TURBIDITY INSTRUMENTATION - AN OVERVIEW OF TODAY'S AVAILABLE TECHNOLOGY

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ABSTRACT

Introduction: Turbidity been used for many years as a surrogate for monitoring the combined quantity of particulate material in a water sample and as such, has been one of the parameters used to provide a basic assessment of water quality. The development of the first analytical turbidimeters was in the 1960s and the fundamental optical technology remained unchanged until the mid-1980s. Since then, instrument design technology has advanced dramatically and many new designs have resulted. These new designs have evolved to address many of the traditional interferences associated with turbidity. Because different technologies (such as light sources and detector design) have been used to compensate or eliminate interferences such as color, bubbles, stray light, absorption, and path length, it is often difficult or impossible to compare measurements.

This paper will provide a brief description of turbidity and review the current instrument designs. How each design attempts to address specific interferences will be addressed and a proposal will be made to assign specific units to each instrument design. The author proposes that a more meaningful turbidity value will be produced.

General Overview of Turbidity Measurement: In its simplest terms, turbidity is the optical measurement of scattered light resulting from the interaction of incident light with particulate material in a liquid sample. Typically, the liquid is a water sample and the suspended material causing the light to be scattered can be composed of a broad variety of components. Examples of particles include: suspended solids such as silt, clay, algae, organic matter, various microorganisms, colloidal material, and even large molecules that are dissolved in the sample such as tannins and lignins.

The Theory of Light Scattering and Common Interferences: Particulate matter in a water sample will cause the incident light beam to be scattered in directions other than a straight line through the sample. The scattered light that returns to the detector causes a response correlating to the level of turbidity in the sample. A higher level of scattered light reaching the detector results in a higher turbidity value.

The measurement of turbidity is not directly related to a specific number of particles or to particle shape. As a result, turbidity has historically been seen as a qualitative measurement. In an attempt to make turbidity methods more quantitative, we can use standards and standardization methods.

Although interferences have a dramatic and ever-present impact on turbidity measurements, the type and magnitude of the interference often depends on the turbidity level being measured. When performing low-level turbidity measurements (<5 NTU),

primary interferences are stray light, bubbles, ambient light, and contamination. For high turbidity testing (5 NTU or greater), a greater impact from color, particle absorption, and particle density is seen. Table 1 summarizes these interferences:

Table 1 – Typical Interferences Associated with Turbidity Measurement

Interference	Effect on the Measurement
Absorbing particles (colored)	Negative bias (reported measurement is lower than actual turbidity)
Color in the matrix	Negative if the incident light wavelengths overlap the absorptive sprectra within the sample matrix
Particle Size	Either positive or negative (wavelength dependent) a) Large particles scatter long wavelengths of light more readily than small particles. b) Small particles scatter short wavelengths of light more efficiently than long wavelengths
Stray light	Positive bias (reported measurement is higher than actual turbidity)
Particle Density	Negative bias (reported measurement is lower than actual turbidity)
Contamination	Positive bias (reported measurement is higher than actual turbidity)

In an attempt to minimize interferences, several new turbidity measurement methods have been developed. Many of these methods have been designed to maximize sensitivity and minimize the effects of interferences. It is important to understand and identify the prominent interferences in your sample stream. Doing so can help identify the instrument design that will provide the most accurate and "interference-free" measurement. Instrument designs can be categorized as shown in Table 2 below:

Table 2 – Summary of Instrument Designs:

Design	Prominent Feature and Application
Nephelometric non-ratio	White light turbidimeters – Comply with EPA 180.1 for low level monitoring.
Ratio White Light turbidimeters	Complies with LT1 and SM. Uses a nephelometric detector as the primary detector, but contains other detectors to minimize interference. Can be used for both low and high level measurement.
Nephelometric near IR turbidimeters	Complies with ISO 7027 – The wavelength (860-890-nm) is less susceptible to color interferences. Good for samples with color and good for low level monitoring.
Nephelometric Near IR turbidimeters	GLI method 2, ISO 7027 and USEPA approved. Compliant and contains a ratio algorithm to monitor and compensate for interferences.
Surface Scatter Turbidimeters	Turbidity is determined through light scatter from or near the surface of a sample. The detection angle is still nephelometric, but interferences are not as substantial as nephelometric non-ratio measurements. This is primarily used in high-level turbidity applications.
Back Scatter/Ratio Technology	Backscatter detection for high levels and nephelometric detection for low levels. Backscatter is common with probe technology and is best applied in high turbidity samples.
Light attenuation FAU	The use of a transmitted detector (180 degrees to the incident light beam). Most susceptible to interferences, best applied at medium turbidity levels (5-1000).

The dilemma: The units for reporting turbidity are commonly the same, no matter which turbidimeter design is being used. Depending on the interferences present (especially in high level reporting), the instrument design can have a dramatic effect on the reported result. For example, if a high level sample is measured with a white light non-ratio instrument, the results will be dramatically different from a reading obtained using a 4-beam, IR ratio method. One solution is to apply the correct measurement units to the measured value to help rationalize the results. Table 3 contains a proposal for using standardized units to report turbidity.

Table 3 – Proposed Units for Technology Traceability

Unit	Name	Description of Compliant Technology
NTU	Nephelometric Turbidity Unit	White light, 90 degree detection only
NTU_R	Ratio Nephelometric Turbidity Unit	White Light, 90 degree detection with additional correction detectors
FNU	Formazin Nephelometric Unit	860-nm Light (near IR) with 90-degree detection (ISO7027 compliance).
FNU_R	Formazin Nephelometric Unit	860-nm Light with 90-degree detection and additional interference correction detectors.
FNU_{2B}	Formazin Nephelometric Unit – Dual Beam Detection Technology	4 beam IR Detection utilizing 2 light sources and two detectors.
FNU_{BS}	Formazin Nephelometric Unit using Backscatter Detection	860-nm detection angle with a backscatter detector (270 – 285) degrees angle relative to the incident beam
FAU_{XXX}-nm	Formazin Attenuation Unit using a defined wavelength	The detection angle is 180 degrees of the incident light beam

Conclusion: The correct assignment of turbidity units to the recorded turbidity result is critical in understanding if interferences were addressed to some level. Currently, the NTU unit is used for all turbidity measurements and the reported value does not have any traceability to the instrument technology used. At the very least, the units should be listed to the level of NTU, FNU, or FAU to the measured unit.

The ability to accurately trace the measurement to an instrument design technology is necessary to effectively quantify the turbidity measurement. Attaching more specific units to the results will help to clarify the turbidity value and will allow the user to determine when it is appropriate to directly compare results obtained with different instruments.