Continuous Measurement of Turbidity Using a
SWAN AMI Turbiwell Turbidimeter

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1. SCOPE AND APPLICATION

1.1. This method is applicable to drinking, surface, saline, ground and effluent water samples, domestic and industrial, in the range from 0 to 40 Nephelometric Turbidity Units (NTU). It meets the requirements for compliance monitoring and reporting as demanded under the Safe Drinking Water Act (SDWA).

2. SUMMARY OF METHOD

2.1. The method is based upon a comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension. The higher the intensity of scattered light, the higher the turbidity. Readings, in NTUs, are made in a nephelometer designed according to specifications given in section 6.2.

   2.1.1. Formazin, prepared under closely defined conditions, is used as a primary standard suspension to calibrate the instrument. However, any other approved primary standard may be used with this method.

3. DEFFINITIONS

3.1   CALIBRATION BLANK (CB) – A volume of reagent water fortified with the same matrix as the calibration standards, but without the analytes, internal standards, or surrogate analytes.

3.2   INSTRUMENT PERFORMANCE CHECK SOLUTION (IPC) – A solution of one or more method analytes, surrogates, internal standards, or other test substances used to evaluate the performance of the instrument system with respect to a defined set of criteria.

3.3   LABORATORY REAGENT BLANK (LRB) – An aliquot of reagent water or other blank matrices that are treated exactly as a sample including exposure to all glassware, equipment, solvents, reagents, internal standards, and surrogates that are used with other samples. The LRB is used to determine if method analytes or other interferences are present in the laboratory environment, the reagents, or the apparatus.

3.4   LINEAR CALIBRATION RANGE (LCR) – The concentration range over which the instrument response is linear.

3.5   MATERIAL SAFETY DATA SHEET (MSDS) – Written information provided by vendors concerning a chemical/s toxicity, health hazards,

physical properties, fire, and reactivity data including storage, spill, and handling precautions.

3.6   PRIMARY CALIBRATION STANDARD (PCAL) – A suspension prepared from the primary dilution stock standard suspension. The PCAL suspensions are used to calibrate the instrument response with respect to analyte concentration.

3.7   QUALITY CONTROL SAMPLE (QCS) - A solution of the method analyte of known concentrations that is used to fortify an aliquot of LBR matrix. The QCS is obtained from a source eternal to the laboratory, and is used to check laboratory performance.

3.8   SECONDARY CALIBRATION STANDARDS (SCAL) – commercially prepared, stabilized sealed liquid or gel turbidity standards, or other apparatus or mechanism calibrated against properly prepared and diluted Formazin or styrene divinylbenzene polymers.

3.9   STOCK STANDARD SUSPENSION (SSS) – A concentrated suspension containing the analytic solution prepared in the laboratory using assayed reference materials or purchased from a reputable commercial source. Stock standard suspension is used to prepare calibration suspensions or other needed suspensions.

4. INTERFERENCES

4.1. The presence of floating debris and coarse sediments which settle out rapidly will give low readings of turbidity. Finely divided air bubbles will cause high readings. These interferences can be eliminated by using a degasser.

4.2. The presence of true color, that is color of water which is due to dissolved substances that absorb light, will cause turbidities to be low, although this effect is generally not significant with drinking water.

4.3. Light-absorbing materials such as activated carbon in significant concentrations can cause low readings.

5. SAFETY

5.1 The toxicity or carcinogenicity of each reagent used in this method has not been fully established. Each chemical should be regarded as a potential health hazard and exposure should be as low as reasonably achievable.

5.2   Each laboratory is responsible for maintaining a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method. A reference file of Material Safety Data Sheets (MSDS) should be made available to all personnel involved in the chemical analysis. The preparation of a formal safety plan is also advisable.

5.3 Hydrazine sulfate (7.2.1) is highly toxic and may be fatal if inhaled, swallowed or absorbed through the skin. Formazin can contain residual hydrazine sulfate. Proper protection should be employed.

6. EQUIPMENT

6.1. The installation shall be according to the manufacturer's instructions.

6.2. The turbidimeter shall consist of a nephelometer, with a light source for illuminating the sample, and a photo-electric detector with a readout device to indicate the intensity of light scattered at a right angle to the path of the incident light.

6.2.1. A condensing lens shall collect the rays from the light source to illuminate a small circular field stop. A second lens shall collimate the light passing through the field stop and shall provide a uniform parallel light beam, not deviating more than ±1.5°, to illuminate the sample.

6.2.2. A beamsplitter shall deflect a small fraction of the incident light beam onto a photo-electric detector for monitoring the intensity of the light source (reference signal).

6.2.3. The incident light beam shall be refracted at the sample surface at an angle of 45°±5°.

6.2.4. The light scattered at a right angle, not exceeding ±30°, to the refracted incident light beam shall be collected by a lens above the sample surface and shall be directed onto a photo-electric detector (scattered light signal).

6.2.5. An algorithm shall be used to calculate the turbidity value based on the intensity of both signals.

6.2.6. Spectral Sensitivity: the light source shall be a white LED emitting visible light. The LED, all optical elements and detectors shall have a spectral peak response between 400 nm and 600 nm.

6.2.7. The distance traversed by incident light and scattered light within the sample shall be less than 10 cm.

6.2.8. The turbidimeter should be designed so that little stray light reaches the detector in the absence of turbidity and should be free from significant drift after a short warm-up period.

6.3. The sensitivity of the instrument shall permit detection of turbidity differences of 0.02 NTU or less in waters having turbidities less than 1 NTU unit. The instrument shall measure from 0 to 40 NTU turbidity units. Several ranges may be necessary to obtain both adequate coverage and sufficient sensitivity for low turbidities.

6.4. The sample flowing through the measurement cell of the turbidimeter shall not have direct contact neither with the optical exit window of the incident light beam nor with the optical entrance window of the scattered light. Both windows shall be kept extremely clean.

6.5. The sample cell shall be kept clean to produce the lowest background blank value.

6.6. A turbidimeter sample that meets these specifications is the SWAN AMI Turbiwell turbidimeter.

7. REAGENTS AND STANDARDS

7.1   Reagent water, turbidity-free: Pass deionized distilled water through a 0.45 micron pore-size membrane filter if necessary. Water should have a turbidity $\leq$ 0.03 NTU. This value should be considered when preparing standards.

7.2   Stock standard suspension (Formazin)

    7.2.1   Dissolve 1.00g hydrazine sulfate (CASRN 10034-93-2) in reagent water and dilute to 100 mL in a volumetric flask.

    7.2.2   Dissolve 10.00g hexamethylenetetramine (CASRN 100-97-0) in reagent water and dilute to 100 mL in a volumetric flask. In a 100 mL volumetric flask, mix 5.0 mL of each solution (7.2.1 + 7.2.2). Allow to stand 24 hours at 25 ± 3 degree C, then dilute to the mark with reagent water.

7.3   Primary calibration standards: Mix and dilute 10.00 mL of stock standard suspension (7.2) to 100 mL with reagent water. The turbidity of this suspension is defined as 40 NTU. For other values, mix and dilute portions of this suspension as required.

    7.3.1   A new stock standard suspension (7.2) should be prepared each month. Primary calibration standards (7.3) should be prepared daily by dilution of the stock standard suspension.

7.4   Formazin in commercially prepared, certified, concentrated stock standard suspension (SSS) may be diluted and used as required. Dilute turbidity standards should be prepared daily.

7.5   Styrene divinylbenzene polymer in commercially prepared, certified, concentrated stock or ready to use dilutions. Manufacturer's instructions should be followed for choosing the appropriate standard for the instrument.

7.6   Secondary standards may be acceptable as a calibration check, but must be monitored on a routine basis for deterioration and replaced as required.

8. SAMPLE COLLECTION AND INSTRUMENT SETUP

8.1   Online instrumentation does not require sample cooling, preservation or storage.

8.2   Install and set up the instrument according to the manufacturers instructions.

9. QUALITY CONTROL

9.1   Each laboratory using this method is required to operate a formal quality control (QC) program. The minimum requirements of this program consist of an initial demonstration of laboratory capability and analysis of laboratory reagent blanks and other solutions as a continuing check on performance. The laboratory is required to maintain performance records that define the quality of data generated.

9.2   INITIAL DEMONSTRATION OF PERFORMANCE

   9.2.1   The initial demonstration of performance is used to characterize instrument performance (determined of LCRs and analysis of QCS).

   9.2.2   Linear Calibration Range (LCR) – The LCR must be determined initially and verified whenever a significant change in instrument response is observed or expected. The initial demonstration of linearity must use sufficient standards to insure that the resulting curve is linear. The verification of linearity must use a minimum of a blank and three standards. If any verification data exceeds the initial values by ± 10%, linearity must be reestablished. If any portion of the range is shown to be nonlinear, sufficient standards must be used to clearly define the nonlinear portion.

   9.2.3   Quality Control Sample (QCS) – When beginning the use of this method, on a quarterly basis or as required to meet data-quality needs, verify the calibration standards and acceptable instrument performance with the preparation and analysis of a QCS. If the determined concentrations are not within ± 10 % of the stated values, performance of the determinative step of the method is unacceptable. The source of the problem must be identified and corrected before continuing with on-going analyses.

10.   CALIBRATION AND STANDARDIZATION

10.1   Turbidity Calibration: The manufacturer's operating instructions should be followed. Measure standards on the turbidimeter covering the range of interest. If the instrument is already calibrated in standard turbidity units, this procedure will check the accuracy of the calibration. At least one standard should be run in each instrument range to be used. Some instruments permit adjustments of sensitivity so that scale values will correspond to turbidities. Solid standards, if used, must be protected from surface scratches which may cause potential calibration changes. If a pre-calibrated scale is not supplied, calibration curves should be prepared for each range of the instrument. Calibration must be performed under identical optical conditions as operational conditions.

11. PROCEDURE

11.1. A sample from the treatment process is taken and flows through the turbidimeter for measurement. It is then drained or recycled back into the process after the measurement has been taken.

11.2. The sample flow rate shall be in accordance with the instrument specifications. The sample flow fed to the instrument shall be constant without variations due to pressure changes or surges. Installation of a flow control device such as a rotameter in the sample line can eliminate fluctuations of the flow rate.

11.3. The range of the sample temperature should be in accordance with the instrument specifications. The sample temperature within this range should be constant.

12.   DATA ANALYSIS AND CALCULATIONS

12.1. Report results as follows:

NTU	Record to Nearest
0.0 ÷ 1.0	0.05
1 ÷ 10	0.1
10 ÷ 40	1
40 ÷ 100	5
100 ÷ 400	10
400 ÷ 1000	50
> 1,000	100

13.   METHOD PERFORMANCE

13.1. Off-Line Testing

The SWAN White LED Method was conducted in a single, qualified laboratory. As the SWAN instrument requires a constant sample flow a recirculation system was used to introduce fortified DI water samples for analysis to the SWAN turbidimeter and in parallel to a EPA 180.1 compliant series turbidimeter from another supplier. Ten low nephelometric turbidity samples with a theoretical value of 0.071 NTU units and ten high nephelometric turbidity samples with a theoretical value of 0.800 NTU units were tested. Each replicate sample was introduced individually. Before the formazin spike DI water was pumped through the recirculation system and a blank reading was taken. Following each measurement the instruments were flushed clean.

13.2. On-Line Testing

The SWAN White LED Method was also tested at two public water utilities, one using surface water and the other groundwater. The SWAN Turbiwell turbidimeter and an EPA 180.1 compliant on-line turbidimeter were connected to the same source water line for analysis. Both turbidimeters were operated for 24 hours, collecting data once per minute. Time series of these data show that the SWAN Turbiwell measurements and the method 180.1 compliant measurement track well. Changes in turbidity are shown at the same time and to the same extent for both turbidimeters.

13.3. Accuracy of the SWAN White LED Method

The recoveries of turbidity of the fortified samples are listed in the following tables:

Low–level spike: 0.071 NTU

	SWAN AMI Turbiwell Reading [NTU]			Turbidimeter compliant EPA 180.1 Reading [NTU]		
Spike #	Blank	Spike Blank corrected	Recovery [%]	Blank	Spike Blank corrected	Recovery [%]
1	0.066	0.082	115	0.1564	0.0864	121
2	0.019	0.093	130	0.1052	0.0905	127
3	0.006	0.128	179	0.0605	0.1484	208
4	0.004	0.059	83	0.0564	0.0855	120
5	0.005	0.061	85	0.0612	0.0918	129
6	0.010	0.081	113	0.0730	0.1059	148
7	0.006	0.076	106	0.0575	0.1127	158
8	0.009	0.067	94	0.0588	0.0893	125
9	0.011	0.071	99	0.0619	0.0857	120
10	0.031	0.080	112	0.1026	0.0849	119
Average	0.017	0.80	112	0.0794	0.0981	137
S-Dev.	0.019	0.0198		0.0327	0.0200	

High-level spike: 0.800 NTU

Spike #	SWAN AMI Turbiwell Reading [NTU]			Turbidimeter compliant EPA 180.1 Reading [NTU]		
	Blank	Spike Blank corrected	Recovery [%]	Blank	Spike Blank corrected	Recovery [%]
1	0.009	0.872	109	0.0620	0.8888	111
2	0.012	0.893	112	0.0633	0.9089	114
3	0.012	0.888	111	0.0638	0.9072	113
4	0.014	0.866	108	0.0734	0.8726	109
5	0.025	0.876	110	0.0869	0.8801	110
6	0.037	0.906	113	0.1062	0.8978	112
7	0.022	0.854	107	0.0873	0.8516	106
8	0.017	0.827	103	0.0739	0.8324	104
9	0.017	0.896	112	0.0699	0.9369	117
10	0.027	0.848	106	0.1048	0.9413	118
Average	0.019	0.873	109	0.0792	0.8918	111
S-Dev.	0.009	0.024		0.0165	0.0345	

The average percent recoveries of turbidity for the low-level and high-level samples were:
SWAN AMI Turbiwell 112 % (low-level) and 109 % (high-level)
Turbidimeter comp. EPA180.1 137 % (low-level) and 111% (high-level).

13.4. Precision of the SWAN White LED Method

The standard deviations of turbidity for the low-level and high-level samples were:
SWAN White LED Method 0.0198 (low-level) and 0.024 (high-level)
Turbidimeter comp. EPA180.1 0.02 (low-level) and 0.0345 (high-level).

13.5. Accuracy and precision should be checked on a routine basis to monitor the overall performance of the instrument. A series of reagent blanks and check standards should be run to validate the quality of sample data. These checks should occur at a frequency that is required for regulatory compliance.

14. POLLUTION PREVENTION

14.1 Pollution prevention encompasses any technique that reduces or eliminates the quantity or toxicity of waste as the point of generation. Numerous opportunities for pollution prevention exists in laboratory operation. The EPA has established a preferred hierarchy of environmental management techniques that places pollution prevention as the management option of first choice. Whenever feasible, laboratory personnel should use pollution-prevention techniques to

address their waste generation. When wastes cannot be feasibly reduced at the source, the Agency recommends recycling as the next best option.

14.2 The quantity of chemicals purchased should be based on expected usage during its shelf life and disposal cost of unused material. Actual reagent preparation volumes should reflect anticipated usage and reagent stability.

15. WASTE MANAGEMENT:

15.1 The U.S. Environmental Protection Agency requires that laboratory waste management practices be conducted consistent with all applicable rules and regulations. Excess reagents, samples and method process wastes should be characterized and disposed of in an acceptable manner. The Agency urges laboratories to protect air, water, and land by minimizing and controlling all releases from hoods and bench operations; complying with the letter and spirit of any waste discharge permit and regulations; and by complying with all solid hazardous waste regulations, particularly the hazardous waste identification rules and land disposal restrictions.

16. REFERENCES

1 USEPA., Method 180.1 Determination of Turbidity by Nephelometry, Revision 2.0, (1993).

2 USEPA, Guidance Manual Turbidity Provisions, Appendix D. "Turbidity GLI Method 2", (1999).

3 Batelle, "Comparative Analysis of SWAN AMI Turbiwell Turbidimeter and EPA Method 180.1 Compliant Turbidimeter, (2009).