insertion of a sensor into the sample itself as the sample is being processed. The in-situ use in this method is intended for the monitoring of water during any step within a processing train, including immediately before or after the process itself.

1.3 This test method is applicable to the measurement of turbidities greater than 1.0 turbidity unit (TU). The absolute range is dictated by the technology that is employed.

1.4 The upper end of the measurement range is left undefined because different technologies described in this method can cover very different ranges of turbidity.

1.5 Many of the turbidity units and instrument designs covered in this 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 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 method may be

practiced and would include the listing of the make and model number of the instrument used to determine the turbidity values.

1.5.1 In this 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.

1.6 This standard does not purport to cover all available technologies for high-level turbidity measurement.

1.7 This test method was tested on different waters, and with standards that will serve as surrogates to samples. It is the user's responsibility to ensure the validity of this test method for waters of untested matrices.

1.8 Those samples with the highest particle densities typically prove to be the most difficult to measure. In these cases, the process monitoring method can be considered with adequate measurement protocols installed.

1.9 *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. Refer to the MSDSs for all chemicals used in this procedure.*

2. Referenced Documents

2.1 ASTM Standards:²

- D1129 Terminology Relating to Water
- 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 Continual On-Line Monitoring Systems for Water Analysis
- D6698 Test Method for On-Line Measurement of Turbidity Below 5 NTU in Water
- D7315 Test Method for Determination of Turbidity Above 1

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.

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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 Technologies for Measuring Turbidity Greater Than 1 TU that can be used for In-Line or On-Line Applications

Design and Reporting Unit	Prominent Application	Key Design Features	Typical Instrument Range	Suggested Application
Nephelometric non-ratio (NTU)	White light turbidimeters. Comply with EPA 180.1 for low level turbidity monitoring.	Detector centered at 90 degrees relative to the incident light beam. Uses a white light spectral source.	0.012 to 40 NTU	Regulatory reporting of clean water
Ratio White Light turbidimeters (NTRU)	Complies with ISWTR regulations and Standard Method 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.	0.012 - 10,000 NTRU	Regulatory Reporting of clean water
Formazin 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 degrees relative to the incident light beam. Uses a near-IR (780-900 nm) monochromatic light source.	0.012 - 1,000 FNU	0 - 40 FNU ISO 7027 Regulatory reporting
Formazin 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.	0.012 - 1,000 FNU	0- 40 FNRU ISO 7027 Regulatory reporting
Surface Scatter Turbidimeters (SSU)	Turbidity is determined through light scatter from a defined volume beneath the surface of a sample. Applicable for reporting for USEPA compliance monitoring.	Detector centered at 90 degrees relative to the incident light beam. Uses a "white light" spectral source.	0.012-10,000 FNRU	10 - 10,000 SSU
Formazin 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 0° and 90°. An instrument algorithm uses a combination of detector readings, which may differ for turbidities varying magnitude.	0.012 to 4000 NTMU	0 to 40 NTMU Reporting for EPA and ISO compliance
Formazin Attenuation Unit (FAU)	Compliance Reporting for ISO 7027 for samples that exceed 40 units	Uses a near-IR light source at 860±30 nm and the detector is 0 degrees relative to the centerline of the incident light beam. The measurement is an attenuation measurement.	10 - 10,000+ FAU	100 - 10,000+ FAU Reporting for ISO 7027 for levels in excess of 40 units
Attenuation Unit (AU)	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 0° relative to the incident light beam.	10 - 10,000+ AU	100 - 10,000+ AU
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 between 90 and 180° relative to the incident light beam.	10,000+ FBU	10,000 FBU
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- degrees 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.	The measurement of ambient waters such as streams, lakes, and rivers. The range is typically from about 1 – 800 FSRU, depending on the manufacturer.	Forward Scatter Ratio Unit (FSRU)

Turbidity Unit (TU) in Static Mode

3. Terminology

3.1 *Definitions*—For definitions of terms used in this method refer to Terminology **D1129**.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *Calibration turbidity standard, n*—A turbidity standard that is traceable and equivalent to the reference turbidity

standard to within statistical errors; calibration turbidity standards include commercially prepared 4000 NTU Formazin, stabilized formazin, and styrenedivinylbenzene (SDVB). Discussion - these standards may be used to calibrate the instrument. Calibration turbidity standards may be instrument specific.

3.2.2 *calibration-verification standards, n*—Defined standards used to verify the accuracy of a calibration in the

measurement range of interest. Discussion - these standards may not be used to perform calibrations, only calibration verifications. Included verification standards are opto-mechanical lightscatter devices, gel-like standards, or any other type of stable-liquid standard. Calibration verification standards may be instrument specific.

3.2.3 Detection Angle, n —The angle formed with its apex at the center of the analysis volume of the sample, and such that one vector coincides with the centerline of the incident light source's emitted radiation and the second vector projects to the center of the primary detector's view. Discussion - this angle is used for the differentiation of turbidity-measurement technologies that are used in this method.

3.2.3.1 Nephelometric-Detection Angle, n —The angle that is formed between the incident light source and the detector, and that is at 90-degrees

3.2.3.2 Backscatter- detection Angle, n —The angle that is formed between the incident light source and the primary detector, and that is greater than 90- degrees and up to 180-degrees.

3.2.3.3 Attenuation-detection Angle, n —The angle that is formed between the incident light source and the primary detector, and that is at exactly 0- degrees.

3.2.3.4 Discussion—this is typically a transmission measurement.

3.2.3.5 Forward-scatter-detection angle, n —The angle that is formed between the incident light source and the primary detector, and that is between 0 and 90-degrees.

3.2.3.6 Discussion—most designs will have an angle between 10 and 45 degrees.

3.2.4 In-situ Turbidimeter, n —A turbidimeter that determines the turbidity of a sample using a sensor that is placed directly in the sample. Discussion - this turbidimeter does not require transport of the sample to or from the sensor.

3.2.5 nephelometric-turbidity measurement, n —The measurement of light scatter from a sample in a direction that is at 90° with respect to the centerline of the incident-light path. Discussion - units are NTU (Nephelometric Turbidity Units). When ISO 7027 technology is employed units are FNU (Formazin Nephelometric Units).

3.2.6 ratio- turbidity measurement, n —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.

3.2.7 reference-turbidity standard, n —A standard that is synthesized reproducibly from traceable raw materials by the user. Discussion - all other standards are traced back to this standard. The reference standard for turbidity is formazin.

3.2.8 seasoning, v —The process of conditioning labware with the standard that will be diluted to a lower value. Discussion - the process reduces contamination and dilution errors. See Appendix X2 for suggested procedure.

3.2.9 slipstream, n —An on-line technique for analysis of a sample as it flows through a measurement chamber of an instrument. Discussion - the sample is transported from the source into the instrument (for example a turbidimeter), analyzed, and then transported to drain or back to the process

stream. The term is synonymous with the terms “on-line instrument” or “continuous-monitoring instrument.”

3.2.10 stray light, n —all light reaching the detector other than that contributed by the sample.

3.2.11 turbidimeter, n —An instrument that measures light scatter caused by particulates within a sample and converts the measurement to a turbidity value. Discussion - the detected light is quantitatively converted to a numeric value that is traced to a light-scatter standard. See Test Method D7315-06.

3.2.12 turbidity, n —An expression of the optical properties of a sample that cause light rays to be scattered and absorbed rather than transmitted in straight lines through the sample. Discussion - Turbidity of water is caused by the presence of matter such as clay, silt, finely divided organic matter, plankton, other microscopic organisms, organic acids, and dyes

3.2.13 Surface-Scatter Detection, n —A turbidity measurement that is determined through the detection of light scatter caused by particles within a defined volume beneath the surface of a sample. Discussion - both the light source and detector are positioned above the surface of the sample. The angle formed between the centerline of the light source and detector is typically at 90-degrees. Particles at the surface and in a volume below the surface of the sample contribute to the turbidity reading.

4. Significance and Use

4.1 Turbidity is undesirable in drinking water, plant effluent waters, water for food and beverage processing, and for a large number of other water dependent manufacturing processes. Removal of suspended matter is accomplished by coagulation, settling, and filtration. Measurement of turbidity provides a rapid means of process control to determine when, how, and to what extent the water must be treated to meet specifications.

4.2 This test method is suitable for the on-line monitoring of turbidity such as that found in drinking water, process water, and high purity industrial waters.

4.3 The instrumentation used must allow for the continuous on-line monitoring of a sample stream.

4.4 When reporting the measured result, appropriate units should also be reported. The units are reflective of the technology used to generate the result, and if necessary, provide more adequate comparison to historical data sets.

4.4.1 Table 1 describing technologies and reporting results. Those technologies listed are appropriate for the range of measurement prescribed in this method are mentioned, though others may come available. Figure X3-1 from Appendix 3 contains a flowchart to assist in technology selection.

4.4.2 For a specific design that falls outside of these reporting ranges, the turbidity should be reported in turbidity units (TU) with a subscripted wavelength value to characterize the light source that was used.

4.4.3 Ratio White Light Turbidimeters are common as bench top instruments but not as a typical process instrument. However, if fitted with a flow-cell they meet the criteria of this method.

5. Safety

5.1 Wear appropriate personal protection equipment at all times.

5.2 Follow all relevant safety guidelines.

5.3 Refer to instrument manuals for safety guidelines when installing, calibrating, measuring or performing maintenance with any of the respective instrumentation.

5.4 Refer to all Material Safety Data Sheets (MSDSs) prior to preparing or using standards and before calibrating or performing instrument maintenance.

6. Interferences

6.1 Bubbles, although they cause turbidity, may result in interferences in measured turbidity as determined by this test method. Bubbles cause a positive interference and color typically causes a negative interference.

6.2 Color is characterized by absorption of specific wavelengths of light. If the wavelengths of incident light are significantly absorbed, a negative interference will result unless the instrument has special compensation features. Depending on the application color may or may not be considered an interference. Some instrument designs are intended to remove the effect that color imparts on a turbidity measurement. Other designs do not remove the effects of color.

6.2.1 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.

6.2.2 Dissolved material that imparts a color to the water may cause errors in pure nephelometric readings, unless the instrument has special compensating features to reduce these interferences.

6.3 *Absorbing Particles*—particles such as carbon, anthracite, fire residue will absorb incident light and bias readings to be negative.

6.4 Scratches, finger marks, or dirt on the walls of the sample cell or windows of the sample chamber may give erroneous readings, especially at lower turbidity levels. Sample cells or windows should be kept scrupulously clean both inside and outside and cells should be discarded when they become etched or scratched. The sample cells or windows must not be handled where light strikes them in the measurement chamber.

6.5 Sample cell caps and liners (if applicable for process turbidimeters), and sample chambers must also be scrupulously clean to prevent contamination of the sample. Seasoning of the sample cells or sample chamber should be performed each time a new sample is measured.

6.6 The optical quality and geometry of the sample cells can also impact results. At all turbidity levels, sample cells that are not optically consistent can result in error. Errors greater than 10% relative to the turbidity value can be reduced through indexing or replacement of the cells. See Section 14.2 for additional information.

6.6.1 Sample cells that are used in process instruments should be optically matched or a single cell should be used to perform calibrations and measurements.

6.7 Particle size distribution can be considered a interference but is typically considered an inherent part of the sample. The particle-size distribution in a sample, 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.

6.8 The path-length of the sample cell or equivalent will impact the sensitivity of measurements. A shorter path length will extend the range and reduce the interference proportionally. However, use of a shorter path-length will reduce the sensitivity of the measurement.

6.8.1 Ideally, the same indexed sample cell should be used first for standardization and then for measurement in process instruments. If this is not possible, then sample cells must be matched. Refer to the instrument manual or the instrument manufacturer for instructions regarding the matching of sample cells.

NOTE 1—Indexing of the sample cell to the instrument chamber is accomplished by placing a mark on the top of the sample cell and a similar mark on the upper surface of the sample chamber so that the sample cell can be placed in repeatable position each time.

6.9 Condensation on optical elements, windows, or sample cells can lead to severe errors in measurement.

6.10 Fouling of optical elements or windows will cause severe errors in measurement. Inspection of sample chambers for fouling should be conducted in a timely manner.

6.11 Rapidly settling particles are also an interference. Particles such as sand can settle rapidly and cause false high or false low turbidity readings. The user of this test method must use care to ensure particles are suspended in solution the instant the measurement it taken.

6.12 Certain turbulent motions also create unstable reading conditions of nephelometers.

7. Apparatus

7.1 The sensor used for the monitoring of turbidity is designed for continuous monitoring of the sample stream.

7.2 The instrument design should eliminate signal spikes resulting from bubbles present in samples through the use of either internal or external bubble rejection chambers (traps), sample pressurization, and/or electronic rejection methods.

7.3 The instrument design should allow for effective flow passage so that the settling of particulate materials does not occur in the measurement chamber.

7.4 The sensor must be designed to be calibrated. The calibration should be performed by following the manufacturer's recommended procedures. If a calibration algorithm for the instrument is used, it should be derived through the use of a reference or calibration turbidity standard.

7.5 The instrument should permit detection of turbidity differences of 0.10 TU or less in waters with turbidity between 1.0 and 5.0 TU (see 13.1).

7.6 *Instrument Types*—Two types of instruments are available for the nephelometric turbidity method, the nephelometer and ratio nephelometer.

7.6.1 The Photoelectric Nephelometer— (see Fig. 1). This instrument uses a light source for illuminating the sample and a single photo-detector with a readout device to indicate the intensity of light scattered at 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 should be a Tungsten lamp operated at a color temperature between 2200 and 3000 K. Light Emitting Diodes (LEDs) and laser diodes in defined wavelengths ranging from 400-900 nm may also be used. If LEDs or laser diodes are used, then the LED or laser diode should be coupled with a monitor detection device to achieve a consistent energy output. The total distance traversed by incident light and scattered light within the sample is not to exceed 10 cm. Angle of light acceptance to the detector: centered at 90° to the centerline of the incident light path and not to exceed $\pm 10^\circ$ from the 90° scatter path center line. The detector must have a spectral response that is sensitive to the spectral output of the incident light used.

7.6.1.1 Differences in physical design of photoelectric nephelometers will cause slight 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 design is not recommended.

7.6.2 Ratio Photoelectric Nephelometer— (see Fig. 2 for single beam design; see Fig. 3 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 sense 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, instrument noise and/or sample color. The ratio photoelectric nephelometer should be designed so 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. 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 energy 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 at 90° to the centerline of the incident light path and should not exceed $\pm 10^\circ$ from the scatter path center line. The detector must have a spectral response that is sensitive to the spectral output of the incident light used. The instrument calibration (algorithm) must be designed such that the scaleable reading is from the nephelometric detector(s), and other detectors are used to compensate for instrument variation described in 3.2.5.

7.6.2.1 Differences in physical design of ratio photoelectric nephelometers will cause slight differences in measured values for turbidity even when the same suspension is used for calibrations. Comparability of measurements made using instruments differing in optical and physical design is not recommended.

7.7 Surface Scatter Turbidimeters—Surface scatter turbidimeters determine the turbidity through the scatter of light from a defined volume beneath the surface of a flowing sample stream. The incident light strikes the surface of a sample at an angle and the detector of scattered light is also at a different angle but in the same plane with the incident light source. The detection angle is 90 degrees relative to the centerline of the incident light beam, prior to it striking the surface of the sample. Surface scatter turbidimeters have a high operating range and allow for high flow rates (See Fig. 4).

7.8 Formazin Backscatter Turbidimeters— This technology utilizes a near-IR monochromatic light source in the 780-900 nm range. The detector geometry is any angle between 90° and 180° relative to the incident light beam (See Fig. 5).

7.9 Forward Scatter Technologies— This technology encompasses a single, solid-state light source and either a single detector or multiple detectors (ratio). The detection angle for the forward scatter detector is greater than 0-degrees but less

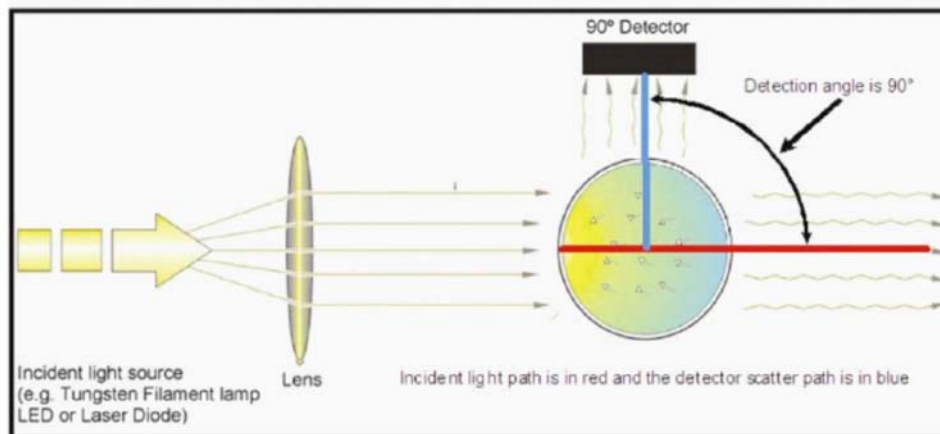


FIG. 1 The Photoelectric Nephelometer – Monitor detector is optional (not shown) and its use is typically with LED light sources

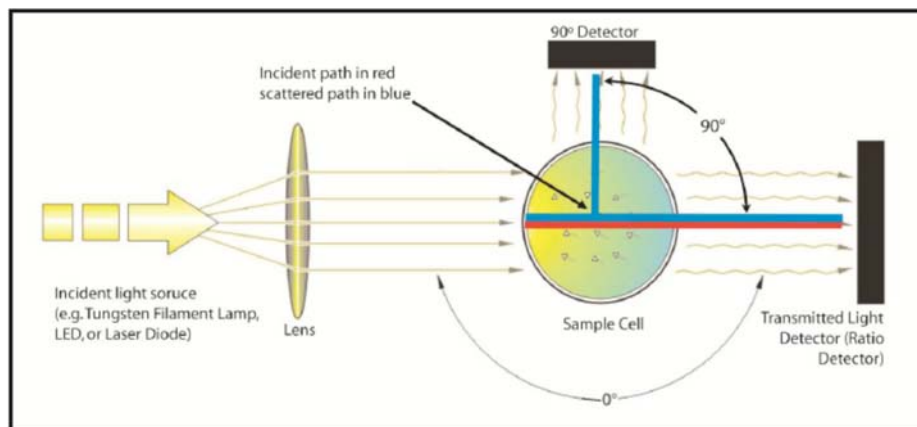


FIG. 2 The Ratio Photoelectric Turbidimeter. The monitor detector (not shown) is optional and it typically used with LED light sources.

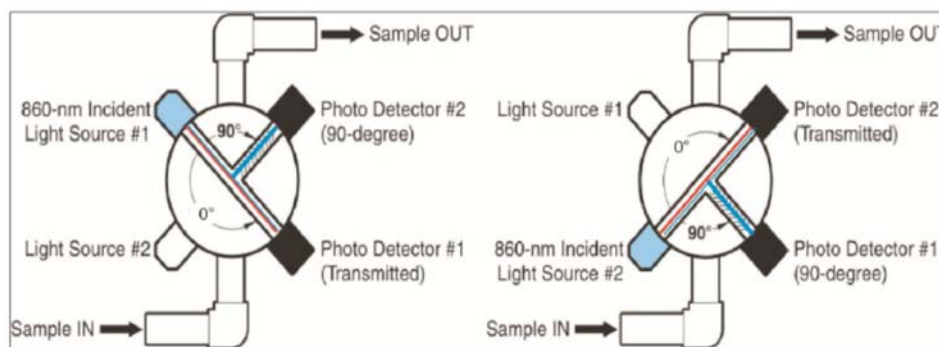


FIG. 3 Multiple Beam Design Utilizes two detectors and two light sources. Incident light path is in red and scattered light paths are in blue.

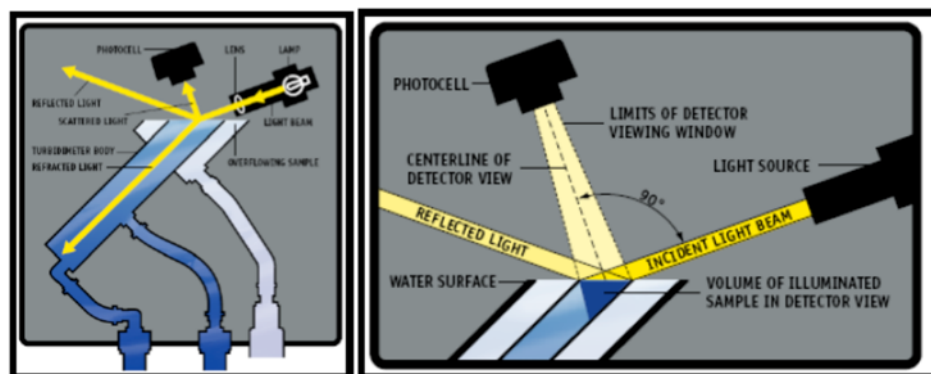


FIG. 4 Surface Scatter Design – Left figure displays the application of the technology and sample flow. Right figure displays the measurement technology for surface scatter detection (photos courtesy of Hach Company, Loveland Colorado.)

than 90-degrees relative to the centerline of the incident light beam. A second ratioing detector may be incorporated into some designs.

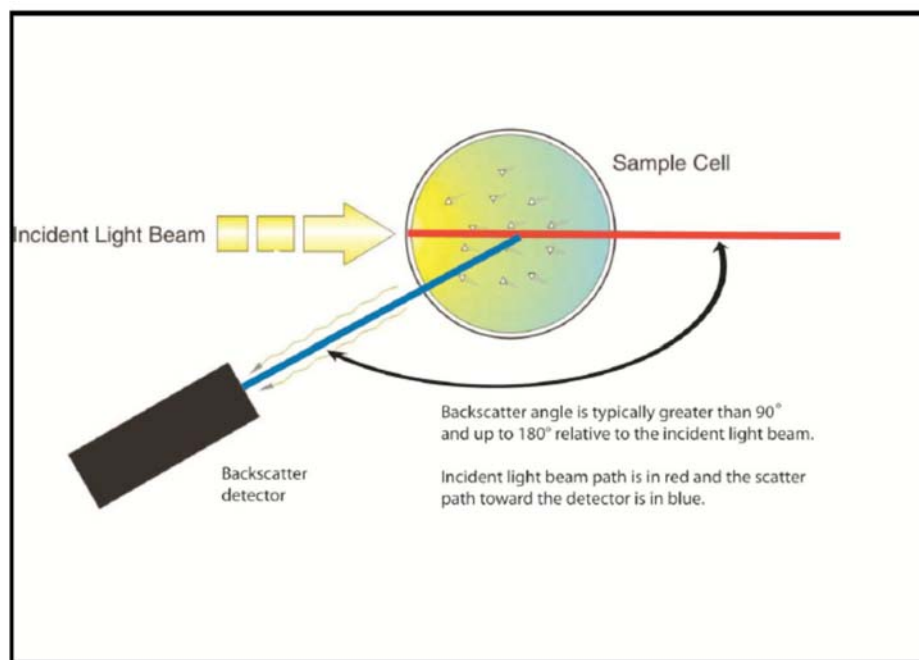


FIG. 5 Backscatter Measurement Design

8. Purity of Reagents

8.1 ACS grade chemicals of high purity (99+ %) shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Other grades may be used providing it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

NOTE 2—Refer to product MSDS for possible health exposure concerns.

8.2 Standard dilution, reagent and rinse waters shall be prepared by filtration of Type III water, or better, through a 0.22 microns or smaller membrane or other suitable filter within 1 hour of use to reduce background turbidity. Reverse osmosis (RO) water is acceptable and preferred in this method.

9. Reagents

9.1 Reagent, dilution and final rinsing water, see 8.2.

9.2 *Turbidity Standards:*

NOTE 3—A standard with a turbidity of 1.0 NTU is the lowest formazin turbidity standard that should be produced on the bench. Preparation of formazin standards shall be performed by skilled laboratory personnel with experience in quantitative analysis. Close adherence to the instructions within this section is required in order to accurately prepare low-level turbidity standards.

9.2.1 Equivalent, commercially-available, calibration standards may be used. These standards, such as stabilized formazin and SDVB, have a specified turbidity value and accuracy. Such standards must be referenced (traceable) to formazin. Follow specific manufacturer's calibration procedures.

NOTE 4—All volumetric glassware must be scrupulously clean. The necessary level of cleanliness can be achieved by performing all of the following steps: washing glassware with laboratory detergent followed by 3 tap water rinses; then rinse with portions of 1:4 HCl followed by at least 3 tap water rinses; finally, rinse 3 times with rinse water as defined in 8.2. Reference Formazin Turbidity Standard (4000 NTU) is synthesized on the bench.

9.2.1.1 Dissolve 5.000 grams of ACS grade hydrazine sulfate (99.5 % + purity) ($\text{N}_2\text{H}_4 \cdot \text{H}_2\text{SO}_4$) into approximately 400 mL of dilution water (see 8.2) contained in a 1-liter Class A volumetric flask.

9.2.1.2 Dissolve 50.000 grams of ACS grade hexamethylenetetramine (99 % + purity) in approximately 400 mL of dilution water (see 8.2) contained in another flask. Filter this solution through a 0.2 mm filter.

9.2.1.3 Quantitatively pour the filtered hexamethylenetetramine solution into the flask containing the hydrazine sulfate. Dilute this mixture to 1 liter using dilution water (see 8.2). Stopper and mix for at least 5 minutes, and no more than 10 minutes.

9.2.1.4 Allow the solution to stand for 24 hours at $25 \pm 1^\circ\text{C}$. The 4000 NTU formazin suspension develops during this time.

9.2.1.5 This suspension, if stored at $20\text{--}25^\circ\text{C}$ in amber polyethylene bottles, is stable for 1 year; it is stable for 1 month if stored in glass at $20\text{--}25^\circ\text{C}$.

9.2.2 Stabilized formazin turbidity standards are prepared stable suspensions of the formazin polymer. Preparation is limited to inverting the container to re-suspend the formazin polymer. These standards require no dilution and are used as received from the manufacturer.

9.2.3 Styrenedivinylbenzene (SDVB) polymer turbidity standards are prepared stable suspensions, which are used as

received from manufacturer or distributor. These standards exhibit calibration performance characteristics that are specific to instrument design.

9.2.4 Formazin Turbidity Suspension, Standard (40 NTU)—All labware shall be seasoned (see Appendix X2). Invert 4000 NTU stock suspension 25 times to mix (1 second inversion cycle); immediately pipette, using a Class A pipette, 10.00 mL of mixed 4000 NTU stock into a 1000-mL Class A volumetric flask and dilute with water to mark. The turbidity of this suspension is defined as 40 NTU. This 40-NTU suspension must be prepared weekly.

9.2.5 Dilute Formazin Turbidity Suspension Standard (1.0 NTU)—Prepare this standard dilution daily by inverting the 40 NTU stock suspension 25 times to mix (1 second inversion cycle) and immediately pipetting a volume of the 40.0 NTU standard (109.2.4). All labware shall be seasoned (see Appendix X2).

NOTE 5—The instructions below result in the preparation of 200 mL of formazin standard. Users of this method will need different volumes of the standard to meet their instrument's individual needs; glassware and reagent volumes shall be adjusted accordingly.

9.2.5.1 Within one day of use, rinse both a glass Class A 5.00 mL pipette and a glass Class A 200 mL volumetric flask with laboratory glassware detergent or 1:1 hydrochloric acid solution. Follow with at least ten rinses with rinse water.

9.2.5.2 Using the cleaned glassware, pipette 5.00 mL of mixed 40.0 NTU formazin suspension (9.2.4) into the 200 mL flask and dilute to volume with the dilution water. Stopper and invert 25 times to mix (1 second inversion cycle). The turbidity of this prepared standard is 1.0 NTU.

9.2.6 Miscellaneous Dilute Formazin Turbidity Suspension Standard—Prepare all turbidity standards with values below 40.0 NTU daily. All labware shall be seasoned (see Appendix X2). Standards with values above 40.0 NTU have a useful life of one week. Use Class A glassware that has been cleaned per the instructions in 9.2.5.1 and prepare each dilution by pipetting the volume of 40 NTU (9.2.4) into a 100-mL volumetric flask and diluting to mark with dilution water (8.2). For example, prepare so that 50.0 mL of 40 NTU diluted to 100 mL is 20.0 NTU and 10.0 mL of 40 NTU diluted to 100 mL is 4.00 NTU.

10. Instrument Installation, Sample Lines and Sampling

NOTE 6—In principle there are three sampling methods for on-line measurement set ups: slipstream (bypass), in-line, and in-situ. For the slipstream sampling method, a sample is continuously transported out of the process and through the measurement apparatus, and is then either transported back to the process or to waste. For the in-line sampling method, the sensor is brought directly into the process (see Fig. 7). For the in-situ sampling method, the sensor is placed directly into a sample that is in the environment. The in-situ does not measure a sample that is in the process of being transported (that is, such as through a pipe).

10.1 Slipstream Sample Technique:

10.1.1 Instrument Installation—Proper location of the sensor and the instrument will help assure accurate results. Assuring that the sensor sees a flowing, bubble free and representative sample is essential for accurate results. Refer to the instrument manufacturer for proper instrument set-up and installation; also see Practices D3370 Practices for Sampling Water from Closed Conduits.

10.1.1.1 Locate the sensor as close to the sample location as possible to minimize sample response time. Additionally, locate the instrument for safe, easy access for maintenance and calibration. The location must also provide adequate flow at a rate that particulate settling will not take place in the sample lines, instrument, or drain lines.

10.1.1.2 Locate the instrument so external interferences such as vibration, ambient light, humidity, and extreme conditions are minimized.

10.1.1.3 Position the instrument so it is level and stable to ensure the sample stream is consistent and adequate over long periods of time.

10.1.2 Sample Lines—Refer to the instrument manufacturer for recommended sampling procedures for the respective instrument.

10.1.2.1 Sample inlet lines should be a minimum of 4 mm inner diameter, rigid or semi-rigid tubing to allow easy passage of large particles and to minimize the possibility of air lock.

10.1.2.2 Examples of tubing that can be used for sample lines include but are not limited to: polyethylene, nylon, polypropylene, or Teflon-lined tubing.

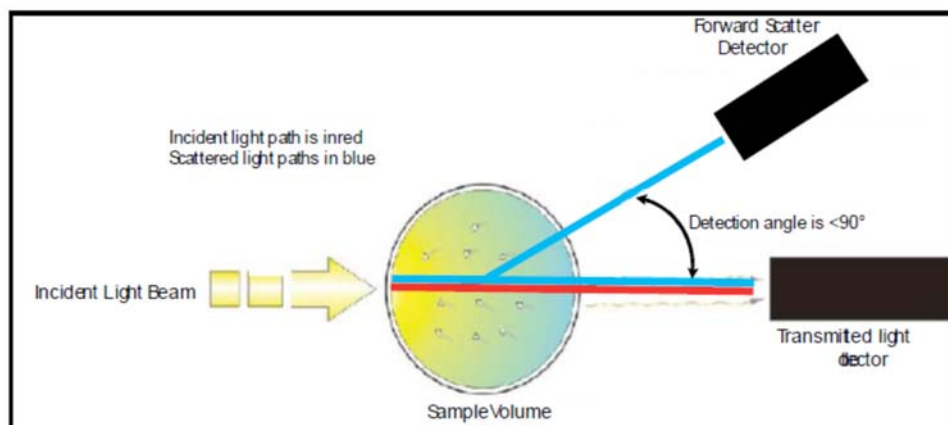


FIG. 6 Forward Scatter Design

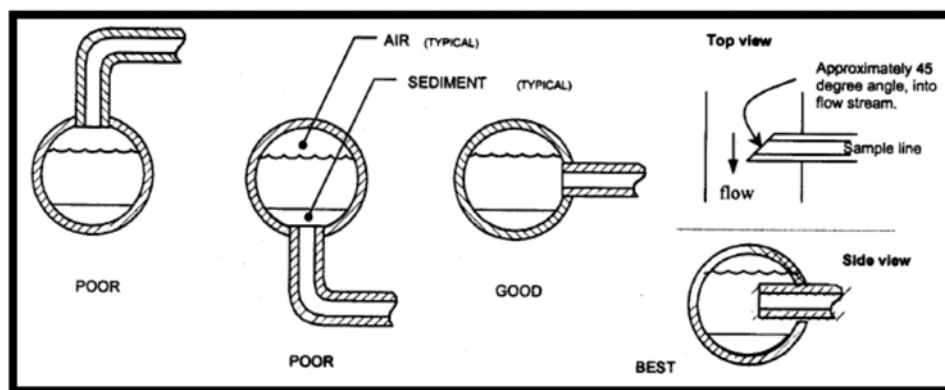


FIG. 7 Illustration of Proper and Improper Sampling Techniques

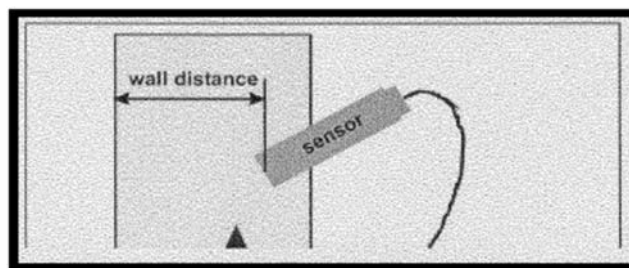


FIG. 8 Principal Set-Up for Inline Turbidity Measurement

10.1.2.3 Soft or porous tubing that could harbor the growth of micro-organisms or contribute turbidity to the sample should not be used.

10.1.3 Sampling:

10.1.3.1 A sample tap should project into the center of the pipe to minimize interference from air bubbles or pipeline bottom sediment. See Fig. 7 for proper sample taps or review instrument manual.

10.1.3.2 Run sample lines directly from the sample point to the turbidimeter sensor to minimize sample flow lag time (response time) or refer to instrument manual.

10.1.3.3 Adjust the flow rate to minimize particle fallout in the sample lines while maximizing bubble removal so bubbles are not carried through the sensor or refer to instrument manual. The best practice is to determine the maximum allowable sample flow in which bubble removal is still effective. This maximum flow will provide the best condition to prevent sample settling.

NOTE 7—There will be some instances where the sample flow rate will be inadequate in the prevention of particle settling. In such cases, a different technique should be used that allows for more rapid passage of sample through the instrument. Or, the user should consider an in-situ measurement technique.

Refer to the instrument installation procedures from the manufacturer for optimization of sample flow rates through the instrument.

10.1.4 The use of either internal or external bubble removal devices (bubble traps) prior to performing measurement of the sample is recommended. Reference Practices D3370 and Guide D3864.

10.1.4.1 When using bubble removal devices, flow must be sufficient to prevent particulate settling within these devices. If particle settling cannot be prevented, then the bubble removal device should be abandoned.

10.2 In-line Measurement Technique:

10.2.1 The principal set up for an in-line turbidity measurement is shown below.

10.2.2 For proper set-up and installation of sensor and transmitter refer to the instrument manufacturer. Some general recommendations for the installation should be followed:

10.2.2.1 The sensor should be mounted into process lines so that the sample flow is consistent and adequate to minimize interference from air bubbles or pipeline bottom sediment. Avoid dead spots in flow or areas where the flow through the line slows significantly.

10.2.2.2 Install sensor surface at an angle with respect to medium flow so that flow increases self cleaning effects of optical parts and repels air bubbles.

10.2.2.3 The sensor should be installed with maximized wall distance to reduce backscattered or reflective signal (see Fig. 8).

10.2.2.4 Locate transmitter and sensor so that there is easy access for maintenance or calibration.

10.2.2.5 Adjust the flow rate to minimize particle fallout in the sample lines while maximizing bubble removal.

10.2.2.6 Measurement should be done under pressure to avoid degassing.

10.2.2.7 The location of the in-line sensor should be such that the sensor can be easily removed from the process for servicing.

10.3 The in-situ measurement technique

10.3.1 Before making an in-situ turbidity determination, ensure that the instrument to be used has been cleaned, verified, and or calibrated properly, if need be, and that the verification/calibration process has been accurately documented.

10.3.2 Guidelines for long-term instrument deployment fall under the topic of continuous monitors—refer to the manufacturer's instructions and recommendations.

10.3.3 Perform a calibration verification on the instrument in the laboratory or on-site using a calibration solution before inserting it into the process and if verification does not confirm the calibration is still within 5 percent, then re-calibrate.

10.3.3.1 Allow at least 60 seconds (or follow the manufacturer's guidelines) for sensors to equilibrate with sample water. Take instrument readings until the stabilization criteria of $\pm 10\%$ is met. Record the median of the final three or more readings as the value to be reported for that measurement point. (Some instruments may require as much as 10-20 minutes warm-up time.) Stability is reached if values for three or more sequential readings, spaced at regular time increments, are within 10 percent.

10.3.3.2 Document verification readings and any metadata, including the instrument manufacturer and model. Use reporting units appropriate for the instrument, as described in [Table 1](#).

10.3.3.3 After verification, clean the sensor with a thorough rinse of deionized water prior to installation. Follow the manufacturer's recommendations for storage of sensors.

10.3.4 If turbidities are higher than the instrument range, dilutions will be necessary. Turbidity will need to be measured with static methods ([D7315](#)). Take a representative sample and dilute it with one or more equal volumes of turbidity-free water, recording the volume of water used for dilution.

10.4 When taking an aliquot for dilution from an on-line technology, it is important to use the same technology to measure the dilution. If a different technology is used, the measurements may not be comparable.

10.4.1 Quality control. Periodically check instrument performance by placing a primary or secondary calibration solution in the instrument storage vessel and comparing the standard value with the reading displayed. Record in the instrument maintenance logbook all the readings obtained. Re-calibrate if the following criteria are exceeded: ± 0.5 turbidity unit or $\pm 5\%$ of the measured value, whichever is greater.

11. Calibration and Calibration Verification

11.1 Calibration of In-line and On-Line Turbidimeters

11.1.1 Determine if the instrument requires any maintenance such as cleaning the sample chamber, bubble removal devices, or flow-through cell, adjusting sample flow rates, wiper maintenance, and so on. Follow the manufacturer's instructions for any required instrument maintenance prior to calibration.

11.1.2 Follow the manufacturer's instructions for calibration and operation. Calibrate the instrument to assure proper operation for the range of interest with appropriate standards.

NOTE 8—Close adherence to the calibration procedure and to the rinsing/seasoning techniques is very important to ensure the data remains consistent across all locations with all of the turbidimeters.

11.1.3 Formazin-based calibration standards should be re-suspended through inversion (1 second inversion cycle) 25 times followed by a 2–10 minute wait to allow for bubble removal. Standards of 40 NTU or below will remain suspended for up to 30 minutes; standards greater than 40 NTU may require resuspension more frequently.

11.1.3.1 The relationship between turbidity and nephelometric light scatter is known to be linear only up to 40 NTU. Above 40 NTU, the relationship may become non-linear and additional calibration standards will be necessary. It is imperative that the user of this method follow the manufacturer's instructions for calibration and calibration standard values. Following these instructions will optimize the measurement performance of the respective turbidimeter. Verify calibrations and performance in the range of interest (or as close to the measurement range of interest as possible) using defined calibration or calibration verification standards with a known accuracy. (Consult manufacturer's recommendations for guidance associated with verification methods and devices.) In case of verification failure: 1. Repeat the cleaning of the instrument body and optical surfaces that are accessible. 2. Perform maintenance as prescribed by the manufacturer. 3. Perform re-verification. If verification failure results a second time, then follow with a recalibration according to manufacturer's calibration instructions, or at a minimum on a quarterly basis (see 14.3).

11.1.4 Verify instrument calibration accuracy in the expected measurement area using a calibration verification standard. The calibration verification standard used should have a defined value with known accuracy. The calibration verification standard should allow the instrument to perform to within its defined performance specifications. Verification should be conducted at timely intervals between calibrations. (Consult manufacturer's recommendations for guidance associated with verification methods and devices.)

NOTE 9—Close adherence to the calibration procedure and to the rinsing/seasoning techniques is very important to ensure the data remains consistent across all locations with all of the turbidimeters.

11.2 Calibration if In-Situ Meters

11.2.1 Check calibrant in the 1 to 5 turbidity-unit (low-level) range to assess the actual performance of the instrument near the detection limit; instrument reliability often decreases at turbidities less than 2 turbidity units—consult the manufacturer's specification for the expected accuracy of the measurement.

11.2.2 Calibrate the instrument using calibration turbidity standards before installation into the process stream. Check instrument performance periodically using a calibration or verification calibrant and turbidity-free water.

11.2.3 The optical surface of the sensor must be clean before beginning the calibration procedure. When deployed into processes, inspect pipes or other structures that house the sensor also may require periodic cleaning.

NOTE 10—To calibrate a submersible turbidity sensor modify the general instructions that follow as necessary so that they are compatible

with the manufacturer's instructions.

11.2.3.1 Prepare a sufficient volume of the selected calibration solution or verification calibrant. The volume of calibrant required could be 500 mL for some instruments, particularly if the entire sensor bundle will be immersed.

11.2.3.2 Select Procedure (A) or (B). The same procedure, once tested and selected, also should be applied to instruments used in future studies against which the data could be compared.

Procedure A – Immersion of the entire sensor (or bundle of field-measurement sensors including the turbidity sensor) requires larger volumes of calibrant; calibrant is vulnerable to the contamination and dilution. The sensor guard may need to be removed.

Procedure B – Immersion of the turbidity sensor only. Depending on the sensor configuration, isolation of the turbidity sensor and achieving a bubblefree optical surface could be difficult. This technique minimizes the volume of calibrant required for calibration.

11.2.3.3 Determine the number of calibration points to be used (a minimum of two, but three is preferred) and configure the instrument for this number of points, if applicable.

Clean the optics before calibration. If the system has a mechanical wiper, it is good protocol to use this mechanism before performing the calibration.

11.2.3.4 For a turbidity-free water calibrant:

(a) Rinse sensor with deionized water, followed by a portion of the turbidity calibrant.

(b) Immerse sensor in calibrant, or add enough calibrant to cover the sensor in the calibration chamber.

(c) Agitate the sensor repeatedly to remove bubbles from the optical surface (activate mechanical wiper, if present).

(d) Set sensor vertically on a flat surface or use a ring stand to hold it.

(e) Monitor turbidity readings for 1 to 2 minutes or longer to ensure that readings are stable (consult manufacturer's recommendations and signal processing information). Record the pre-calibration value in the instrument logbook or on the field sheet.

(f) Confirm the calibration value or adjust the instrument calibration using the manufacturer's instructions.

(g) Remove the sensor and dry thoroughly to minimize dilution or contamination of the next calibrant.

(h) Discard the calibrant into a labeled waste container and hold for proper disposal.

(i) If measurement of color-derived turbidity is not desired, filter (using a 0.2- μ m pore-size filter) an aliquot of the sample water and use the filtered water in place of turbidity-free water.

11.2.3.5 Using a second calibrant with a value near the maximum of the expected turbidity range, repeat steps 11.2.3.4. (a-i).

Repeat again with a third calibrant near the middle of the expected range if increased accuracy is desired and instrument software permits. If the software does not permit a three-point calibration, the third calibrant can nonetheless be used to document the accuracy of the calibrated instrument near the middle of the expected range. If an "Out of Range" error is displayed, verify the intended calibrant value and start again with the first (zero) calibrant solution. Repeat the calibration procedure if the measurement is not within the specification. Record all calibration and verification measurements in the instrument logbook.

11.2.3.6 On a one-time basis, determine the maximum value that can be reported by the instrument by holding a lint-free white cloth over the optical sensor and recording the turbidity. Use this value as an indicator that turbidity might have been greater than the range of the instrument during measurements in a water body.

NOTE 11—Calibration procedures vary widely for turbidimeters. Manufacturers typically provide the calibration procedure that will provide the best performance of their respective equipment. Many manufacturers will also make procedures locked so users cannot mis-calibrate the instruments. Because of this, the above procedures should be used as a guide to calibrating the instrument.

12. Procedure

12.1 Warm up the instrument according to the manufacturer's instructions.

12.1.1 Identify the type of technology and the appropriate reporting unit (see 4.4, and Table 1).

12.2 Verify the flow rate is within the manufacturer's guidelines. If it is not, perform adjustments to the flow to meet these guidelines. If the technology cannot meet the sampling requirements with respect to flow and bubble removal, then a different technology should be considered.

12.3 If bubbles are interfering, perform adjustments to minimize bubbles. These adjustments might include pressurizing the measuring chamber, installing bubble traps and ensuring they are working properly, and/or changing the flow rate or setting mathematical reject algorithms.

12.4 *Measurement of Water Turbidity* :

12.4.1 Determine the frequency of sample data that is being logged into an appropriate data base. If no data base is to be used, define the procedure for logging data from the instrument.

12.4.1.1 Data should be logged at defined intervals to determine when a change to the on-line sample has occurred.

13. Results

13.1 Report results as follows:

TU (or Appropriate Reporting Unit)	Report to Nearest (TU or Appropriate Reporting Unit)
<1.0	See Method D6698
1.0 to 9.9 TU	0.1 TU
10 to 99	1 TU
100 to 999	10 TU
1000 to 4000	50 TU
>4000	100 TU

14. Quality Control/Quality Assurance

14.1 In order to be certain that analytical values obtained using this test method are valid and accurate with the confidence limits of the test, the following QC procedures must be followed when running the test.

14.2 Determine if the instrument requires any maintenance such as replacing the lamp, cleaning of the sample cells or sample chambers, windows, optics, etc. Follow the manufacturer's instructions for any required instrument maintenance prior to calibration.

14.3 Follow the manufacturer's instruction for calibration and operation of the instrumentation. Refer to the standard's manufacturer for the preparation and use of calibration and verification standards. Calibrate the instrument to assure proper operation for the range of interest with the appropriate standards.

14.3.1 Verify instrument calibration with calibration and/or calibration verification standards. The recommended frequency for determining calibration verification is dependent upon many things including: data management requirements, regulatory requirement, technology design, manufacturer requirements, and sample site requirements. If no guidance is provided, calibration verification should be performed in an interval that is shorter than the calibration requirements.

NOTE 12—Consult instrument or standards manufacturers for recommendation and available sources for verification standards.

14.4 Determination of acceptance criteria for continuous monitoring sensors.

14.4.1 The values obtained upon analysis of calibration or calibration verification standards must fall within acceptable criteria generated after sufficient data is generated for each of the standards, typically 20 to 30 results. Control limits should be developed from the mean recovery ($\bar{x}$) and the standard deviation (s) of the percent recovery for the standards. These data are used to establish upper and lower control limits as follows:

$$\text{Upper control limit} = \bar{x} + 3s$$

$$\text{Lower control limit} = \bar{x} - 3s$$

14.4.2 New control limits must be calculated using the most recent 20 to 30 data points. If these calculated control limits exceed those established in this method, corrective action must be taken. This includes instrument maintenance, cleaning, flow range confirmation, and re-calibration.

15. Precision and Bias

15.1 In Paragraph 1.3.3 of Practice D2777, an exemption from the requirement to conduct a typical interlaboratory study is specifically granted for test methods involving continuous sampling and/or measurement, such as this method. However, as a demonstration of performance and capability of this method, five applications of high-level turbidity data collection are provided. These applications serve to demonstrate the effective use of high-level turbidity data that can be generated under conditions that comply with this method.

15.2 This section provides data-based examples for the application of a particular type- of turbidimeter measurement technologies that are utilized. The data from these examples that are provided are intended to confirm the demonstration of the capability of this method. The examples provided here represent more common examples from the technologies, but do not represent all of those technologies that are described in this method.

15.3 A brief summary of each application is presented here. The data is expressed in time-based graphs and are found in appendix X.4.

15.4 Example

15.4.1 Defining the Backwash Profiles in A Drinking Water Plant Using the a In-Line Turbidimeter with a FNRU Design.

15.4.1.1 This application utilizes a ratio measurement technology to monitor the profile of the backwash of a granular media anthracite filter from a drinking water application. The turbidity measurement is necessary to confirm effective washing of the filter, but also to prevent an over wash condition. The turbidity measurements of concern are at levels greater than 5 TU.

15.4.1.2 See Appendix X.4.1 for the data and detailed application.

15.5 Demonstration of On-Line Turbidity Data Usage to Confirm Water of Suitable Turbidity for Drinking Water Filtration Plant Applications:

15.5.1 The measurement of turbidity of the raw water source for drinking water plants is a critical measurement. Depending on this turbidity, chemical dosing must be adjusted accordingly to successfully coagulate and flocculate the particles so the maximum mass of solids is removed prior to filtration. In doing so, this will prevent fouling of the filter and increase forward filtration run times. Further, the removal of turbidity from water reduces the potential for disinfectant byproduct (DBP) formation and pathogen passage beyond the final filtration steps. This application utilizes a surface scatter technology to monitor the raw water turbidity and reports the values in SSU.

15.5.2 Appendix X.4.2 for a discussion and presentation of the data and its usage.

15.6 Demonstration of on-line turbidity for the monitoring of water as it passes through a distribution system using NTU design technology.

15.6.1 The measurement of turbidity of post-filtered water has become a common application to help in the monitoring of drinking water distribution system integrity. As distribution systems age, the possibility of a water line breaking or some other breach becomes heightened. Thus, turbidity and other

analytical parameters are being used to monitor the stability of these systems. An on-line turbidimeter was utilized to measure the turbidity on a continuous basis.

15.6.1.1 Appendix X4.3 provides a summary of this turbidity application.

15.7 Demonstration of how an In-Situ sensor can be modified to provide Continuous Monitoring of Turbidity in Southwestern Ohio Rivers Using a Modified On-Line Method.

15.7.1 This example covers the general measurement of turbidity in this “process-type” application, including the correlation of turbidity with conductivity during rainfall events. The temporal differences in the turbidity/conductivity events in the two rivers located near Dayton Ohio are discussed in this application.

15.7.1.1 Appendix X4.4 provides a summary and data in reference to this high-level turbidity application.

15.8 Demonstration of Backscatter monitoring

15.8.1 Appendix X4.5 provides a summary of use of this measurement technology. This application covers the use of

backscatter technologies that are used in-situ to measure coastal waters. Two backscatter and one nephelometric scatter instrument is used to demonstrate the technologies capability down to about 5 turbidity units.

NOTE 13—Because an interlaboratory study is not possible with on-line turbidity measurement, the data provided above should be considered only as examples of the precision and bias that have been achieved using this method. Because this method covers a wide range of turbidity measuring technologies, the precision and bias characteristics associated with any specific instrument, compliant with this method, will also vary amongst varying technologies. Referencing manufacturers specifications and third party technology verification reports will assist the user of this method in better understanding the performance characteristics that can be expected from a specific instrument.

16. Keywords

16.1 calibration; calibration verification; continuous; formazin; measurement; monitoring; nephelometer; nephelometric; on-line; standard; styrenedivinylbenzene; turbidimeter; turbidity; turbidity standards

APPENDIXES

(Nonmandatory Information)

X1. STABILITY OF FORMAZIN

X1.1 Stability studies of low level and high level formazin standards were conducted by ASTM members to support the formazin preparation instructions set forth in this document.

X1.1.1 **Table X1.1** summarizes the stability data collected

for low level formazin standards.

X1.1.2 **Table X1.2** summarizes the stability data collected for high level formazin standards.

TABLE X1.1 Summary of Low Level Formazin Stability^A

NTU Standard	%Change in the Measured Value Vs Time Since Preparation									
	0.1 Days	1 Day	2.2 Days	7.3 Days	13.1 Days	21 Days	28 Days	47 Days	61 Days	81.3 Days
0.10	-0.92	-1.61	0	-2.99	-5.06	-6.70	-8.05	-14.0	-20	-32.4
0.30	-0.74	0	3.31	3.23	-3.23	-5.38	-6.45	-14.8	-22.9	-44.5
0.50	-1.70	-1.70	-0.94	-2.21	-6.97	-5.53	-6.38	-8.50	-11.3	-11.4
20.0	0.00	-0.77	-0.51	-2.05	-4.60	-3.07	-3.07	-4.60	-4.86	-6.39

^AASTM Low-Level Formazin Stability Study. ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

TABLE X1.2 Summary of High Level Formazin Stability^A

Formazin 20 NTU						
	Day 0.08	Day 1.00	Day 1.92	Day 6.92	Day 13.92	Day 28.79
Average	19.67	19.47	19.31	19.12	18.80	18.12
Std Dev	0.5630	0.5227	0.5250	0.5766	0.5891	0.6034
% Error vs Theoretical	-1.650	-2.650	-3.425	-4.375	-5.975	-9.375

Formazin 0.60 NTU						
	Day 0.08	Day 1.00	Day 1.92	Day 6.92	Day 13.92	Day 28.79
Average	0.610	0.592	0.591	0.586	0.569	0.533
Std Dev	0.0176	0.0175	0.0190	0.0190	0.0170	0.0221
% Error vs Theoretical	1.091	-1.267	-1.523	-2.417	-5.183	-11.23

^AASTM High-Level Formazin Stability Study. ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

X2. PROCEDURE FOR SEASONING GLASSWARE WHEN PREPARING CALIBRATION STANDARDS

X2.1 Introduction:

X2.1.1 Seasoning is a procedure in which glassware is conditioned immediately prior use in the preparation of turbidity standards. Seasoning will reduce contamination and volumetric dilution errors and is a common practice in volumetric quantitative analysis. The process involves rinsing the glassware twice with the specific standard that will be diluted to prepare a standard of lower value. Seasoning should be used when preparing any standard from the Stock 4000 NTU Formazin Standard. It is of primary importance to season pipets used to prepare low-level turbidity standards. Seasoning should be performed immediately before performing the actual volumetric dilution. Below is the general procedure that should be used for seasoning a pipet. A similar practice should be applied when filling sample cells with sample immediately before analysis.

X2.2 Procedure:

X2.2.1 Prepare the solution that is to be diluted. For formazin, this involves mixing the standard immediately prior to use.

X2.2.2 Rinse a small beaker with a small portion of the standard. Discard the rinsing to waste. Repeat this a second time.

X2.2.3 Fill the beaker with enough standard to accommodate at least three times the volume required to prepare the dilution. For example, if a 10 mL dilution volume is to be used, then at least 30 mL of standard should be placed in the beaker.

X2.2.4 Draw a small amount of the standard from the beaker into the pipet. Swirl the standard around the pipet, making sure it contacts all internal surfaces up to the draw line. Then, discard this to waste.

X2.2.5 Draw up a second amount of standard from the beaker up slightly past the fill line. Immediately discard to waste.

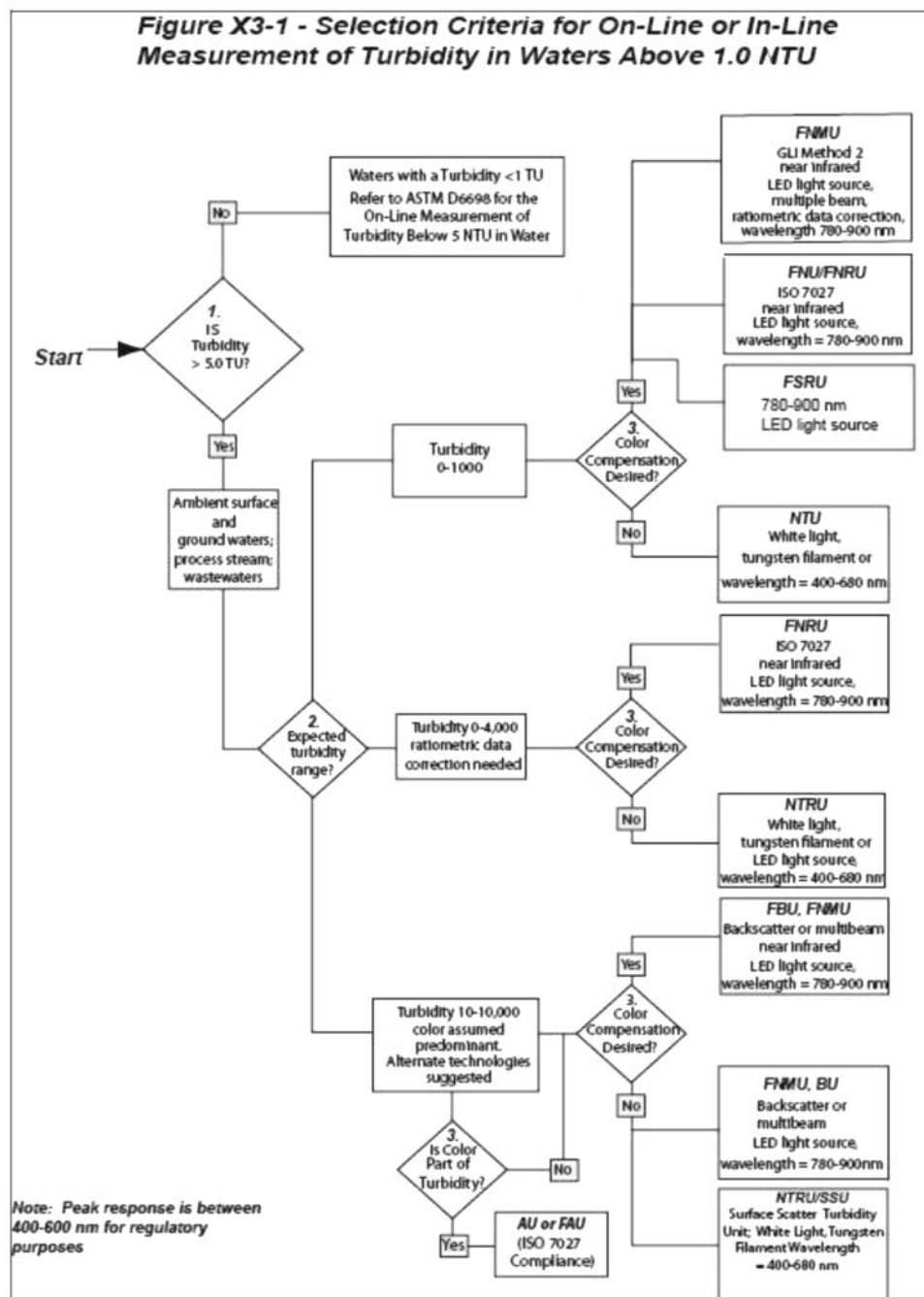
X2.2.6 The pipet is now ready for volumetric draw of the standard. There should be enough standard left in the beaker to use. This volumetric draw of the standard should take place immediately after the seasoning.

X3. SELECTION CRITERIA FLOWCHART FOR TURBIDIMETERS.

X3.1 Introduction: The criteria was developed as a cooperative effort between ASTM and the United States Geological Survey (USGS).

X3.2 Some technologies listed in this flow chart may be

better suited for the measurement of turbidity under a given set of conditions than others. For low-level on-line measurements, refer to Method **D6698** for appropriate technologies.



X4. Examples Depicting the Demonstration of Capability for High Range Turbidity Measurement.

X4.1 Example 1: Defining the Backwash Profile in a Drinking Water Plant Using an In-Line Turbidimeter with a FNRU design.

X4.1.1 Introduction:

Today's drinking water plants (DWP) are required to meet many challenges to satisfy regulatory, health and ultimately their customer's needs. These challenges specifically relate to the final quality of the water, and that the means used to achieve this quality are economically favorable. To meet these challenges, total optimization of the DWP must be achieved

which includes all the processes associated with the production of drinking water. One of the key processes that require optimization in a DWP process is filter backwash. This application covers issues associated with monitoring the turbidity during a filter backwash cycle.

X4.1.2 The Importance of Backwash Monitoring for Turbidity

Filter backwash is a challenging issue in the drinking water industry. Excessive backwash practices can contribute to poor filter performance and/or shortened filter run times. Studies

have shown that if a filter is over-washed, the subsequent ripening phase is often ineffective. The result is shortened run times and the larger potential to have a filter breakthrough. Excessive wash can eventually lead to loss of filter media, and which will contribute to poorer filter performance over time. Backwash requires a significant volume of water and excessive backwashing can significantly reduce the output of a DWP. Drinking water plants can use as much as 3-5 percent of a filtered water supply to backwash filters. Such large volumes can have a dramatic impact on both the operating costs of the DWP and in the available supply of water for public use. The ideal method to monitor backwash and then the subsequent termination of the backwash cycle is based on turbidimetric analysis using reliable instrumentation. Studies have shown that the final turbidity at the termination of a backwash cycle is directly related to subsequent filter performance and run time. In light of these studies, the American Water Works Association (AWWA) has recommended turbidity range to target for backwash termination. This range is set at 10-15 NTU. When the backwash cycle is terminated in this range, sufficient particulate material available in the backwash water to allow for an effective ripening period. This in turn, leads to longer and more effective filter run times. Fig. 10 displays a typical filter backwash profile and the AWWA recommended turbidity range for backwash termination. Notice that the turbidity changes in a backwash can be rapid, and that the backwash cycle itself is a rather short duration. Thus, backwash cycle optimization requires rapid and accurate turbidity measurement. On-line (Process) analysis of the backwash water as the filter is cleaned is considered to be an ideal means of determining the respective turbidity. To be successful, real-time analysis is necessary to accurately respond to the rapid turbidity changes that occur during backwash. The turbidity monitor must be at a location directly above the filter or in the backwash drain line that will allow for representative sampling. Measurements then need to be performed at rapid intervals to capture the rapid turbidity changes that occur during the backwash cycle. Because the backwash turbidity is a rapidly changing parameter, the instrument must have a rapid and accurate response to accurately derive the backwash profile

for a filter. Again, fast response was a limitation of older instrumentation. To be successful in automated backwash cycle monitoring for turbidity, several criteria must be addressed. Ultimately, if turbidity interferences (e.g. ambient light, bubbles, and representative sampling) along with proper sensor installation can be addressed, process control of backwash based on turbidity can be achieved.

X4.1.2.1 Using Turbidity for Backwash Optimization

Newer turbidimeter designs can help the DWP operator optimize the backwash cycle. This, in-turn, will lead help achieve the goal of total plant optimization. The new instrumentation has several features that address those issues that have limited the application of conventional on-line turbidimeters in the past. Each of these features are discussed here:

(1) Probe Design – The sensor should be of an in-line design and can be mounted in any location above the filter in a DWP or in the wash line. This allows for representative sampling and reduces the interference effects caused by surface reflectance and bubbles.

(2) Light Source - The light source used is narrow band of colimated light, with an approximate wavelength of 860-nm. This light source is modulated, which reduces ambient light interference. A second interference, color is also dramatically reduced because the wavelength at 860-nm is not typically absorbed by those constituents found in backwash water. This design parameter provides for high linearity and high accuracy in turbidity measurements that can be made over a wide turbidity range.

(3) Real-time measurement - The instrument is capable of performing near-instantaneous response to turbidity fluctuations that occur during the backwash cycle. Measurements are made as often as one per second. The instrument response has a user selectable range. This allows for measurement averaging, which is often necessary with samples that have significant changes in its profile.

(4) Data Collection - The instrument can log data at the rate of one point per second. This data can be plotted on the screen for immediate analysis, or transmitted via 4-20mA or through digital means to the peripheral data collection system. Thus, backwash profiles to be easily generated for each filter and for each backwash. This will allow the opportunity to control backwash based on unbiased instrument analysis.

The above-described turbidimeter possesses the necessary features to perform accurate and rapid backwash measurements. The instrument design eliminates all the interference problems that would normally be common in backwash measurement. When this is coupled to the real-time monitoring capability of the instrument accurate backwash profiling is possible. Thus, examination of the profile allows the operator to determine exactly when they should terminate the backwash cycle in order to optimize the performance of the proceeding filter run.

X4.1.3 Application of the In-Line Turbidimeter for Backwash Profiling at a Colorado WTP

X4.1.3.1 The Installation:

At this plant the sensor was mounted in a horizontal position directly into the water flow and approximately 18 in. above the filter media. This allowed for bed expansion to occur without

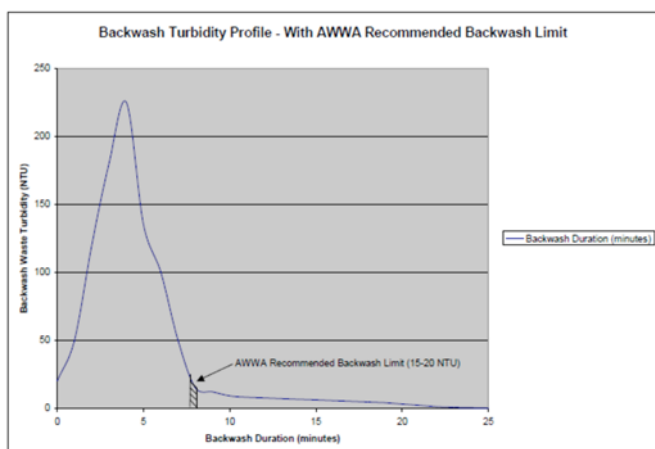


FIG. 10 The importance for measuring the turbidity during backwash.

interfering with turbidity measurements. Overall, the sensor was submerged approximately 4 feet below the surface of the water, which reduced bubble interferences. The probe faced away from any wall or object in the filter that could result in a reflective interference.

X4.1.3.2 Data Collection:

Backwash turbidity is typically changes very rapidly. Accurate profiling required data logging at intervals at the rate of once every five seconds. This allows for accurate correlation between turbidity and the events that occur during the backwash cycle. Time versus turbidity data was then plotted for the backwash. Then, those specific steps that were made during a backwash could be related to the turbidity and the impact of each step to the overall effectiveness of the backwash could be evaluated. Fig. 11 shows a backwash profile with all the stages in the backwash denoted by letters. Table X4.1 provides a more complete description of the specific stage of this backwash. Fig. 11 displays the backwash profile from the local water treatment plant. The displayed turbidity measurements were recorded every 5 seconds. Signal averaging was set at 30 seconds to reduce noise levels. The signal averaging reduces noise that occurs due to the large amount of turbulence that occurs above the filter during the backwash. Table X4.2 contains the details of each step in the backwash cycle that makes up the profile in Fig. 11.

X4.1.4 Results and Discussion:

First the profile displayed in Fig. 11 shows a smooth curve with two distinct peaks. This backwash (BW) begins with a gradual increase of flow up to 6000 gallons per minute (gpm). By the time the flow reaches the 6000 gpm peaks, the turbidity of the backwash level has peaked at 55 FNU and begins to drop. Six minutes into the backwash cycle, the turbidity has dropped to below 5 FNU. Next, a second (and final) surface wash procedure is initiated. The backwash turbidity ramps up to a second peak value of 15 FNU, at which time the surface wash is terminated. Then, the backwash flow rate is slowly reduced from 6000 to 2000 gpm. At nine minutes into the procedure, the BW turbidity is between 1 and 2 FNU, which is the same turbidity as the settled water immediately prior to its application to this filter. As the backwash cycle progresses, the filter becomes exceedingly clean with the final backwash turbidity measuring at 0.081 FNU at the end of the backwash

cycle. From start to finish, the backwash cycle lasted just under 14 minutes. Based on this profile, several observations can be made. First, the final turbidity at termination of the backwash was recorded to be 0.08 FNU. This is below the turbidity limit recommended by the AWWA of 10-15 FNU. There is a good chance that the filter is over-washed which could limit the filter run time and filter effectiveness. The effect of the surface wash was shown to increase the turbidity of the backwash water only by about 10 FNU. The overall effect of this on subsequent filter run was not known, but the BW could have been terminated at the peak of the final surface wash when the turbidity of about 15 FNU. This then could be followed by the ripening period. Further interrogation of this backwash profile could also reduce backwash time and save a substantial quantity of backwash water. As was noted above, the filter was washed beyond the turbidity of the settled water that is applied to the filter. If the wash would have been terminated when the turbidity was equal to that of the settled water (9 minutes into the wash), a substantial quantity of backwash water could have been saved. During times of high plant throughput, this could be a substantial aid toward efficient plant operation. When determining the profile of a backwash cycle, it is imperative to understand that the turbidity readings will contain a significant level of noise if the measurement settings are not optimized. The noise is primarily due to the severe turbulent state of the backwash water as it passes from the filter surface to waste. Much of the material that passes in front of the sensing zone of the turbidimeter can be substantially large. Exceptionally large particle are often seen as noise in process instruments. To compensate for this noise, a level of instrument measurement averaging (signal averaging) must be employed. When signal averaging is utilized, the instrument will take several consecutive measurements and average them together and display the value. As each new measurement is taken, the oldest measurement used in the averaging process is removed and a new average value is calculated. In summary, the use of a process in-line turbidimeter can provide a substantial amount of accurate information regarding the backwash profiling. It is crucial that the instrument be positioned in a proper location for representative sampling and that the instrument settings allow for noise reduction to the level that the data is discernable. Once the profile is constructed, the water treatment plant can determine what changes to the backwash cycle can be made to result in a more efficient and economical backwash regimen. Thus turbidity measurements are valuable to insure that the backwash regimen provides adequate wash of a filtration system while insuring that over washing of the filtration system does not take place.

X4.2 Demonstration of On-Line Turbidity Data Usage to Confirm Water of Suitable Turbidity for Drinking Water Filtration Plant Applications

X4.2.1 Introduction:

The measurement of turbidity of the raw water source for drinking water plants is a critical measurement. Depending on this turbidity, chemical dosing must be adjusted accordingly to successfully coagulate and flocculate the particles so the maximum mass of solids is removed prior to filtration. In doing so, this will prevent fouling of the filter and increase forward

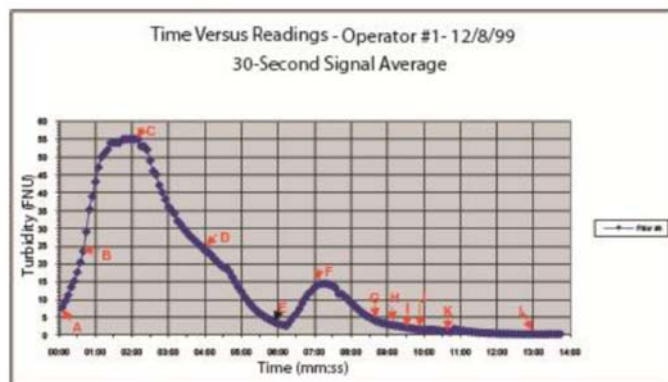


FIG. 11 Backwash profile for a dual media filter. Refer4 to Table X4-1 below for the referenced events in this process

TABLE X4.1 Detailed Description of the Backwash Strategy

Point	Description	Reading (FNU) at initial point	Time (minutes:seconds)
A	Surface Wash On	7.6	00:05
B	Flow Rate = 4,000 gpm	23.5	00:40
C	Flow Rate = 6,000 gpm	55	02:10
D	Surface Wash Off	23.6	04:00
E	Surface Wash On; Flow Rate = 3,900 gpm	3.1	05:55
F	Surface Wash Off; Flow Rate = 6,000 gpm	14.3	07:10
G	Flow Rate = 5,300 gpm	3.9	08:40
H	Flow Rate = 4,600 gpm	2.57	09:10
I	Flow Rate = 3,900 gpm	1.7	09:35
J	Flow Rate = 3,200 gpm	1.35	09:55
K	Flow Rate = 2,600 gpm	0.85	10:40
L	Flow Rate = 2,000 gpm	0.081	13:00

TABLE X4.2 Averaged Turbidity Data from a Source Water Lake for both a Conventional and Membrane Water Treatment Plants

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Average	2.00	2.26	1.67	3.07	5.91	9.40	14.75	13.48	10.90	6.38	3.49	2.12
Min	1.60	1.84	0.10	0.00	2.65	3.82	0.00	1.62	4.39	0.00	2.08	1.46
Max	3.43	2.65	7.17	26.90	44.86	19.76	37.24	28.30	20.88	29.78	7.78	5.35
Range	1.84	0.81	7.07	26.90	42.21	15.95	37.24	26.68	16.49	29.78	5.70	3.88

filtration run times. Further, the removal of turbidity from water reduces the potential for disinfectant byproduct (DBP) formation and pathogen passage beyond the final filtration steps. The turbidity of the raw water also relates to the overall condition of the water throughout the year. The water source is a 150-acre lake that primarily receives surface water runoff. The source is also used for recreational purposes and during times of high water demand, drawdown of this raw water source becomes significant. During drawdown, sediments can become re-suspended and this offers additional challenges for the drinking water facility. These include the need to remove iron and manganese that impacts both taste and odor of the water and causes staining of surfaces.

X4.2.2 Methods:

The water plant uses surface scatter measurement technology to monitor their raw water source. The instrument has a nephelometric design but both the light source and the detector are positioned above a flat surface of the sample that flows upward over a weir. Turbidity in the water causes the light to become scattered and a portion of this light scatter will be detected by the detector that is set at 90-degrees. The method provides a wide range of turbidity linearity from 0.5 to 4000 surface scatter units (SSU), which meets the practical application needs for this plant. The plant calibrates the instrument using formazin turbidity standards that are prepared as described in the standard preparation sections of this method. Though not a regulatory requirement for this type of measurement, the plant still calibrates the instrument every 90-days and uses secondary standards to verify the instrument's performance on a weekly basis. This insures measurement reliability.

X4.2.3 Data:

Data is transferred from the instrument to the plant's SCADA system. Here the data is logged every minute and the SCADA system provides an updated graph of the turbidity of the sample every time the new measurement is logged. In Fig. 12, a graph from 1-year of data collection provides an accurate assessment of the turbidity cycle over this time and helps the plant staff to better plan and manage the important chemical dosage portion of water treatment. Fig. 12 presents the turbidity

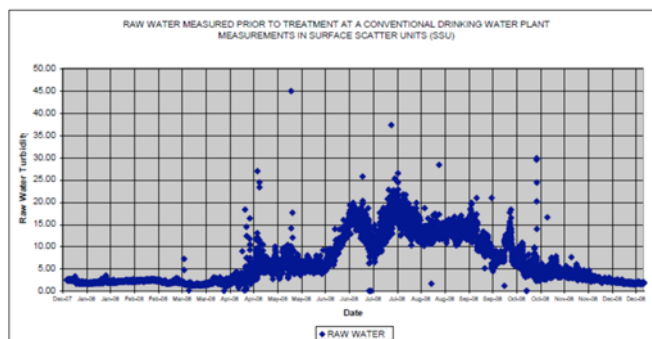


FIG. 12 Graph of source water turbidity for drinking water facilities on the Colorado front range.

data average, min and maximum for each month. Either presentation of data helps the plant assess the quality of their raw water source through turbidity measurement.

X4.2.4 Discussion:

The turbidity data of the source water shows that seasonal variations have a significant impact on the turbidity. Summer turbidity values are higher which is correlated to a combination of increased recreational usage and drawdown. Winter months, which are times of lower water demand and recreation show a more stable and lower turbidity.

X4.2.5 Conclusion:

The data in this application was collected under the prescriptive usage of the high-level on-line turbidity method. The turbidity data, which ranges up to 45 SSU is critical to the operation of the drinking water plants that utilize this source water.

X4.3 Demonstration of Turbidity Data Usage to Monitoring or Drinking Water Filtration Plant Post Filtration Applications

X4.3.1 Introduction:

The measurement of turbidity of post-filtered water has become a common application to help in the monitoring of drinking water distribution system integrity. As distribution

systems age, the possibility of a water line breaking or some other breach becomes heightened. Thus, turbidity and other analytical parameters are being used to monitor the stability of these systems. An on-line turbidimeter was utilized to measure the turbidity on a continuous basis.

X4.3.2 Method:

In this application, a turbidimeter that utilizes a white light and a 90-degree detection angle is used to monitor the turbidity of the distribution system from a major metropolitan area. The measurements are continuous and data is logged every minute. The turbidity signal is integrated into an algorithm along with several other process analytical parameters that together contribute to a single signal that is used as the baseline for the distribution system's stability. If the turbidity or any other measurement parameter changes, the combined signal will also change and will indicate that there has been a sudden change in the distribution system that warrants further investigation. The turbidimeter is calibrated using those standards and preparation procedures that are provided by the ASTM method. Further, the turbidimeter performance is also verified and maintained as prescribed in this method. The turbidimeter reports in the units of NTU and this technology was found to be appropriate because the sample is void of color and the turbidimeter technology effectively removes bubble interferences.

X4.3.3 Data:

Data is generated every three seconds and is automatically fed into the multi-parameter algorithm for processing. In addition, the data is logged at one-minute intervals into a historical file that can be used for post processing if deemed necessary. Fig. 13 provides a typical turbidity graph that contains data that is logged over a one-week period.

X4.3.4 Discussion:

Ideally, the turbidity of the distribution system should be relatively stable and within some pre-defined control limits. In the case of this application, no control limits were necessary because the turbidity value is used in congruence with other analytical values to provide a single value for assessing the stability of the distribution system. The data is stored graphically and can provide a historical baseline for the individual

turbidity parameter and is used in troubleshooting uncharacteristic trends or events.

X4.3.5 Conclusion:

The data in this application was collected under the prescriptive usage of the high-level on-line turbidity method. The turbidity data, is typically above 1 NTU was found to be highly useful in contributing to the assessment of the stability of the distribution system for this metropolitan city.

X4.4 Continuous Monitoring of Turbidity in Southwestern Ohio Rivers Using a Modified On-Line Method

X4.4.1 Introduction:

In a collaboration an instrument manufacturer, and the Miami Conservancy District in Southwest Ohio, the water quality of the Mad and Stillwater rivers in the Dayton, OH area is continuously monitored at gage stations (Fig. 17) using a sidestream method. Fig. 18 shows the extent of flooding at one of the sites, indicating the worth of the sidestream methodology in keeping water quality sensors from flood damage during these types of events. As shown in Fig. 19 and Fig. 20, the gage houses have been fitted with a vessel into which river water is pumped continuously and then discharged back into the river. The gage house vessel is not sealed, instead utilizing a drain stem which assures that the river water is not discharged until the vessel is full. This method allows the insertion of the sampling filter of an automatic sampler and a multiparameter sonde which contains sensors for temperature, conductivity, pH, dissolved oxygen, chlorophyll, blue green algae, AND turbidity (Fig. 21). This note covers the general measurement of turbidity in this "process-type" application, including the correlation of turbidity with conductivity during rainfall events. The temporal differences in the turbidity/conductivity events in the two rivers are also briefly discussed.

X4.4.2 Equipment:

Data has been acquired with a variety of multi-parameter monitoring platforms (sondes), into which a turbidity probe was installed along with other sensors. For the turbidity studies, the sondes were equipped with turbidity sensors which are automatically cleaned with an attached wiper to remove bubbles and fouling prior to the logging of a data point (see Fig. 21). The wiper is activated within approximately 1 minute of the recording of data. The turbidity sensor is characterized by an optical system in which the angle between the emitted and detected radiation is approximately 90 degrees. In addition, the sensor utilizes an 860 nm near-infrared LED as the light source. These features (90 degree scatter and 860 nm radiation) are consistent with the recommendations of the International Standards Organization (ISO) 7027 method. The sondes are attached to web-based data collection platforms that are powered from the AC outlets available in the gage houses. The sondes are in turn powered by the DCPs via an SDI-12 interface. The DCPs are set up to trigger sonde acquisition of data every 1 or 2 hours, depending on the site.

X4.4.3 Typical Data:

The data below for the Stillwater River from the winter of 2006-2007 is typical of that obtained during rainfall events. The data was acquired at a 2 hour sample interval and the study length is approximately 6 months. Note Fig. 14, the excellent

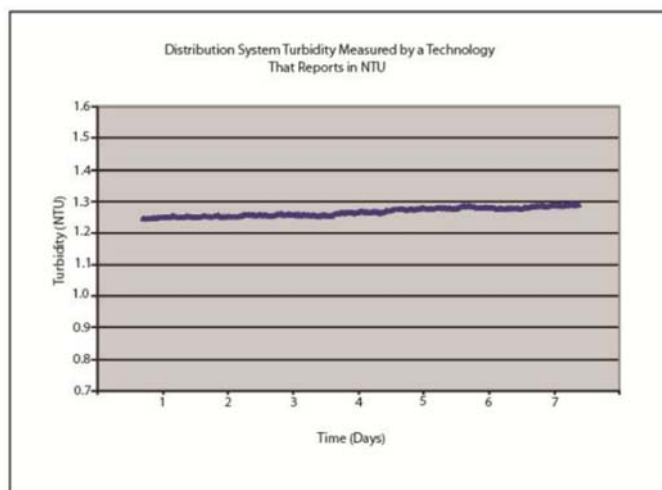


FIG. 13 Turbidity measurement of a distribution over a one-week period. The lack of any spike indicates a stable system.

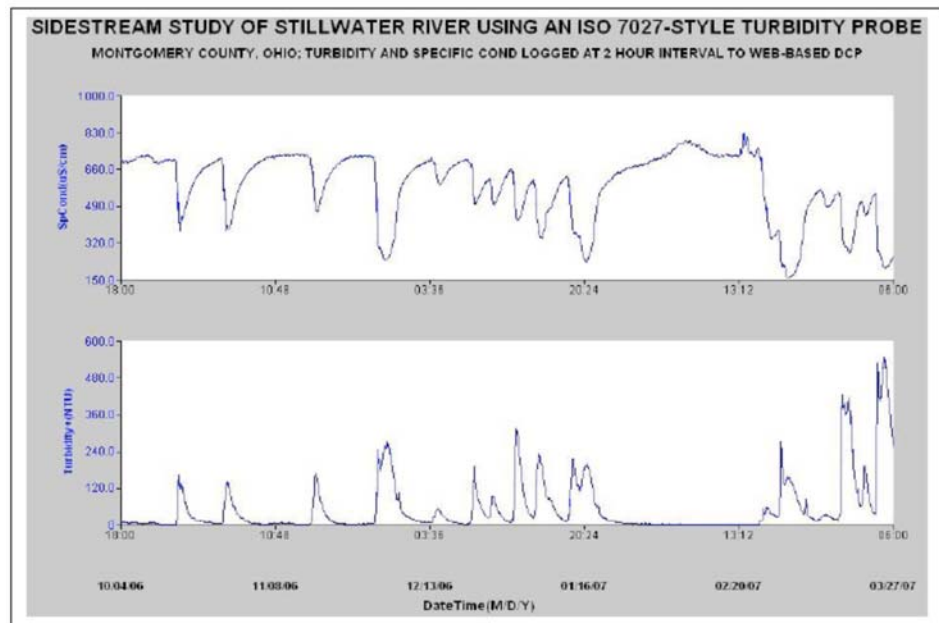


FIG. 14 Turbidity measurement (bottom of the Stillwater River) over a 6-month period. The turbidity spikes are due to rainfall events that took place over the analysis period.

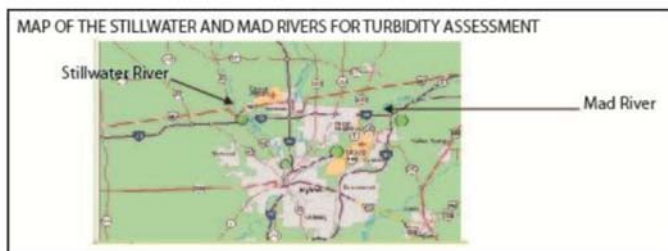


FIG. 15 Map of the Dayton Ohio Area, where the turbidity of two local rivers were being monitored during rain events.

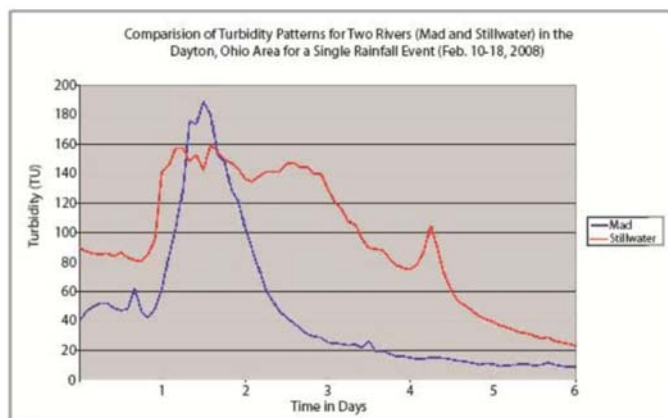


FIG. 16 Turbidity measurements of the Mad and Stillwater rivers during the same weather event. The difference in the values over time shows demonstration of capability of the technology to measure the turbidity.

inverse correlation of turbidity as measured with the ISO 7027-type sensor with specific conductance which occurs because rainwater is effectively free of ions and lowers the

conductivity of the overall river while it also results in sediment being washed from fields, etc. contiguous to the river. Since there is also a continuous measurement of river flow (3

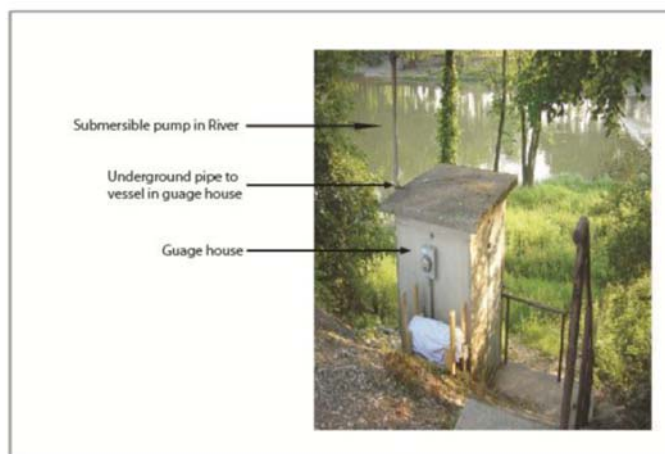


FIG. 17 Typical Gage House for Sidestream monitoring of rivers at Normal Flow.



FIG. 18 Same gage house for Sidestream monitoring of rivers at flood stage.

ft/sec) at the site, the turbidity data shown above could be combined with flow to estimate sediment transport, particularly during rainfall events. The additional parameter required is a correlation between a turbidity reading in NTU and the amount of local sediment in mg/L which is present for that value of turbidity. Usually a good estimate for this geographic area is that 1 NTU corresponds to about 1 mg/L, but clearly this value will vary somewhat depending on the ground conditions. It is also possible to compare the intensity and temporal pattern of the turbidity at different sites on the same river system. Fig. 16 shows the turbidity data for a rainfall event in 2009 for sites on the Mad and Stillwater Rivers in the Dayton, OH area. Note that both rivers flow into the Great Miami in downtown Dayton and probably together account for half the total flow of the

Great Miami after the confluence. The sharper turbidity pattern for the Mad River relative the Stillwater is typical of most rainfall events in the Dayton area. The effect for the data above is due in part to the fact that the Mad is a smaller, more canalized river with high overall velocity. However, the additional turbidity events in the Stillwater after day 2 are likely due to additional localized rainfall in the watershed of this river, but not in that of the Mad. Note from the map (Fig. 15) above that the main rivers are 20- 30 miles apart in the upper regions of their respective watersheds.

X4.4.4 Summary:

Turbidity sensors of the ISO 7027-type design can provide high quality data in long-term studies when used in a process-style, sidestream application in which river water is pumped to



FIG. 19 Contents of gage house showing sonde and sidestream vessel

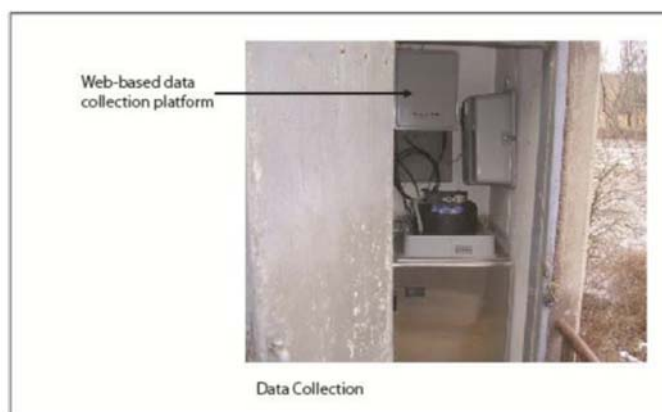


FIG. 20 Web-based data collection system for monitoring site

a vessel which contains the turbidity sensor and then discharged back into the river. When the turbidity sensor is attached to the proper data collection platform, the data is available in real-time. As shown in Fig. 21, the use of a mechanically cleaned turbidity sensor may be necessary in order to obtain this type of continuous data, since fouling can be expected to be an issue in river systems characterized by high turbidity events. As expected, the turbidity data shows a good inverse correlation with the conductivity of the water due to the fact that the rainwater which generates the high turbidity events has effectively zero ion content. The continuous logging of turbidity in the described applications allows semi-quantitative comparison of patterns of sediment transport for different watersheds and, with the proper correlation of turbidity with suspended sediment concentration, will allow fairly accurate calculations of the total sediment transported.

X4.5 Demonstration of Turbidity Data Usage with a Backscatter Technology

X4.5.1 Introduction:

The in-situ monitoring of natural coastal waters conducted using three different technologies. The duration of monitoring was over a three-day period, in August 2010.

X4.5.2 Method:

Three turbidimeters were used in the monitoring process. One turbidimeter was a 90-degree scatter technology, with the light source that provides a FNU technology designation. The other two turbidimeters used the same technologies, which were both FBU measurements. The difference between these two instruments was the use of an anti-fouling approach for the sensor on one versus no anti-fouling on the other. All three instruments were calibrated using those procedures provided by the ASTM method.

X4.5.3 Data:

Data is generated every at automated predetermined intervals over the monitoring period. The data was automatically logged and then later plotted to provide run-charts comparing the three sensors. Fig. 22 contains the plotted data over the three day monitoring period.

X4.5.4 Discussion:

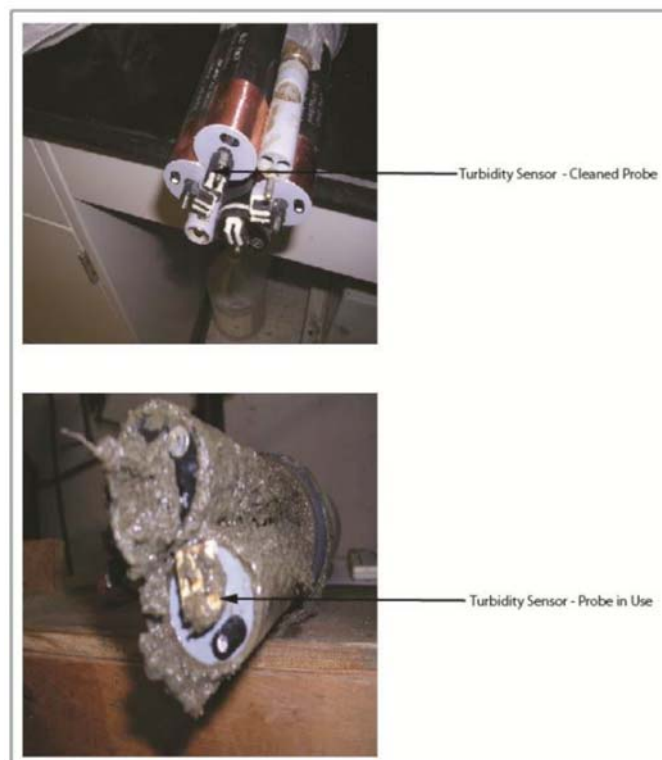


FIG. 21 Comparison of a clean and dirty sensor. Cleaning features are may be necessary depending on the sample.

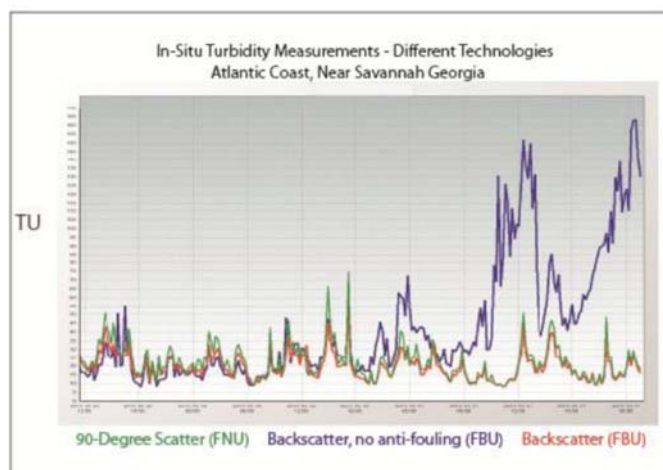


FIG. 22 Monitoring of coastal waters near Savannah, Georgia. The two backscatter technologies compare closely, throughout the study, but the 90-degree technology shows elevated response to turbidity as the study progresses.

Fig. 22 shows that the turbidity is highly varied. Through the first half of the monitoring period, all three technologies agree closely, but as time passes, the 90-degree measurements show a positive deviation from the FBU technologies. The turbidity of the FBU measurements were all in the 10 to 50 FBU range, and the FNU measurement ranged from about 10 to over 160 units on the same sample. All three technologies do demonstrate the capability to measure the turbidity.

X4.5.5 Conclusion:

The data in this application was collected under the prescriptive usage of the high-level on-line turbidity method. The turbidity data, above 1 NTU was found to be successfully measured by two different technologies (FBU and FNU).

REFERENCES

- (1) EPA 180.1 Methods for Chemical Analysis of Water and Wastes, Turbidity
- (2) Standard Methods for the Examination of Water and Wastewater 2130B, 19th edition
- (3) ISO 7027 (The International Organization for Standardization) for the Determination of Turbidity
- (4) Hach Method 8195 from Hach Company, 5600 Lindbergh Drive, Loveland, CO 80537
- (5) GLI Method 2 from Hach Company, 5600 Lindbergh Drive, Loveland, CO 80537
- (6) United States Geological Survey (USGS), —National Field Manual for the Collection of Water Quality Data||. Website: <http://www.usgs.gov/FieldManual/Chapters6/6.7.htm>.
- (7) US Patent 4,283,143 from Advanced Polymer Systems, Inc., 123 Saginaw Dr., Redwood City, CA 94063
- (8) US Patent 4,291,980 from Advanced Polymer Systems, Inc., 123 Saginaw Dr., Redwood City, CA 94063
- (9) S Patent 5,777,011 from Hach Company, 5600 Lindbergh Drive, Loveland, CO 80537

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