

PRINCIPLES OF SURFACE SCATTER[®] TURBIDITY MEASUREMENT

Technical Information Series Booklet

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Introduction

The nephelometric¹ or light-scattering principle of turbidity measurement in a liquid often is considered applicable only to measurement of low turbidities, such as in filtered water. This is because of upper range limitations that can be measured without dilution and the natural tendency of turbid samples to coat optical surfaces. Also there is a problem with loss of sensitivity due to sample matrix or particulate absorption of both the incident and scattered light on high turbidity samples. Hach Company's 'surface scatter' design minimizes these adverse effects. Embodied in the Surface Scatter[®] 7sc Turbidimeter, this design essentially has no upper turbidity range limit, negligible stray light interference and no loss of sensitivity due to dirty optical surfaces. For purposes of introduction, a simple 90-degree scattering nephelometer is illustrated in Figure 1.

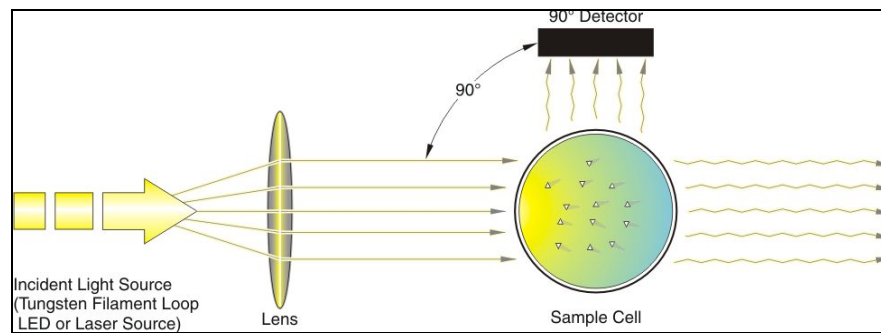


Figure 1: 90° Scattering Nephelometer

Response to High Turbidities

Figure 2 illustrates the response of a 90° light-scatter nephelometer is a linear function of the turbidity beginning at approximately zero but becomes nonlinear at higher values of turbidity. The slope of the linear portion of the curve is dependent upon the strength of the incident light beam, sensitivity of the detection system and the path length inside the measurement cell. For example, there are turbidimeters with a sensitivity of 100 percent of full scale with turbidities as low as 1.0 Nephelometric Turbidity Unit (NTU).

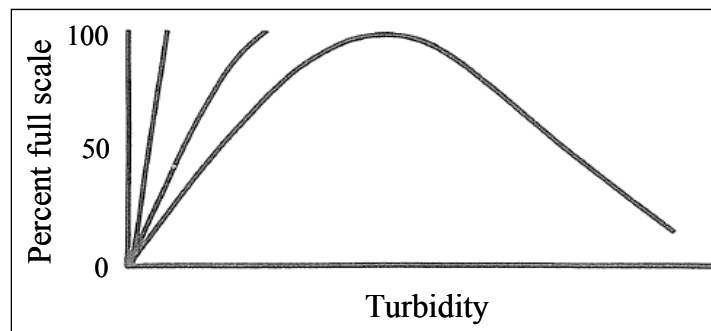


Figure 2: Response Characteristic for 90° Nephelometer

¹ The word "nephelometric" describes an optical principle of instrumentation whereby turbidity is determined by measuring the amount of light scattered at some angle from the incident light path by particles suspended in the test solution. The American Public Health Association and the U. S. Environmental Protection Agency have adopted nephelometry as the accepted instrumental method for turbidity measurement in potable water and wastewater and stipulated an angle of detection of 90° to the incident light path. The NTU nomenclature is used in the 14th edition of Standard Methods for the Examination of Water and Wastewater, 1976, and subsequent editions, including the 21st edition, 2005. Calibration of Hach turbidimeters always has been based on Formazin; a polymer suspension almost universally accepted in the water industry and associated industries as the primary reference standard. All other turbidity standards, including the stabilized Formazin, SDVB and PSL composites are ultimately traced to primary Formazin.

The length of the straight portion of the response curve is dependent upon the length of the total light path of the turbidimeter sample cell or chamber. The average light path in the simple nephelometer of Figure 1 is illustrated in Figure 3. The total average light path can be seen as $0.50 + 0.50$ inch ($1.3 \text{ cm} + 1.3 \text{ cm}$) or 1 inch (2.54 cm). If the cell dimensions are altered and, correspondingly, the cross section of the light beam is altered, the light path can be lengthened or shortened as much as required. The response of nephelometers of various light paths is illustrated by Figure 4.

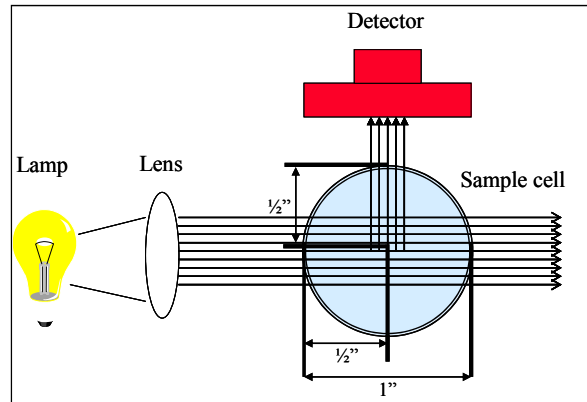


Figure 3: Average Light Path for 90° Nephelometer

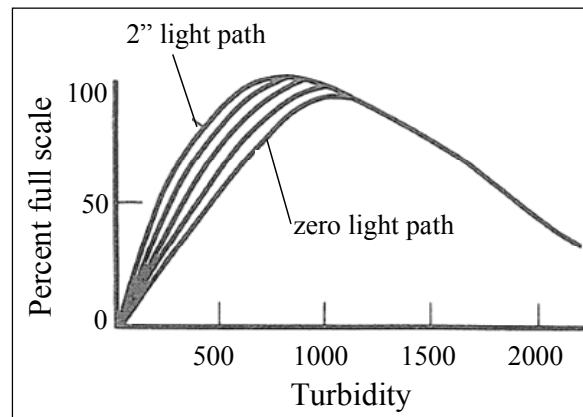


Figure 4: Response Characteristic for Nephelometers of Various Light Paths

In Figure 4, the span of the nephelometer was set up for 0-1000 NTU. As the light path is lengthened, the response linearity decreases in the range of 0-1000 NTU. Also note the curve begins at zero as a linear function in every case and then becomes non-linear as turbidity increases. This is because turbidity of both the sample, and to a lesser extent, the sample matrix of a respective sample absorbs and scatters some of the incoming light. This diminishes the strength of the incident light beam as it penetrates the sample, thereby decreasing sensitivity of the instrument.

There is less light to be scattered from the part of the sample in the view volume of the photocell. In addition, some of the light scattered by the turbidity is absorbed by the sample turbidity as it emerges from the cell, further reducing the light reaching the photocell. Consequently, in order to obtain a full-scale meter reading at 1000 NTU (when using a cell of long light path), the sensitivity of the instrument is increased (through amplification of the detection system or through a stronger light source or a longer path length or a combination of all three) to a higher level than would be the case if the light path length were short. This results in an exaggerated response of the meter for turbidity values of less than 1000 NTU. Thus, a non-linear response curve is obtained.

Note, too, as the turbidity increases (Figure 4) using the cells of long light path, the response curve becomes flat. As turbidity continues to increase, the response decreases and finally approach a low and non-responsive value at a very high turbidity. Termed "going blind," this occurs when the turbidity becomes so high the light beam is completely absorbed and scattered away from the view volume of the detection system.

Stray Light

The stray light of an optical system also must be considered because it is a significant source of measurement error at low turbidity levels. Stray light reaches the photocell because of reflections from all sources other than the sample (illustrated in Figure 5).

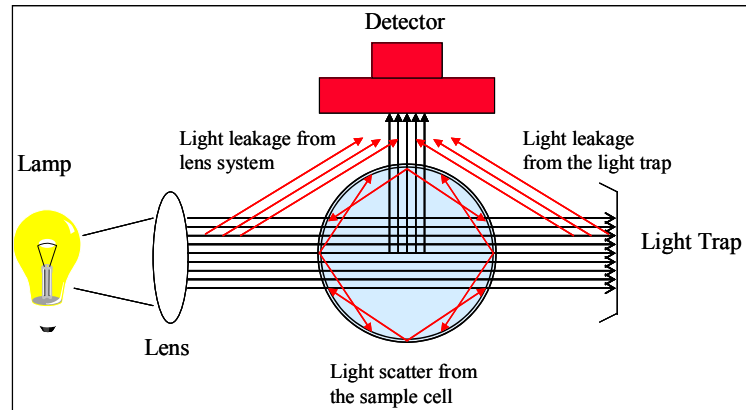


Figure 5: Sources of Stray Light

Turbidimeter design must minimize sources of stray light from scattering or reflecting to the detector from any surface of the optics, enclosure or other fixtures, fittings or accessories. One problem in quantifying stray light is uncertainty as to whether absolutely pure water scatters light – thus has turbidity. It now is widely accepted that pure water does scatter light – hence pure water has turbidity. Many attempts have been made to quantify the turbidity of pure water. Current evidence suggests the value may be well below 0.007 NTU.

Maintenance Challenges for On-line Turbidity Measurement

Minimizing maintenance of instruments for on-line turbidity measurements presents a major challenge. Convenience of continuous monitoring can be offset quickly if frequent maintenance is required. Problems can occur with laboratory or portable turbidimeters as well. Among them are:

- Dirty and damaged sample cells
- Cells which are not perfectly round
- Damage to the instrument if the sample is corrosive
- Time-consuming, difficult procedures for calibrating the instrument
- Maintaining sample cells in good condition, free from dirt and sediment, is a time-consuming task.
- Sample cells can be scratched and broken during cleaning and handling.
- Fogging of outside surfaces also can be troublesome.
- Entrained air bubbles can cause false high and erratic measurements.
- Process instruments using sample cells are susceptible to the same problems encountered with laboratory instruments.
- Process instruments are susceptible to changes in flow and pressure which can create false positive and negative spikes.
- Samples with rapidly settling particulates of high densities are difficult to measure. Agitation to suspend such material introduces air which will cause false positive results.

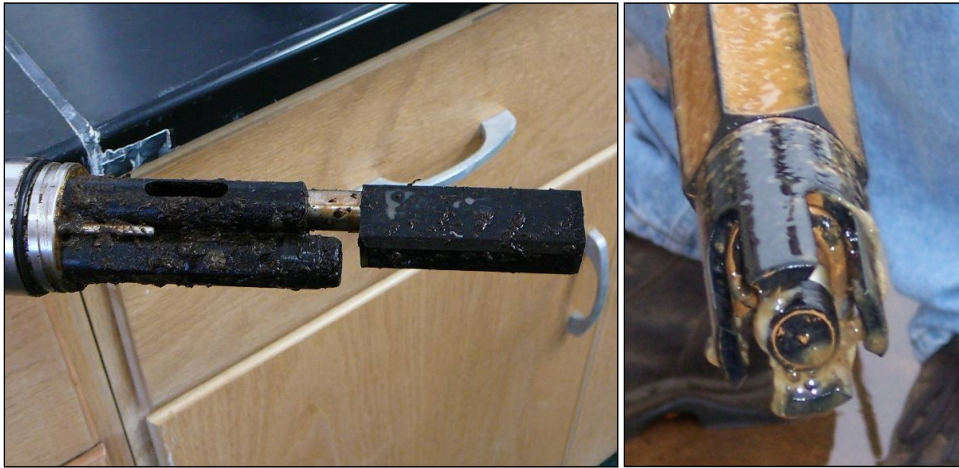


Figure 6: Sensors immersed in the sample

Sensors in contact with sample can become fouled with plant debris, mineral deposits, biofilms and live organisms. The surface scatter design eliminates all contact of the sample with the instrument's optics.

These conditions can either prevent light scattered by the sample from reaching the detector or can increase stray light, a major factor contributing to measurement errors.

Measuring samples presenting corrosion problems, severe scaling or build-up of biological growths and films can provide major challenges. These conditions cause difficulty when using an instrument with a sample cell. The best possible solution for these conditions would be to make measurements without a physical sample cell and without the sample contacting any part of the optical system—the light source, focusing lenses or photo detector. Corrosive samples also can give off corrosive vapors. Accordingly, all electronic parts must be sealed or housed in a remote enclosure. Even high humidity can cause severe corrosion of electronic parts.

The ease of calibration and degree of accuracy achieved are primary factors in any instrument maintenance protocol. Calibration of an on-line turbidimeter must be:

- with primary standards
- accurate
- rapid
- easy to complete
- verifiable with secondary standards

Surface Scatter Principle

The patented² turbidimeter design—termed Surface Scatter—is based on a principle developed in the glass industry, the float process.³ In the Surface Scatter design, see Figure 7, water enters an inclined tube (the turbidimeter body) about halfway between the surface and the bottom and flows upward, overflowing a broad-crested weir around the top of the body to form a nearly perfect level liquid surface. Light from the instrument lamp is projected to interface near the center of this flat surface. A photo detector positioned above the surface at 90° to the centerline of incident light path detects scattered light. The term *surface scatter* is derived from this positioning of the light source and photo detector. The instrument does not measure light scattered from the surface, as will be explained below.

² U.S. Patent No. 3,309,956

³ In this process, molten glass is poured upon the surface of a molten metal. Both top and bottom surfaces of the glass attain a high finish and brilliance, better than that achieved by grinding or polishing.

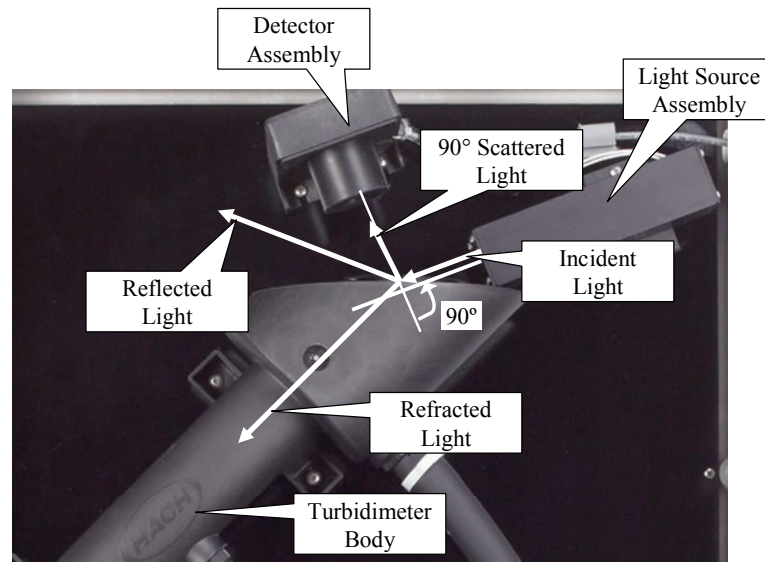


Figure 7: Surface Scatter Optical Design Diagram

Optical Design

The light source, operating at a color temperature of approximately 2200 - 3000°K, is directed at the surface at an angle of 70° relative to the level surface of the sample. The photo detector, with a peak spectral response of 540 nm, is positioned above the surface.

The angle of the light source relative to the turbidimeter body is such that as the incident light reaches the water surface the majority of the light is refracted and the beam enters the water parallel to the inclined turbidimeter body. Light not scattered by particles is trapped by the turbidimeter body thus minimizing stray light. A very small amount of the light is reflected away from the detector and into the upper corner of the instrument enclosure where it also is trapped.

The detector assembly is centered at 90° from the centerline of the incident light path to monitor scattered light. However, as Figure 8 illustrates, light is scattered by particles in the sample, not from the surface.

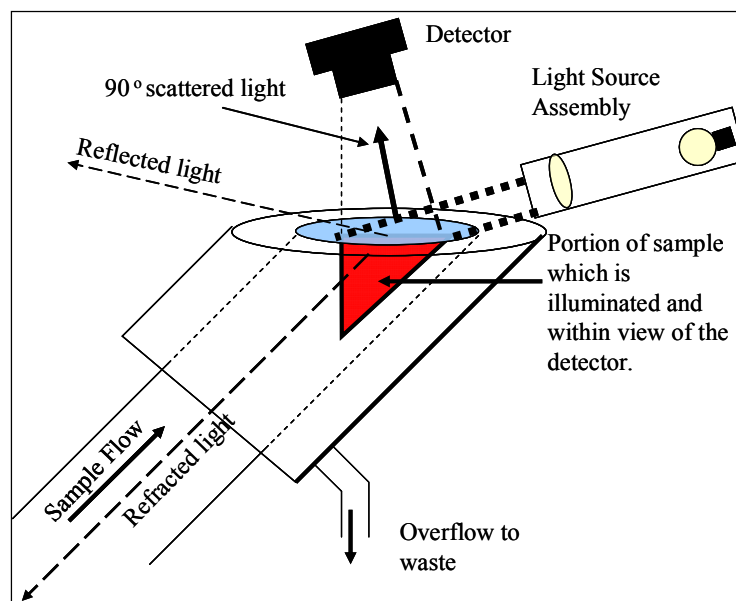


Figure 8: Cross Section of Sample Light Path

A portion of the sample is illuminated. The top of the inclined body forms a broad crested weir. The water overflowing the weir forms a convex pool of water 'behind' the weir. The center of the pool is optically flat. Incident light from the lamp assembly is focused on this optically flat area. Maintaining a flow of one to two L/min is critical to maintain the height of the water surface in relation to the incident light beam. If the flow is too high or too low, the light beam will not fall on the proper position to create the view volume needed for accurate measurements. A light source alignment template is supplied with the instrument to properly align of the lamp assembly after maintenance to the light source assembly.

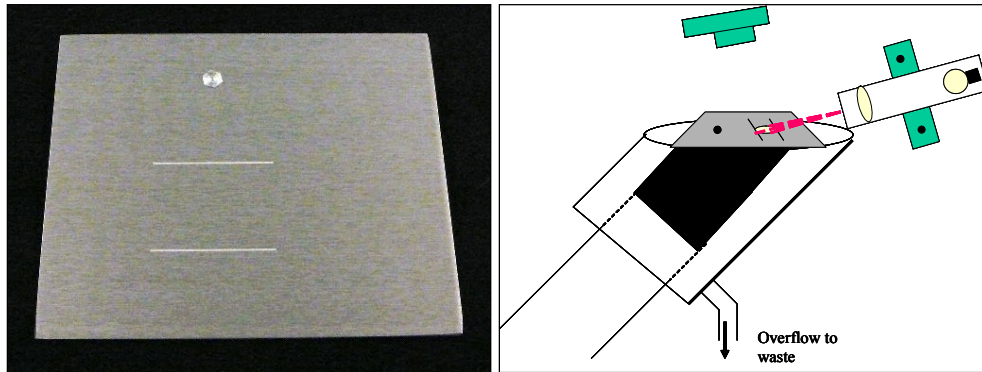


Figure 9: Light Source Alignment Template

After the lamp is changed or other maintenance is performed on the light source assembly the lamp alignment is checked and reset as needed by first inserting the calibration cup. Then, the Light Source Alignment Template is placed on top of the calibration cup as illustrated and the assembly adjusted to center the beam on the lines etched on the plate.

The maximum total light path (incident plus scattered light) in the view of the detector never exceeds 1.6 inches (4.06 cm). This maximum light path would exist only for low turbidity samples. As turbidity increases, the light path decreases until the total light path is a centimeter or less in very turbid water. This automatic 'self-adjusting' light path results in range expansion in much the same way changing from a 1" sample cell to a 1 cm sample cell results in range expansion for a laboratory measurement. Thus, the Surface Scatter Turbidimeter will not go blind as conventional nephelometers do. Range is limited only by the amount of light that can be supplied and by detector sensitivity.

The stray light of the current surface scatter design is estimated to be 0.04 NTU. Since the surface scatter design is intended for higher range environmental and industrial applications, the turbidity of pure water and this level of stray light are not significant. This does not mean the issue of stray light is not important in instrument design and use for the Surface Scatter Turbidimeter. The integrity of the optical design and the instrument enclosure must be maintained or stray light may become a significant source of error.

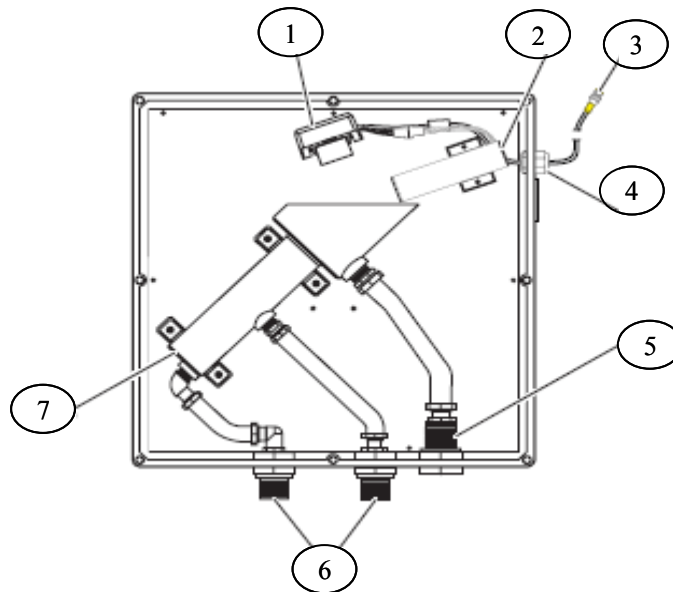
The Surface Scatter 7sc Turbidimeter has a range up to 9999 NTU yet has low range resolution to the nearest 0.01 NTU. The instrument has a remarkable five decades of range. The practical lower limit of the Surface Scatter 7sc Turbidimeter should be considered to be 0.10 NTU. The instrument's wide range capability has led to applications as diverse as detecting formation of frazzle ice (small, needle-like ice crystals) in a river prior to a hydroelectric turbine to monitoring hot, corrosive white liquor in paper manufacturing.

The Surface Scatter design meets requirements of the U.S. EPA method 180.1 and thus is acceptable for reporting for the Safe Drinking Water Act and Clean Water Act. See Appendices B and C.

Mechanical Design

The inclined body acts as a trap for solids with high densities and also acts as a light trap to minimize stray light. An upward directional flow rate of 1 to 2 L/min (0.26 to 0.52 gallons/min) is sufficient to carry particulate material (air bubbles, scum, biological matter) to the surface where it quickly and evenly disperses through the view volume of the optical path then flows into the overflow to waste. This upward flow design prevents errors that are due to rapid settling of particulate materials and maintains sample homogeneity through the view volume of the instrument.

Conventional windows and sample cells have been eliminated. Thus, problems (scratches, dirt, fogging, etching, condensation and contamination by biological growths) that often occur on surfaces that are in contact with the sample have been eliminated. The sample never comes in contact with the optical components.



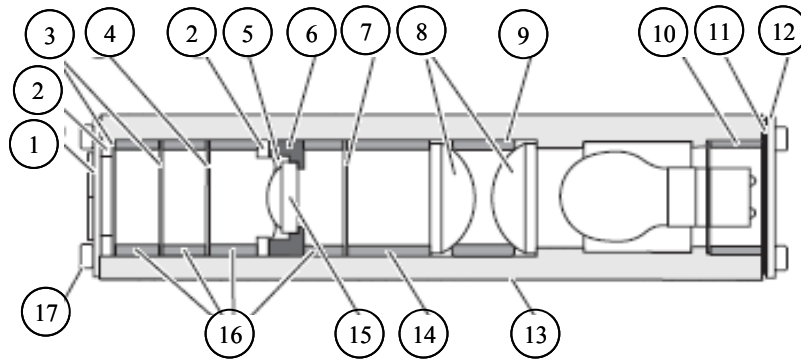
1. Detector assembly	5. Bulkhead fitting, 1" NPT
2. Light source assembly	6. Bulkhead fitting, 3/4" NPT
3. To sc Controller	7. Turbidimeter body
4. Cord grip	

Figure 10: Sample Unit

Potential for corrosion has been reduced to a minimum. The turbidimeter body, a single piece of molded polypropylene, is housed in a rugged NEMA-12 plastic enclosure. All fittings are made from PVC or polypropylene and tubing material is neoprene. Materials used for metallic parts are anodized aluminum or stainless steel. An air-purge connection is provided on the enclosure so an inert gas or instrument-quality air can be provided to purge excess moisture or corrosive gases.

This portion of the instrument, called the Sample Unit, contains few electronic parts: the lamp assembly and detector assembly (photo detector and an A/D converter).

The light source assembly is constructed of an anodized aluminum body with anodized aluminum spacers and aperture plates and glass lenses to collimate and focus the light beam. The incandescent lamp, also housed in the lamp assembly, provides sufficient heat to prevent water vapor or corrosive vapors from condensing on the lamp assembly. The Detector Assembly is heated to prevent condensation from interfering with sample measurement.



1. Shield assembly	10. Spacer, light source
2. Wavy washer	11. Gasket
3. Medium aperture	12. End plate
4. Large aperture	13. Body
5. Retaining ring	14. Large spacer
6. Lens holder	15. Small lens
7. Small aperture	16. Small spacer (4x)
8. Large lens	17. Screws
9. Medium spacer	

Figure 11: Surface Scatter Light Source Assembly

The A/D converter and detector are permanently potted in the Detector Assembly to prevent corrosion from water or other vapors emanating from the sample. All other electronic components are housed in a separate controller. The sealed A/D (analog to digital) converter in the Sample Unit makes it possible to position the Control Unit up to 31.5 feet (9.6m) away. All power received by the Sample Unit comes from the controller. The SC100, SC200 or SC1000 controllers may be used with the Surface Scatter 7sc Turbidimeter.

Caution: The Surface Scatter Turbidimeter is not designed for use with samples that are flammable or explosive in nature. If any sample solution other than water is used in this product, test the sample/product compatibility to assure user safety and proper product performance.

Caution: The Surface Scatter Turbidimeter is not intended for installation in hazardous locations. Contact Hach Company's technical support for application assistance if monitoring in a hazardous location is anticipated.

Electronic Design

Other perplexing problems associated with on-line turbidity measurement—the need to change measurement range, maintaining accuracy over the entire range and dealing with transient sample conditions—can be solved by using the electronics package. An important electronics package function is providing auto-range display from 0 to 9999 NTU while assuring the displayed value is correct. As turbidity increases, response from the photo detector will level off. See Figure 12. However, calibration data are stored permanently in the instrument memory. A microprocessor performs transformations of the calibration data to provide a linear response over the entire range.

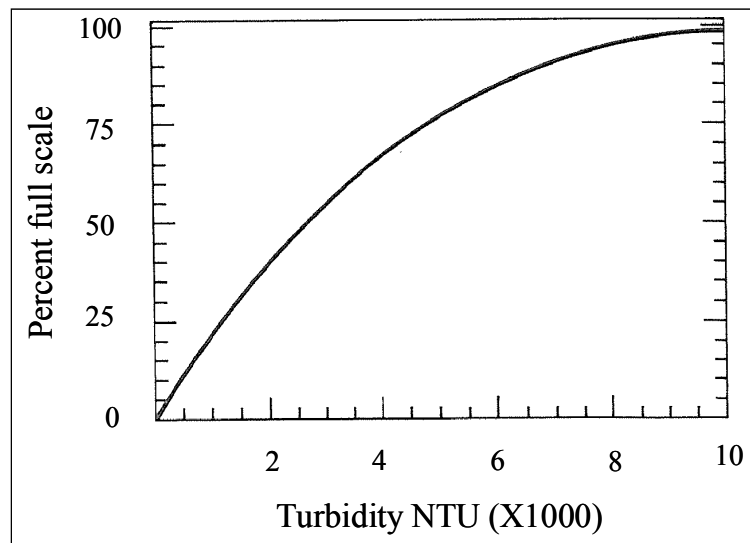


Figure 12: Typical Response Characteristics for a Surface Scatter Turbidimeter

Signal Averaging and Bubble Rejection Methodology

Transient sample conditions such as entrained air and isolated particles can cause momentary turbidity reading spikes, which are not representative of the sample turbidity. These interferences can increase measurement noise and cause false positive turbidities that can set off alarms. Combinations of signal averaging and bubble rejection signals from the Surface Scatter can counter these transient conditions. See Figure 13.

The microprocessor accumulates data at a rate of five to 10 readings per second into a one-second buffer which is the fastest response time of the instrument. This is the condition when signal averaging is turned off. However, the operator can program the instrument for 6-, 30-, 60- or 90-second signal averaging. For example, in 6-second signal averaging, the last six seconds worth of data received, which accounts for a total of six measurements - are averaged to produce the displayed result. Ninety-second signal averaging uses the last 90 one second readings to produce the displayed result. Ninety-second signal-averaging also provides the smoothest output while 6-second signal averaging displays show some transient spikes. If the instrument is to have alarm settings, it is recommended that a level of signal averaging be used, which is dependent on the sample's respective characteristics.

The bubble rejection feature can be turned on or off by the operator. When the bubble rejection feature is on, and the top 40 percent of the highest measurements are discarded, the remaining readings are averaged to generate the displayed value. The displayed value also is dependent on the signal averaging level that is selected. This feature is especially useful if out gassing is an issue and the recommended bubble trap fails to effectively scour all bubbles from the sample prior to entering the instrument.

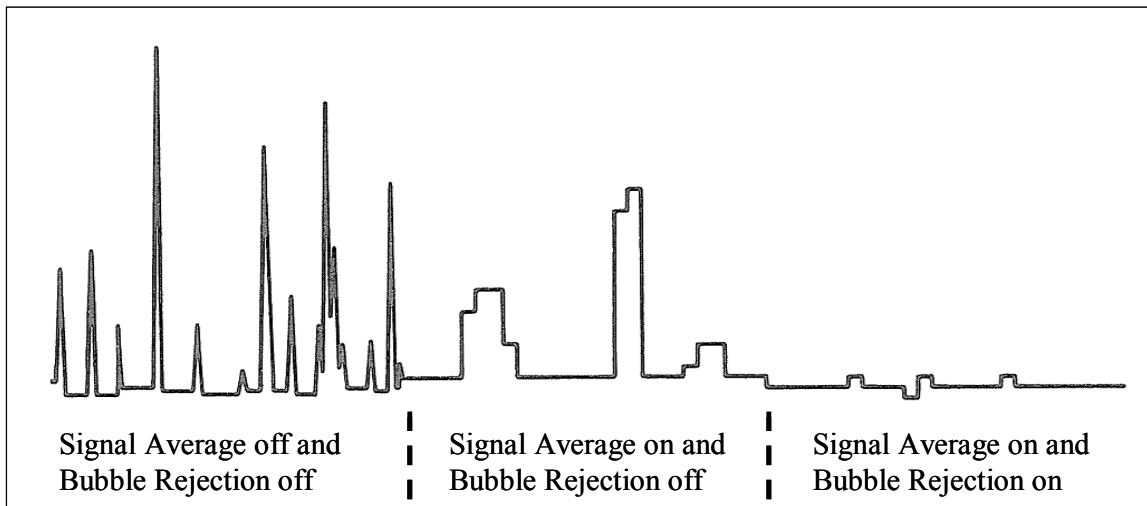


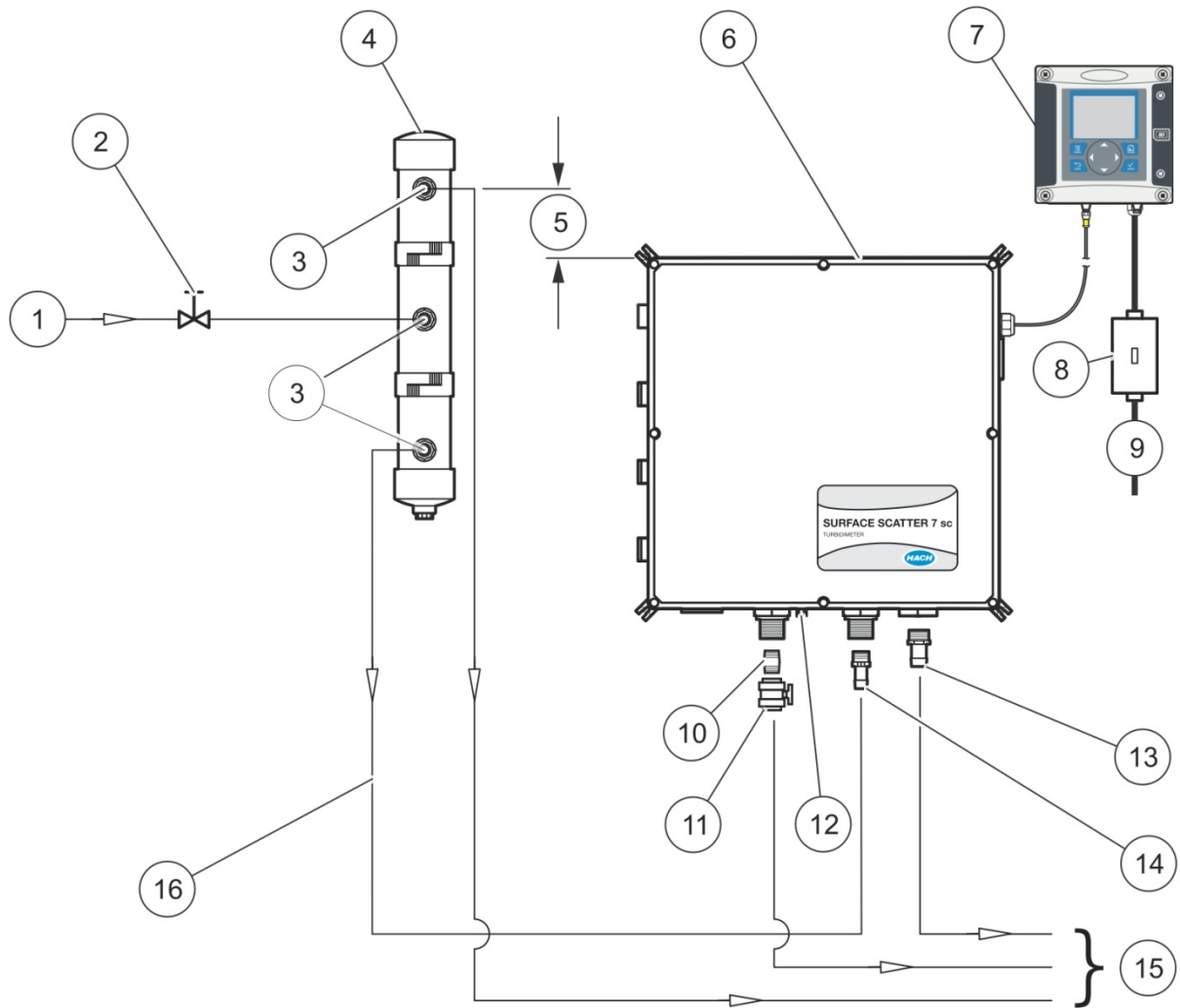
Figure 13: Effect of Signal Averaging and Bubble Rejection

Overcoming Severe Entrained Air and Variable Sample Pressure

The electronic bubble rejection algorithm described above may not be able to overcome problems with severely entrained air. The importance of maintaining proper flow has been discussed. When either variable flow rates and/or significant problems with entrained air exist, a single device can be used to further resolve both problems.

A Bubble Trap (also known as the Bubble Trap/Head Regulator) is recommended if the sample cannot be delivered bubble-free to the analyzer. The device may also be used as to dampen fluctuations in flow due to pulses from a pump and/or sample pressure.

Using the Bubble Trap/Head Regulator will increase response time to changes in sample concentration. This will increase the response time to between 1–2 minutes at 2 L/min flow rate. For fastest response time, use the highest flow possible that results in effective bubble removal. Higher flows decrease the effectiveness of bubble removal. The need for fast response time and bubble removal must be balanced for optimum performance.



1. Sample in	9. Power in for controller
2. Flow control valve (recommended)	10. 3/4" NPT nipple (supplied)
3. 3/4" NPT x 3/4" ID Hose Adapter (supplied with bubble trap)	11. Ball valve (supplied)
4. Bubble Trap/Head Regulator (optional)	12. 1/4" air purge fitting (50SCFH Instrument air, max)
5. 5" (127 mm) minimum outlet height above the SS7	13. 1" NPT nipple (supplied)
6. Sample unit	14. 3/4" nipple (supplied)
7. sc200 Controller	15. To drain
8. Customer supplied power on/off switch box (recommended – NEMA 4X) required for agency compliance.	3/4" ID hose (customer supplied)

Figure 14: Plumbing diagram for Bubble Trap and SS7 Turbidimeter

Smart Sensor Design and Controller Options

On-line process measurement is of little value if the operator doesn't have access to the data for recording or remote display. If an operator's choice of outputs is limited, so is operational flexibility. The Surface Scatter 7sc Turbidimeter is part of the Hach Company family of 'smart sensors.' All information about the sensor itself (instrument diagnostic information, calibration data, etc.) is stored in the measurement unit, in this case the Sample Unit of the Surface Scatter 7sc Turbidimeter. All functions to interface to the outside environment— analog outputs, and digital outputs, alarm relays, display—are provided through one of a family of controllers dubbed the sc-family of controllers including the SC100, SC200, and SC1000 controllers.

The controllers available for the Surface Scatter 7sc Turbidimeter provide single-pole double-throw (SPDT) alarm relays and analog recorder outputs as standard features. The operator has the flexibility to transmit important operating data to remote locations in the form most convenient for the particular application. A variety of digital outputs including RS485, Modbus, HART, and Profibus also are available. Call Hach Company for the most current list of digital outputs protocols.

Recorder and alarm settings are made by the operator from the instrument keypads. See the instrument manuals for the respective controllers for complete instructions.

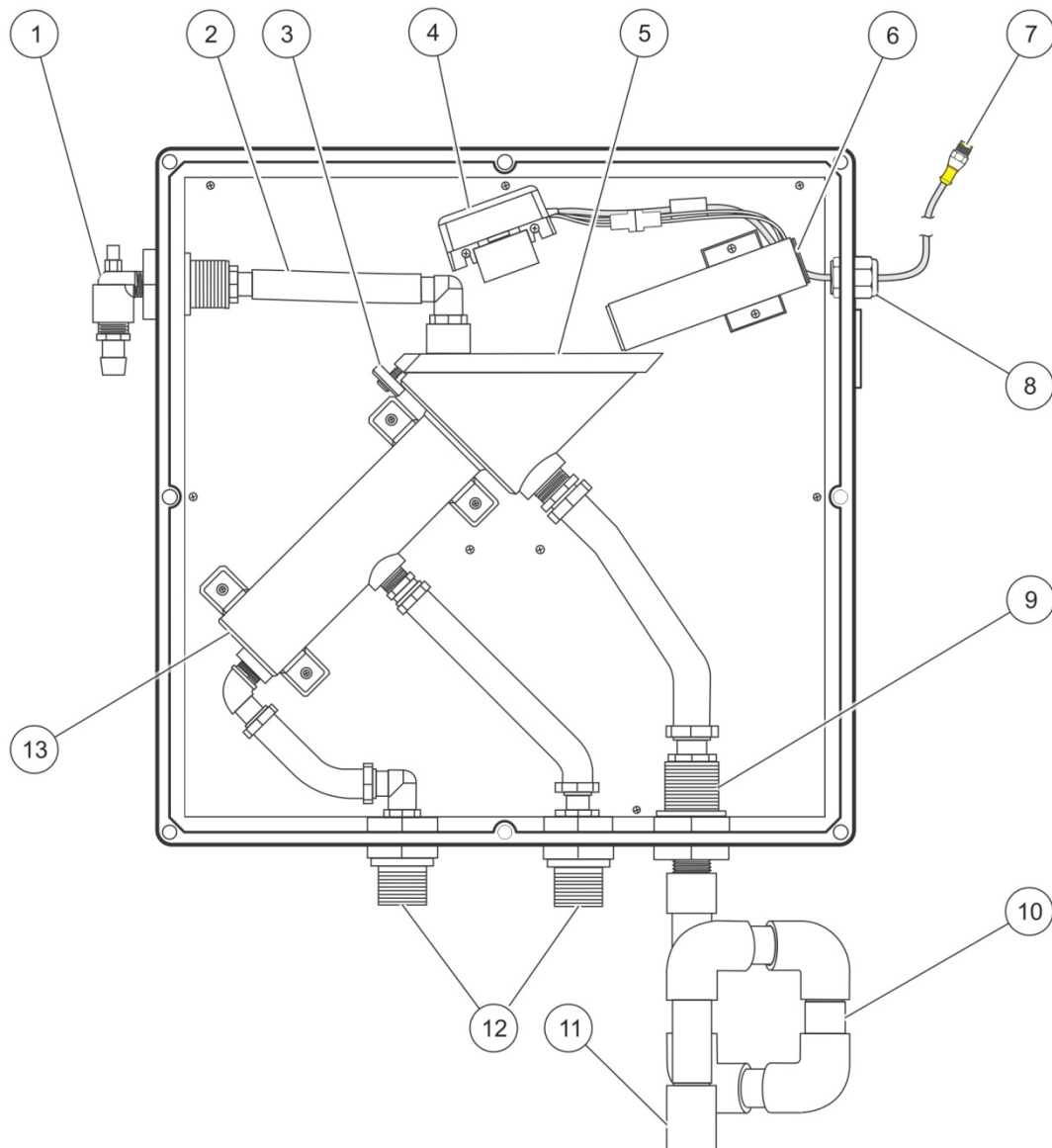
Two Sample Unit Configurations Available

The standard configuration illustrated in Figure 10 is suitable for most municipal water, wastewater, and environmental samples, and for many industrial water applications. However, very hot samples or samples with a high amount of corrosive vapors (i.e. white liquor from pulp processing or other industrial samples) may require the High Sample Temperature (HST) version—the SS7sc-HST

The SS7 sc-HST instrument is designed for high temperature samples or in applications where a significant difference between the sample temperature and the ambient temperature causes condensation and fogging inside the unit. The SS7 sc-HST functions in the same manner as the SS7 sc, but accommodates samples of higher temperature and a moist air removal system has been added.

The moist air removal system contains an air flow multiplier that creates a vacuum to draw moisture away from the sample tube and remove the moisture from the enclosure. The moisture removal system requires the customer to provide a source of air pressure, such as compressed air, shop air, or an on-site air compressor. The air line is connected to the top of the flow multiplier (Figure 15, item 1).

An optional 316 stainless steel heat exchanger (sample cooler) is available for the SS7 sc-HST (Figure 16). The heat exchanger reduces sample temperatures that exceed the temperature requirements of the instrument. It can reduce sample temperatures of up to 100 °C. It is not suitable for steam or superheated water. A source of cooling water is required. The heat exchanger has $\frac{3}{4}$ " MNPT pipe connections. The large plumbing connections help eliminate plugging.

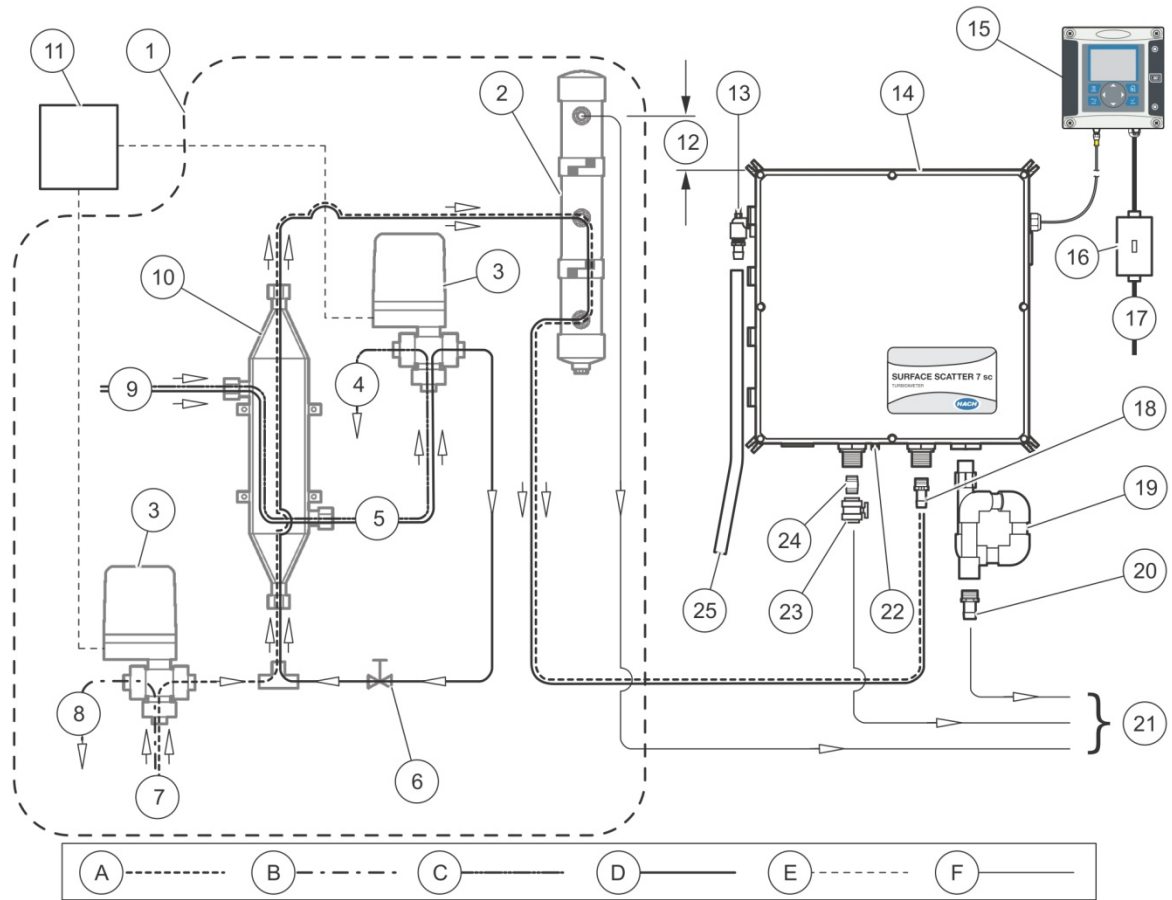


1. Flow multiplier	8. Cord grip
2. 3/4" hose	9. Bulkhead fitting, 1" NPT
3. Threaded disk with 1/4" screw	10. Drain trap
4. Detector assembly	11. 1" NPT gravity drain
5. Vent cover	12. Bulkhead fittings, 3/4" NPT
6. Light source assembly	13. Turbidimeter body
7. Cable to sc Controllers	

Figure 15: SS7 sc-HST Configuration

High Solids Samples

Certain environmental and industrial water samples may contain high solids levels and debris that can plug sample lines or the heat exchanger (see **Two Sample Configurations**, above). An Auto Flush Kit has been developed to automatically back flush sample lines. One of the alarm relays in the sc Controllers can be configured to automatically activate the auto flush system. When activated, the current turbidity measurement signal is held until the system returns to normal operation. The auto flush kit contains the manual and automatic valves necessary to assemble the system as pictured below. The system in Figure 16 is shown with an optional Bubble Trap/Head Regulator (2) and an optional heat exchanger (10).



1. Optional items	14. Sample unit
2. Bubble trap	15. sc200
3. 3-way ball valve (auto flush kit)	16. Customer supplied power on/off switch (NEMA4X) as required for agency compliance
4. Cooling water to drain	17. Power in for sc200
5. Cooling water out	18. 3/4" NPT adapter (supplied)
6. Flow control valve	19. Drain trap (customer supplied)
7. Sample in	20. 1" NPT adapter (supplied)
8. Sample bypass during flush cycle	21. To drain
9. Cooling water in	22. 1/4" air purge fitting (50 SCFH instrument air max.)
10. Heat exchanger (sample cooler)	23. Ball valve (supplied)
11. Electrical connection box	24. 1/4" NPT nipple (supplied)
12. 5" (127 mm) minimum	25. Hose to drain (customer supplied)
13. Customer supplied air to flow multiplier	

A. Sample during normal operation	D. Cooling water during auto flush
B. Sample bypass during auto flush	E. Electrical
C. Cooling water in normal operation	F. Drain

Figure 16: Sample system for hot, corrosive or high solids samples

Configuring the Auto Flush Kit with the sc200

In order to configure the Auto Flush kit with the Surface Scatter 7 and sc 200, follow the wiring diagram presented in Figure 17 and then use the directions below to configure the controller. The flush cycle length and interval should be determined by the amount of solids built up in the system.

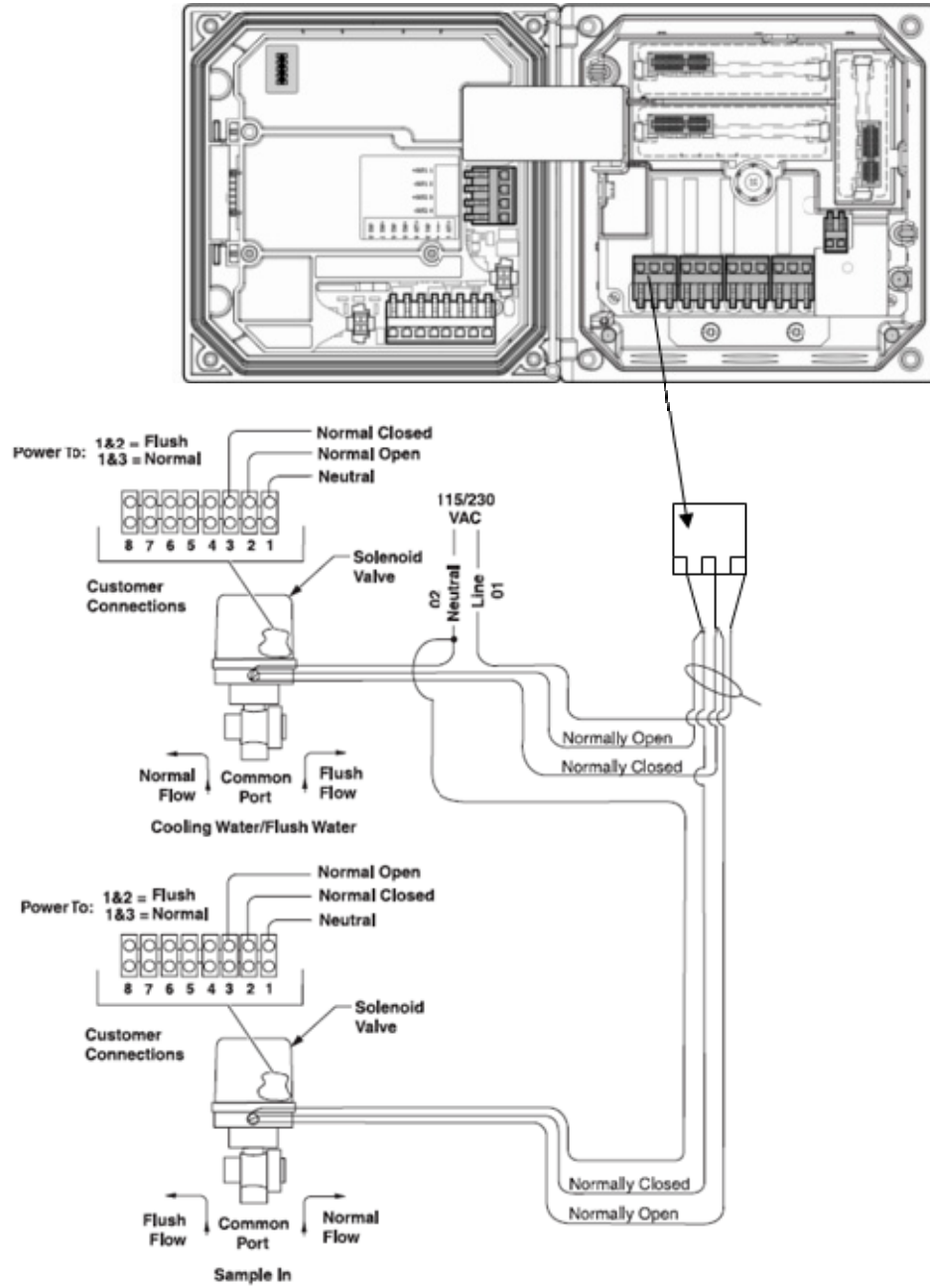


Figure 17: Configuration of the sc200 for auto flush operation

Once the relay connections have been made, follow the instructions below to set up the sc200 relays to control the auto flush valves.

1. Press the Menu button on the front of the controller.
1. Press the down arrow to move the cursor down to select sc200 Setup
2. Press the down arrow to move the cursor down to select Relay Setup
3. Choose to operate the auto flush valve with Relay A, B, C, or D, and then press enter
4. Move the cursor to Select Source and press enter
5. Choose the sc200 and press enter
6. Move the cursor down to select Set Function
7. Choose Scheduler and press enter
8. Move the cursor down to select Set Transfer
9. Choose Inactive and press enter
10. Move the cursor down to select Fail Safe. Select No.
11. Move the cursor up to choose Activation and press enter
 - a. Select Hold Outputs and press enter
 - b. Select Set Outmode and press enter
 - c. Select Hold Outputs and press enter
 - d. Select Set channels and press enter
 - e. Choose None and press enter (measured value will be output on a 4-20 mA loop)
 - f. Press the Back button
 - g. Select Run Days (Choose the days of the week you want auto flush cycle to run. Ensure date and time are correct on controller before setting this) and press the Back button
 - h. Choose start time (entered in 24 hour time using up/down/left/right keys) and press enter
 - i. Choose interval (Time of 0-999 minutes in between flushes) which is entered in with up/down/left/right keys then press the back button.
 - j. Choose duration (flush cycle length of 0-999 seconds) by entering in desired time using the up/down/left/right keys and press enter.
 - k. Choose Off Delay and set it to 0 seconds.
 - l. Press the Home button to return back to the measurement screen.

The flush cycle length and interval should be determined according to the amount of solids built-up in the system.

Determining Correlation of Turbidity Measurement to Suspended Solids

Measurement of total suspended solids (TSS, nonfilterable residue) is important in many industrial samples. Chemical or physical changes in the process may result in filter breakthrough or an increase in turbidity of clarifier effluent leading to process contamination or violation of a discharge permit. Thus, the monitoring of solids yields critical information about the efficiency and quality of an industrial process. Solids analyses, usually completed by gravimetric methods, can offer challenges including:

- It may be difficult to obtain a representative sample.
- The gravimetric analysis procedure is time consuming - typically taking two to four hours or more to complete.
- Indeed, the gravimetric solids test will tell the operator there is a process problem but, by the time the operator knows this, the problem cannot be corrected easily. This leads to costly down time and repairs to fix the problem.

- Techniques in sampling and measurement are important in the gravimetric procedure.
- The sampling procedure must be consistent from one time to the next in order to obtain useful and reliable results.
- The sample must be large enough and sufficiently well mixed to make sure it is representative.
- A grab sample is merely a spot check of the process at a particular point in time. A grab sample will not provide information about the direction of movement of the solids within the process itself, which is a key piece of knowledge for recovery of the respective process.

It is reasonable to want to use a surrogate method for solids testing. Measurement of turbidity with a Surface Scatter Turbidimeter has been used in a variety of industrial samples as a surrogate for gravimetric solids determination. However an acceptable correlation will not always be found. A laboratory procedure, described below, has been developed to determine whether an acceptable correlation can be established between turbidity and solids on a given sample. The procedure, Hach Method 8366, is available for free download from the Hach Company website: www.hach.com.

It will be impossible in nearly all samples to make a quantitative conversion from turbidity measurement in Nephelometric Turbidity Units (NTU) to mg/L of solids. However, it is usually possible to establish sufficient correlation in most samples to be confident that trends in turbidity measurement are representative of trends in solids content.

Conventional turbidimeters employ a single detector positioned at 90° from the incident light path. Measurement with the single detector will become less sensitive if solutions are highly colored, contain light absorbing particles (i.e. activated carbon) or are very turbid. Each of these conditions will decrease the amount of scattered light which can reach the detector. They are negative interferences - the measured turbidity will be low. Turbidimeters with multiple detectors used in combination typically provide accurate measurements even in the presence of color, light absorbing particles or high turbidity. Multiple detector systems will extend the turbidity measurement ranges as well. These types of instruments are commonly referred to as "ratioing" instruments.

Because these interferences are likely to be present in many industrial samples, a laboratory ratioing instrument should be used in most studies of suspended solids versus turbidity. Once the sample has been studied, and found that turbidity measurement can serve as a surrogate for solids content, the next step is to determine if an instrument such as the Surface Scatter 7sc Turbidimeter can be used for process control measurements.

Note: Refer to Hach Company publication 7061, Turbidity Science, for a detailed explanation of the ratioing technique. It can be downloaded free of charge from the Hach Company web site: www.hach.com.

Obtaining a representative sample may be the most important consideration. The sample must be homogeneous. And, the grab sample must come from the actual process stream. Efforts to establish a correlation on a contrived sample (laboratory synthesized, laboratory simulated, etc.) will not be successful. Sample variables may determine the type of instrument appropriate for use and the sample conditioning steps which may be necessary prior to measurement.

The turbidimeter ideally should have wide measurement range so the sample can be monitored without dilution. Dilutions may be used. However, samples requiring dilution will take more time to measure.

Accordingly, the response time to changes will increase. And, dilutions will not always be representative of the original concentration as particles suspended at the higher concentration by dissolve as the dilution increases.

The sample to be used in the correlation study must fit several criteria:

- The sample must be miscible to the point that dilutions of the sample can be made.
- Viscous samples may be difficult to monitor because entrained gas bubbles cannot be easily removed.
 - Gas bubbles scatter light and cause a false high turbidity reading.
 - Degassing by use of vacuum may be ineffective.
 - Degassing by use of ultrasound may simply 'fracture' the gas bubbles and further aggravate the interference.
- The sample cannot possess any excessively buoyant particles.
- Samples cannot be filtered. (This would not be a representative sample.)
- Each sample is site-specific. Thus, correlation established on a sample from one site may not be applicable to a sample from another site either within the same plant or between plants.
- If possible, the most concentrated level of sample should be obtained to gain an understanding of the upper range measurement characteristics of the sample under investigation.
- Sample temperature is critical to a successful correlation.
 - The less sensitive the sample is to temperature, the more consistent the correlation will be over time.
 - A temperature profile for the sample should be used to determine whether temperature will lead to changes in the composition of a sample that could lead to erroneous results.
 - If the nature of a sample is temperature-sensitive, this correlation may become more difficult to accomplish or it may even be impossible to determine.
 - Ideally, sample temperature during turbidity measurement correlation study should be the same as the temperature of the process stream.
 - Temperature changes may affect the solubility or settling characteristics of particles in suspension.
- Sample constituents should be well defined.
 - One must know what is in the sample, the chemical reactions in the sample that can change its characteristics and the conditions of the sample that indicate a process problem.
 - One should know what threshold value is required for process control.
 - The more one knows about the sample of interest, the easier it will be to determine correlation between turbidity and solids measurements.
 - The most concentrated level of sample should be obtained so the full response range of the correlation can be confirmed

It may be impossible to achieve a correlation on samples not meeting one or more of the above criteria. Once a sample is identified as suitable for investigation, the procedure for determining the correlation between turbidity and total suspended solids can be sorted into four major steps:

1. **Sample dilution.** Several dilutions of the sample must be prepared to cover the possible range of TSS for the given sample. These dilutions are to be made with turbidity-free water. The sample must be well mixed when making dilutions. Non-aqueous solutions must use a colorless, particle-free solvent that matches the chemical and physical characteristics of the sample. The most concentrated sample

will provide the broadest range of dilutions and give widest range of correlation for the particular application.

2. **Determining the Total Suspended Solids of each sample dilution.** The gravimetric determination of each of the dilutions of the sample must be determined. Care must be taken to use consistent methodology throughout the entire set of samples.
3. **Measuring the turbidity of each dilution.** The same methodology of sample preparation and measurement must be consistent for all turbidity readings. For example: Each dilution must be inverted the same number of times and the time between mixing and measurement must be consistent throughout the procedures.
4. **The correlation between the turbidity measurements and the gravimetric measurements of the dilutions is determined.** A graph should be prepared in which total suspended solids in mg/L are displayed on the x-axis and respective turbidity is displayed on the y-axis. A least squares (a statistical method to verify the relationship and determine the actual turbidity of a sample to within a certain degree of accuracy) relationship can then be determined. A correlation coefficient of 0.9 or greater indicates a workable relationship of turbidity to TSS for most samples. By graphically plotting this relationship, one can determine the sensitivity of the correlation in order to gain confidence in the correlation. The greater the slope of this correlation, the greater the sensitivity of turbidity to TSS and the better the correlation will be on the sample.

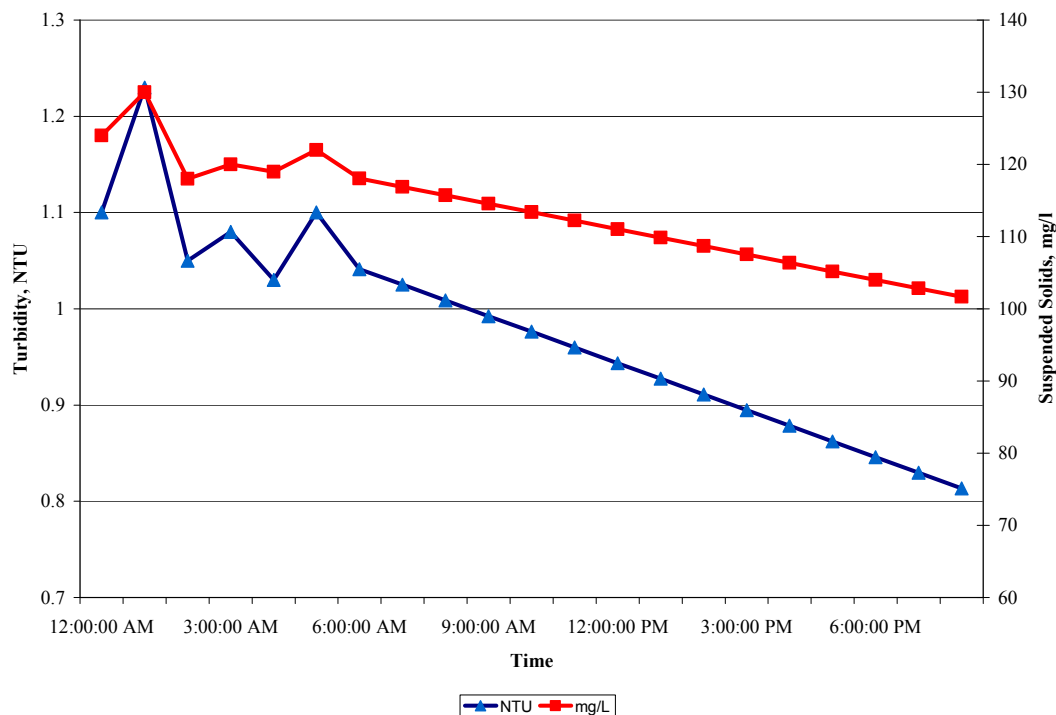


Figure 18: Demonstration of the correlation of turbidity and suspended solids

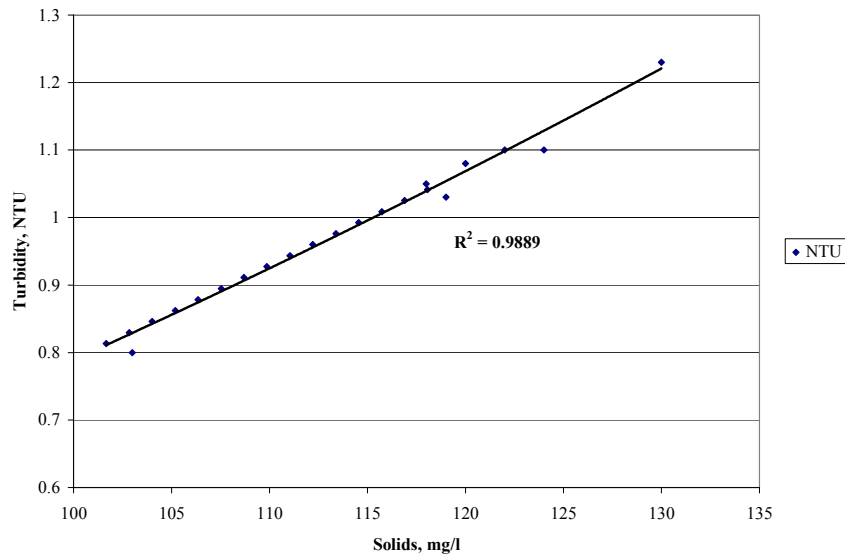


Figure 19: Determining correlation of solids in mg/l to turbidity in NTU

Figure 18 illustrates a data set represented as a line graph (top) and also as a scatter graph. While the lines in the first graph don't appear to have good agreement, the scatter graph illustrates quite good agreement with an $R^2 = 0.9889$.

A turbidimeter can be used as a surrogate measure of suspended solids if sample and instrumental variables can be properly controlled. The keys to obtaining an accurate and reliable relationship between turbidity and total suspended solids are:

1. The sample must be a true representation of the sample stream from which it came.
2. All dilutions must be treated the same throughout the study.
3. Consistent preparation and measurement techniques must be used on each dilution.
4. A well mixed sample and dilutions of the original sample must be used in all sample manipulations (pipetting, measuring turbidity, transferring to sample cells).
5. Environmental conditions must be consistent throughout the test to reduce variability in the instruments and in the sample. When possible, the temperature of dilutions should be the same as the sample will be in the process environment. Dilution water should also be the same temperature as the sample.
6. The correlation study must be done in a timely manner. The longer it takes to perform the correlation study, the more chance exists for the sample, instrument, or environmental changes to occur. Establishing a correlation can be time-consuming. However, the result can save not only time but a significant amount of product and process down-time. The response to a process upset is much faster and the upset is corrected more rapidly, resulting in even greater savings in time, labor and product, if a correlation is established.

The Effect of Color Interference Using the Surface Scatter Turbidimeter

The measurement of turbidity from untreated source water samples such as a surface or ground water source may have some color in them. Color in water causes light to be absorbed. Thus, color in water is a negative interference in turbidity measurements. Hach Company manufactures a number of multiple detector (ratio) laboratory and process turbidimeters, which are effective in compensating for influence of color.

The single detector designs, including the Surface Scatter Turbidimeter, are susceptible to color interference. However, to establish the issue conclusively, tests have been completed to answer the question of whether color affects turbidity measurement on the Surface Scatter Turbidimeter and to what degree⁴. The research was conducted to determine the effect of color on turbidity measurement using the Hach Surface Scatter Turbidimeter.

Five color standards were used in this study: green, red, yellow, blue and brown. The brown color was made from tea and is very representative of several types of real samples (untreated source water from surface or ground water and wastewater). These samples typically contain high levels of dissolved organic materials such as tannin and lignin that impart a tea color to the water. The other four colors came from common food dyes.

The same procedure was then used for the collection of data from all the colored standards as was used for the measurement of a colorless Formazin standard, which provided the baseline for zero interference. Data from the study demonstrate color does cause some interference with turbidity measurement. These results are summarized in Figures 19 and 20. The error in turbidity is negative in all the green, red, yellow, and blue spiked solutions. The magnitude of error between the surface scatter and the ratioing instrument is minimal. The average error was -12.4 percent for the surface scatter and -8.6 percent for the ratioing instrument, an intra-instrument difference in error of only 3.8 percent. See Figure 20. This is the average error over all color, spiked standards in the range of 20 to 1000 NTU. The brown spiked standards had positive error in both instruments. The Surface Scatter had an average error of 12.13 percent and the ratioing instrument had an average error of 24.31 percent over all brown spiked Formazin standards. In the case with the tea-colored samples, the Surface Scatter measurement error was less than the error with the ratioing turbidimeter.

⁴ The original study was completed using the Hach Surface Scatter 6 Turbidimeter and the Hach Ratio[®] XR Turbidimeter. The effect of color on these instruments is a function of the optical design (the number and placement of the detectors, response characteristics of the detectors, color temperature of the light source (wavelength of the incident light) in both instruments and a mathematical algorithm in the Ratio XR. Current production models of these two instruments are the Surface Scatter 7sc Turbidimeter and the Hach 2100AN Laboratory Turbidimeter. Engineering studies during development of the 2100AN were conducted to document response characteristics of the 2100AN vs. the Ratio XR. These studies confirmed nearly identical response characteristics of the two instruments. The Ratio XR contains 90°, transmitted and forward scatter detectors. The 2100AN contains virtually the same detectors in the same location plus one additional detector – a backscatter detector – that has a primary purpose of range expansion to permit measurement of turbidity up to 9999.9 NTU (10,000) in the laboratory. The physical and mechanical changes the Surface Scatter 7 from the Surface Scatter 6 was strictly an electronic upgrade of controller function. The optical configuration – light source, detectors, angle of detection – are identical between the two instrument designs.

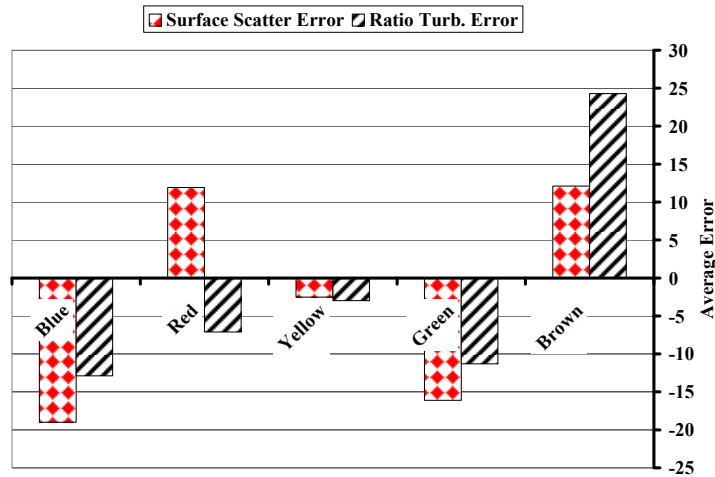


Figure 20: Average error over all standards for each type of color. Blues imparted the largest negative error and brown imparted a positive error in turbidity measurement.

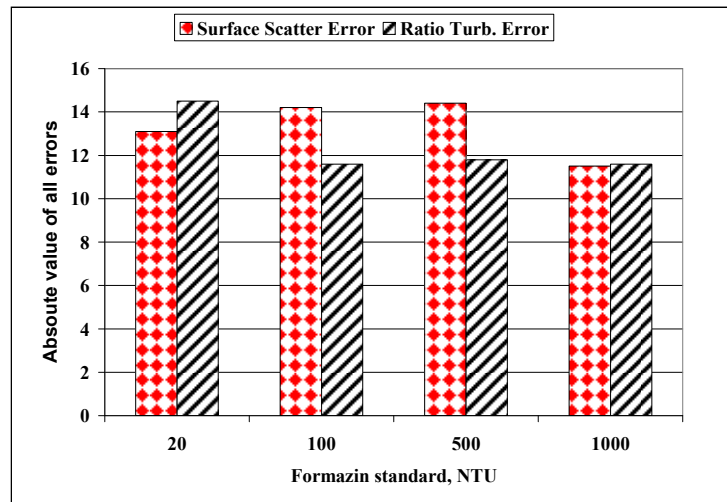


Figure 21: Summary of errors for Formazin spiked with red, blue, green, or yellow dyes.

The amount of color interference on turbidity was also found to be dependent on the type of color causing the interference. Wavelengths responsible for blue color (650 -700nm) caused the most negative interference with both turbidimeters and those wavelengths emitting yellow color (350 - 450 nm) has the smallest effect on turbidity measurements. The brown color (< 500 nm) had very strong positive interference on turbidity measurement with both instruments. Errors in turbidity measurement did not change much over the range of standards tested regardless of which instrument was used. When all the errors for all the colors were averaged together, they all ran within 4 percent of each other throughout the Formazin range tested.

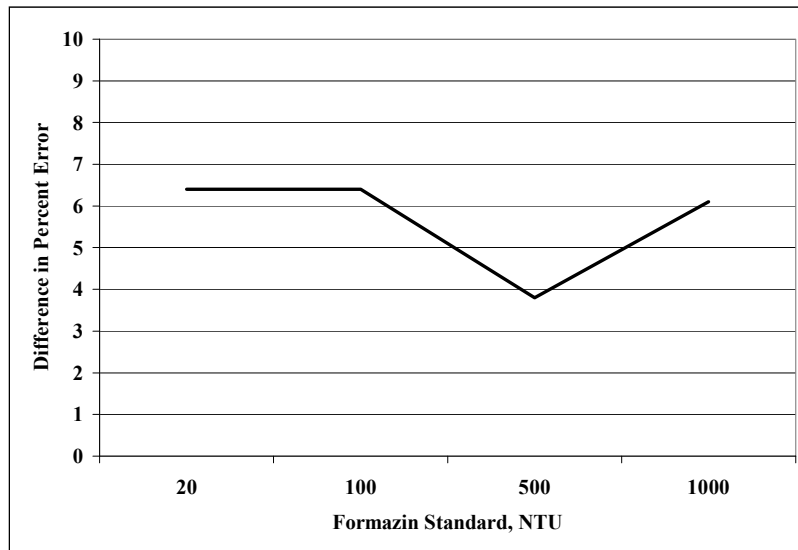


Figure 22: Differences in error between Surface Scatter and Ratio turbidimeters.

Over all, color causes some interference in turbidity measurements whether the ratioing laboratory instrument or the surface scatter instrument was used. However the surface scatter yielded very comparable results to the ratio laboratory instrument on all the colored Formazin standards. Both instruments read within five percent of each other throughout this study. In conclusion, it has been generally accepted that color does cause some small interference when using a ratio turbidimeter, when compared to a typically non-ratio detector design. However, when the surface scatter design is used, its performance was comparable to a ratio turbidimeter design on the minimization of color interferences. Further, the design ultimately will retain adequate sensitivity to turbidity changes in the presence of color, regardless of respective absorbance wavelengths. Since the surface scatter tracks so close to the laboratory ratioing turbidimeter, it could be used for the measurement of turbidity of colored solutions with a high degree of accuracy and confidence.

The Effect of Carbon Using the Surface Scatter Turbidimeter

As with color, light absorbing particles such as carbon are a negative interference in turbidity measurement. Typically, the best means to compensate for the presence of light absorbing substances is measurement with a multiple detector ratioing instrument. Considering the forgoing discussion on effect of color on a surface scatter instrument, it is reasonable to question the influence of particles such as powdered activated carbon, PAC. A study with the Surface Scatter instrument determined light absorbing particles such as PAC have a similar influence on measurement accuracy as with conventional laboratory single-detector, 90° detection systems. Figure 22 illustrates Surface Scatter Turbidimeter response leveling off at approximately 12 mg/l of activated carbon while a laboratory ratioing instrument continues to respond to concentrations of nearly 4000 mg/l.

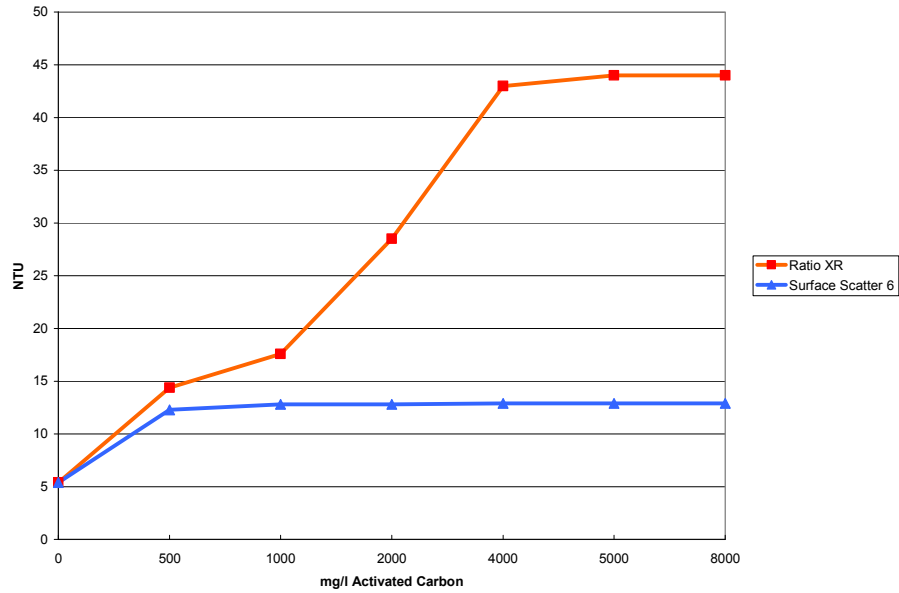


Figure 23: Response comparison of a Surface Scatter Turbidimeter and a laboratory Ratio™ Turbidimeter to activated carbon turbidity in water

Calibration

On-line measurement of turbidity is of little value if accuracy cannot be established, re-established and proven by means of primary and secondary standards. The Surface Scatter 7sc Turbidimeter calibration curve, while not perfectly linear is quite good. The curve can be mathematically modeled to produce a high degree of accuracy over the entire range of the instrument with calibration as described below. A two-point calibration is performed with a zero turbidity point for the first point and a Formazin based calibration standard to set the second point of the calibration. The zero point is performed using the ZERO ELECTRONICS option during calibration. The second point can be set using one of two recommended Formazin turbidity standards: 400 NTU or 4000 NTU. The standard closest to the expected range of measurement of the sample for a given application should be used. That is, if the sample will be consistently less than 2000 NTU, a standard of 400 NTU should be used. If the sample can often exceed or is consistently greater than 2000 NTU, calibration should be performed with the 4000 NTU solution.

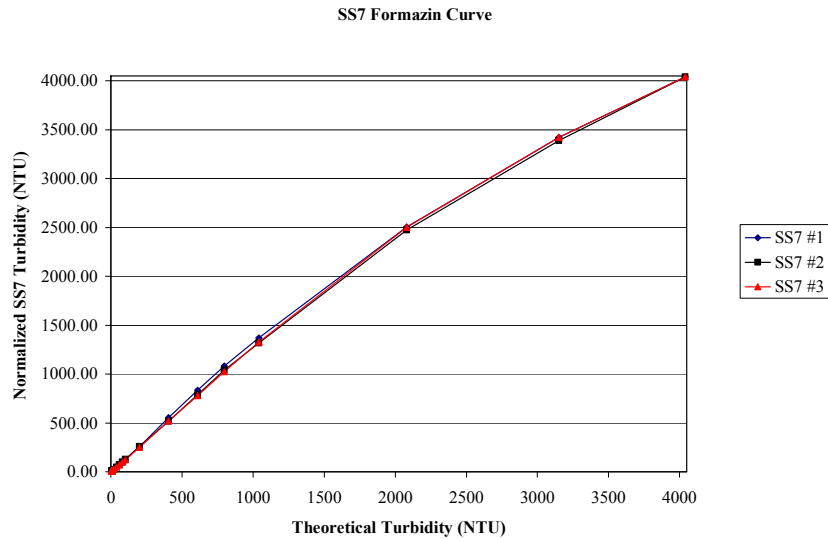
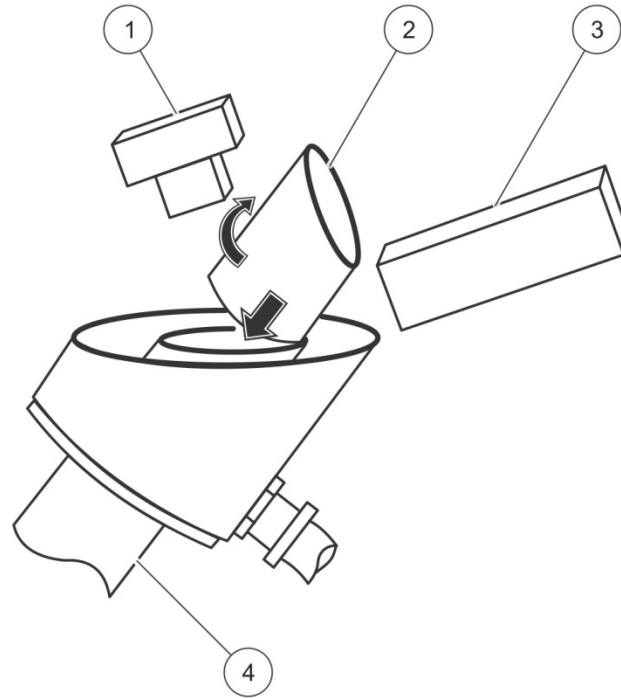


Figure 24: Calibration Curve of three Surface Scatter 7sc Turbidimeters vs. Ideal.

Following calibration procedures carefully is essential to establishing this accuracy.

Calibration of the Surface Scatter 7sc Turbidimeter is based on Formazin, the primary turbidity standard. Calibration is accomplished by inserting a calibration cup into the turbidimeter body and filling the cup with a standard Formazin stock solution. For best performance use either Formazin or StablCal stabilized Formazin standards for calibration. It is recommended that alternative calibration standards such as highly spherical near-mono-dispersed standards (e.g. SDVB or PSL materials) not be used for calibration. These standards are composed primarily of very small (0.1 to 0.5 μm) particles. Particles of that size cause a monodisperse condition resulting in an unbalanced scatter of the incident light – most of the blue light scatters forward and the remainder of the light scatters more symmetrically.



1. Detector Assembly	3. Light source assembly
2. Calibration Cup	4. Turbidimeter body

Figure 25: Inserting the Calibration Cup

The calibration sequence is as follows:

1. Prepare the Formazin standard solution at the desired NTU value.
 - a. **For high range measurement:** If measurements are expected to be primarily greater than 2000 NTU, calibrate using the 4000-NTU standard supplied with the instrument at full strength. It only requires vigorous mixing (by inverting the bottle repeatedly) before use.
 - b. **For lower range measurement:** If measurements are expected to be primarily less than 2000 NTU, dilute the 4000-NTU standard to the desired concentration. Use demineralized water for dilution. Hach Company recommends the dilution be no lower than 400 NTU⁵. Dilutions must be made just prior to use. Dilute Formazin solutions are unstable and should be discarded when calibration is complete. A 400 NTU StablCal[®] Turbidity Standard, Catalog Number 7121649, eliminates the need to prepare dilutions.
2. Turn off sample flow to the instrument and drain the turbidimeter body. Insert the calibration cup into the top of the body.
3. From the Main Menu of the controller, select SENSOR SETUP and confirm.
 - a. If multiple sensors are attached to the controller, choose SELECT SENSOR>SS7 SETUP and confirm.
 - b. Select Calibrate and confirm.
 - c. Select the PERFORM CAL menu entry and confirm.
 - d. Select the Active, Hold or Transfer output mode and confirm.

⁵ The reason dilutions lower than 400 NTU are not recommended is due to the geometry of the calibration cup. The calibration cup contains only about 500 ml, thus it is very shallow. If dilutions greater than 400 NTU are used, incident light will reach the bottom of the calibration cup and be reflected back to the detector thus creating a measurement error.

4. Enter the STD VALUE. Confirm to continue. As indicated above, for measurement greater than 2000 NTU, using the 4000 NTU Formazin Stock Solution is suggested so enter '4000' as the standard value. For measurement less than 2000 NTU, a 400 NTU dilution is suggested so enter '400' as the standard value.
5. Follow the display prompts and pour the Formazin standard solution into the cylinder, allowing it to overflow. Only allow the solution to stand long enough to allow bubbles on or near the surface to dissipate.
6. Close the sample unit door tightly. Confirm to continue.
7. The TURB value displayed is the standard value determined using the gain from the previous calibration. Wait at least one minute but no longer than 2 minutes.
8. Confirm to accept and continue with the calibration.
9. If no selection is made for a set period of time, the screen will prompt to remix the standard to avoid a change in the value of the standard. Open the SS7 sc and discard the old standard from the calibration cup. Refill this cup with another aliquot of well mixed turbidity standard. Close the door.
10. Confirm to calibrate. When the calibration is completed successfully, the display will show "GOOD CAL!" and the new calibration gain value. Confirm to accept the calibration.
11. Follow the prompt and enter the initials of the user performing the calibration. Confirm.
12. The controller will prompt for NEW BASELINE*. Confirm to establish a new baseline or press BACK to exit.
13. Remove the calibration cylinder from the body. The instrument is now calibrated.
14. Close the drain valve and restore the sample flow. If no verification is performed, the display will prompt to return to measurement mode. Confirm to continue measurements.

*This refers to establishing a value for a secondary standard, the Standard Plate used to periodically check calibration of the instrument. See **Secondary Standard**, below.

Once an operator is familiar with the sequence, the procedure can be completed in about five minutes. Information about the most recent 12 calibrations (date, time, user, calibration solution, slope or gain of the calibration) is stored and available for review.

Secondary Standard

A periodic check of calibration is important and easily accomplished by comparing measurements from the Surface Scatter 7sc Turbidimeter to measurements of a laboratory instrument which also has been Formazin-calibrated. When this is impractical, a Standardization Plate Kit (a secondary standard), available as an optional accessory, may be used. Two plates are included in the kit, 0-100 and 0-1000 NTU. The plates are uncalibrated when shipped. Their value must be established on each Surface Scatter 7sc Turbidimeter following a Formazin calibration of the instrument. This value, once established is rechecked and if necessary reset following each calibration of the instrument with primary standard. The standardization plates are constructed of an opaque backing, a clear glass cover and a center portion of Gelex[®] Secondary Standard to simulate light scattering from a sample. Gelex is a stable material consisting of metal oxide particles locked in a gel. As with all scientific measurements, the proper use of standards is extremely important. For a comprehensive discussion of turbidity standards, refer to Hach literature number 7045, Turbidity Standards. It can be down loaded free of charge from the Hach Company web site: www.hach.com.

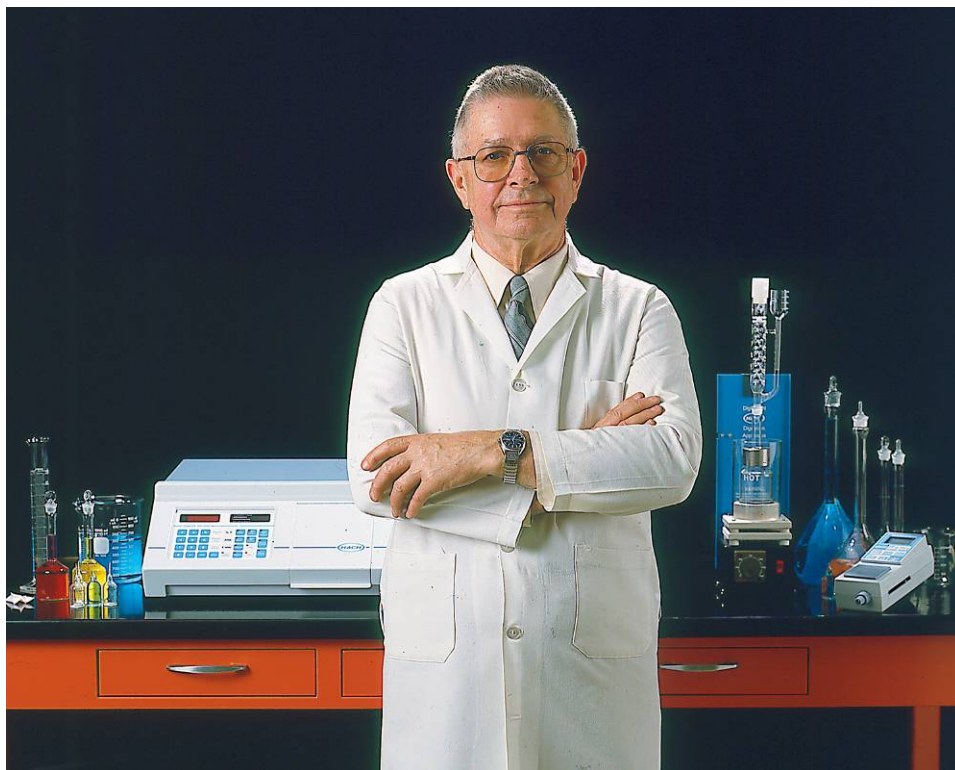
High Turbidity Measurement Options

One size doesn't fit all. While the Surface Scatter 7sc is well suited for a wide range of applications, it is not ideal for all. One of the drawbacks is the sample must be delivered to the analyzer. In many environmental and industrial samples it is desirable to use a sensor which can be immersed directly into a waterway, channel, or into a pipe. Figure 26 illustrates the variety of instruments available from Hach Company for high turbidity and/or suspended solids measurement. All of the sensors listed are in the family of Hach smart sensors and utilize the sc100, sc200 and sc1000 controllers. Contact your Hach Company representative for information about any of these products.

Application	Range	For Insertion in Pipes			For Immersion in Open Tanks				Sample to Sensor
		Inline	Highline	TSS sc	t-line	ts-line	hs-line	TSS sc	SS7
Wastewater									
Final Effluent	0 to 30 mg/L or 0 to 1000 NTU	•		•	•	•		•	•
Influent Suspended Solids	1 to 1.5 g/L			•		•	•	•	
Filtrate/Centrate	1 to 2 g/L	•		•		•	•	•	
Mixed Liquor Suspended Solids	1 to 5 g/L			•		•		•	
Return Activated Sludge	1 to 25 g/L	•		•		•		•	
Waste Activated Sludge	0 to 2% or 0 to 20 g/L	•		•		•		•	
Primary sludge (settled sludge)	0.5 to 10% or 5 to 100 g/L		•	•			•	•	
Anaerobic digested sludge	1.5 to 7% or 15 to 70 g/L		•	•			•	•	
Gravity thickened sludge	2 to 10% or 20 to 100 g/L		•	•			•	•	
Mechanically thickened sludge	3 to 8% or 30 to 80 g/L		•	•			•	•	
Drinking Water									
Source Water Monitoring	0 to 4000 NTU			•	•	•		•	•
	0 to 10000 NTU			•				•	•
Influent Pressurized Raw Water	0 to 4000 NTU			•			•	•	•
	0 to 10000 NTU			•				•	•
Clarifier Efficiency	0 to 20 NTU			•	•	•		•	•
Filter backwash: Monitor Process	0 to 1000 NTU	•		•	•	•		•	
Filter Backwash: Return	0 to 20 NTU	•		•	•	•		•	•
Industrial Water									
Boiler and Cooling Water- Petrochemical Pulp and Paper				•	•			•	•
DAF Oil-In-Water Separators- Petrochemical									•
Make-up Water: Power, Pulp & Paper, Petrochemical		•		•	•	•		•	•
Lime Addition: Petrochemical, Mining, Pulp & Paper			•				•		•
Storm Water: Pulp & Paper, Petrochemical		•			•	•			•
Wastewater (activated sludge): Power, Pulp & Paper		•	•		•	•	•		•
Petrochemical, Food & Beverage				•				•	•
White & Black Liquor Applications: Pulp & Paper					•				•

Figure 26: Hach Company high range turbidity and suspended solids instruments

The late Clifford C. Hach, founder of Hach Company, was a graduate of Iowa State University. Widely respected in the water analysis industry as an inventor, progressive innovator and research scientist, Mr. Hach held numerous patents and many of his papers appeared in technical industry publications.



Hach Company's technical staff at the modern research facilities in Loveland, Colorado and Ames, Iowa combines dedicated chemists, engineers and technicians focused on the development of applied analyses to meet municipal, industrial and agricultural analytical needs. Special emphasis is placed on developing the most practical and economical approaches to methods, reagent formulations, instruments and equipment for analysis.

Appendix A: Surface Scatter 7 Specifications

Range	0 to 9999 Nephelometric Turbidity Units (NTU)
Accuracy	± 0.1 NTU or $\pm 5\%$ from 0 to 2000 NTU, whichever is greater; $\pm 10\%$ from 2000 to 9999 NTU
Resolution	0.01 NTU below 100 NTU; 0.1 NTU between 100 to 9999.9 NTU
Repeatability	1.0% or ± 0.04 NTU, whichever is greater
Response Time	Initial response in 45 seconds
Sample Flow	1.0 to 2.0 L/min (15 to 30 gal/hr)
Sample Temperature	SS7: 0 to 50°C (32 to 122°F); SS7/HST: 0 to 70°C (32 to 158°F), intermittent 70 to 80°C (158 to 176°F) (an optional heat exchanger is available to reduce sample temperature)
Ambient Temperature	0 to 50°C
Humidity	5 to 95% non-condensing
Power Requirements	100 to 230 VAC, 50/60 Hz, auto selecting; 40 VA
Installation Category	Category II
Sample Inlet Fitting	3/4-inch NPT female
Overflow Drain Fitting	1-inch NPT female
Body Drain Fitting	3/4-inch NPT female
Air Purge Fitting	3/4-inch compression fitting; 0-50 SCFH airflow clean instrument air
Enclosure	NEMA-12 plastic instrument enclosure
Mounting	Wall mount
Dimensions	(Sample Unit) 64.2 x 67.5 x 19.0 cm (25.3 x 26.6 x 7.5 in.)


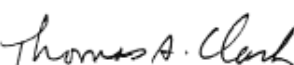
Materials of Construction	
Standard Model	High Sample Temperature
Polypropylene – Turbidimeter body	Polypropylene – Turbidimeter body
Neoprene - Tubing	Neoprene - Tubing
Polypropylene - Fittings	Polypropylene - Fittings
PVC - Bulkheads	Polypropylene - Bulkheads
Teflon tape	Teflon tape
	CPVC - trap assembly

Appendix B: Summary of US EPA Method 180.1 Design Requirements

US EPA Method 180.1 is applicable to turbidity measurements in the range of 0 to 40 NTU and stipulates the following design characteristics:

- “Light Source: Tungsten-filament lamp operated at a color temperature between 2200 and 3000° K.
- Distance traversed by incident light and scattered light within the sample tube not to exceed 10 cm.
- Angle of light acceptance by detector: Centered at 90° to the incident light path and not to exceed ± 30 degrees from 90°. The detector, and filter system if used, shall have a spectral property between 400 and 600 nm

Appendix C: US EPA Acceptance Letter

	<p>UNITED STATES ENVIRONMENTAL PROTECTION AGENCY OFFICE OF RESEARCH AND DEVELOPMENT ENVIRONMENTAL MONITORING AND SUPPORT LABORATORY CINCINNATI, OHIO 45268</p>
<p>June 1, 1988</p>	
<p>Mr. Terry L. Engelhardt Hach Company Post Office Box 389 Loveland, Colorado 80539</p>	
<p>Dear Mr. Engelhardt:</p>	
<p>We have concluded our review of the material submitted concerning calibration procedures for the Surface Scatter 6 (SS6) turbidimeter. We are satisfied that for turbidities above 3.5 nephelometric turbidity units (NTU), calibration is accurate and within the limits specified for the unit. We understand that the SS6 is to be marketed primarily for process monitoring where very high turbidities would be expected. If the unit is used for monitoring either drinking water or wastewater below 3.5 NTU, a sample with a known turbidity of 1.0 NTU or less should be analyzed regularly in order to ensure valid results in that range.</p>	
<p>As noted in previous correspondence, we are also satisfied that the SS6 meets all other requirements for turbidimeters as specified in approved turbidity Method 180.1. Accordingly, the SS6 turbidimeter would be acceptable for reporting purposes under either the National Pollutant Discharge Elimination System or National Primary Drinking Water Regulations compliance monitoring programs.</p>	
<p>Sincerely yours,  Thomas A. Clark Acting Director Environmental Monitoring and Support Laboratory - Cincinnati</p>	
<p>cc: James O'Dell Larry Lobring James J. Lichtenberg</p>	

Appendix D: Replacement Parts and Accessories

Replacement Parts	
Description	Cat. No.
Brush, cylinder, size 2	68700
Calibration cup, SS7 sc	4502100
Drain Valve	4507300
Formazin Stock Solution, 4000 NTU, 500 ml	246149
StablCal® Turbidity Standard, 400 NTU, 500 ml	7121649
StablCal® Turbidity Standard, 800 NTU, 500 ml	2660549
StablCal® Turbidity Standard, 1000 NTU, 500 ml	2660649
Light Source Alignment Template	4507600
Wall Mounting kit	4424700
Light Source Shield Assemblies (2x)	4529900
Detector Assembly	7122100
Lamp Assembly, Surface Scatter 7 sc	4503400
Tubing Replacement Kit	4669100
Accessories	
Auto Flush Kit (120V)	4669212
Auto Flush Kit (220V)	4669222
Bubble Trap/Head Regulator	4668000
Cable Extension for Sensor, 7.6 m (25 ft)	5796000
Latch, replacement, SS7	4499300
Manual, SS7 sc, English	DOC026.53.00769
Manual, SS7 sc, Chinese	DOC026.80.00769
Manual, SS7 sc, Japanese	DOC026.81.00769
Manual, SS7 sc, Korean	DOC026.84.00769
Quick Reference Document	DOC016.53.00769
Power Cord, 125 VAC, 10A, 1.83 m (6 ft)	4630600
Power Cord, 250 VAC, 10A, 1.83 m (6 ft)	4630800
Standardization Plate Kit, uncalibrated , includes 0-100 and 0-1000 NTU plates	2351300
Sun Shield, sc200 Controller	9220600
Upgrade Kit, Converting Standard SS7 sc to a SS7 sc-HST (High Sample Temperature)	4500043

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