THORNTON
Leading Pure Water Analytics

Part No. 84434

Standard Operating Procedure for System Suitability Testing to Meet USP <643> and EP 2.2.44.

Thornton 550/550-HT Total Organic Carbon Analyzer

METTLER TOLEDO

TABLE OF CONTENTS

1. Purpose

This procedure describes the method for verifying the System Suitability of the Thornton 550/550-HT Analyzer for total organic carbon (TOC) measurement of USP and EP Purified Water and Water for Injection (WFI)*.

System Suitability is the determination of a methodology's ability to respond equally to different challenges. In the case of most of today's TOC analyzers, there are two key mechanisms:

- The ability to break carbon-carbon, carbon-hydrogen, and carbon-oxygen bonds. These are the most prevalent chemical bonds found in organic impurities. The strength of each bond depends on the molecule and bond type. Regardless, these bonds need to be broken to form CO_2.
- The ability to oxidize molecular organic carbon (in oxidation states ranging from -4 to +2) to its oxidized form, CO_2. The oxidation state of carbon in CO_2 is +4. Therefore, electrons are required to be removed from each carbon.

Since organic carbon appears in various forms in nature and subsequently in water systems, a wide variety of oxidation states and chemical forms are expected. The challenge to the TOC analyzer is to oxidize two chemicals of different oxidation strengths equally.

The standard solution is a theoretically easy-to-oxidize solution that gives an instrument response at the attribute limit – in this case 500 μg Carbon/L. The technology is qualified by challenging the capability of the instrument using a theoretically difficult-to-oxidize solution in the system suitability portion of the method.

2. Scope

This document provides a procedure to qualify the Thornton 550/550-HT Total Organic Carbon Analyzer for use as a TOC measurement device for USP and EP Purified Water and Water for Injection pharmaceutical waters. This procedure determines the "system suitability" of the Thornton 550/550-HT TOC Analyzer to meet USP <643> and EP 2.2.44. This method is to be performed on an instrument that has been appropriately calibrated. The acceptance of this on-line instrumentation for quality attribute testing is dependent on its location(s) in the water system. The instrument location must reflect the quality of the water used.

This procedure describes one acceptable method to determine system suitability. Alternative procedures may be acceptable if they meet the fundamental requirements of <643> and 2.2.44. For example, alternative concentrations or volumes of the stock solutions may be used. The only requirement is that the required final concentration is achieved.

* In Europe, the terminology is "Water for Injections". In the U.S., it is "Water for Injection". Hereafter, the abbreviated term "WFI" shall refer to both waters.

3. Background

On November 15, 1996, the requirements for testing specific attributes of USP Purified Water and WFI were modified to reflect changes in instrumentation and quality testing. The two most profound changes were:

- The elimination of tests for chloride, ammonia, sulfate, carbon dioxide, and calcium and subsequent replacement by uncompensated conductivity measurements. This is described in USP <645>.
- The option to perform TOC measurements instead of the Oxidizable substances test for USP Purified Water and WFI.

The major impetus for both changes was the opportunity to eliminate costly, labor-intensive tests that were qualitative at best, and replace them with quantitative tests that represented current industry norms. The on-line versatility of these measurements made these new tests more attractive.

While conductivity measurements are common in pharmaceutical water systems, there was reluctance to abruptly delete the Oxidizable substances test in favor of TOC measurements. The technology for low-ppb TOC measurements was relatively new and the cost of TOC instrumentation was prohibitive. For these reasons, the USP permitted the use of either test until May 15, 1998. At that time, the Oxidizable substances test was deleted as a requirement for USP Purified Water and WFI, and USP General Chapter <643> TOC became the exclusive means to measure the organic impurity in USP Purified Water and Water for Injection.

Subsequently, in 2000, the EP implemented a TOC requirement (2.2.44) for their bulk waters. As of this printing, TOC is required for bulk WFI, and it is an optional test for Purified Water as an alternative to the Oxidizable substances Test in the EU only. You should consult the current pharmacopeia to determine your requirements.

4. Principle of Analysis

Organic impurities are introduced into the water from the source water, from purification and distribution system materials, and from biofilm in the system. TOC is an indirect measure of organic molecules measured as carbon. TOC can also be used as a process control attribute to monitor the performance of unit operations comprising the purification and distribution system. This method, Total Organic Carbon, is described in General Chapter <643> in U.S. Pharmacopeia, and in Test 2.2.44 of the European Pharmacopeia.

The Thornton 550/550-HT TOC Analyzer measures the amount of organic carbon in water by oxidizing organic carbon with UV radiation. The resulting increase in conductivity is used to calculate the amount of organic carbon present.

5. Apparatus Required

- Thornton 550/550-HT Total Organic Carbon Analyzer.
- Thornton 550/550-HT Total Organic Carbon Analyzer Instruction Manual
- Pump capable of delivering water up to 125 mL/min(FMI lab pump, Model RHB).
- Calibrated analytical balance with precision of ±1 mg or better (Mettler AE200).

- Class A Volumetric Glassware (pipets and volumetric flasks) or equivalent.
- Storage Glassware.
- Drain, whether a floor drain, sink, or bucket
- Polypropylene Needle Valve with ¼" compression fittings (McMaster-Carr).
- ¼" tubing – Teflon/PFA for **SAMPLE IN** , Polypropylene for **BYPASS OUT** and **OXIDIZED OUT**
- ¼" compression nuts – Teflon/PFA/Kynar for **SAMPLE IN** , Kynar/Polypropylene for **BYPASS OUT** and **OXIDIZED OUT**

6. Materials Required

- **USP Reference Standards <11>** - USP 1,4-Benzoquinone RS; USP Sucrose RS.
- **Reagent Water** – This is the water used to prepare the Sucrose and 1,4-Benzoquinone solutions. Its TOC concentration shall not exceed 100 μg/L*, and its resistivity shall be greater than 1 MΩ–cm.

7. Glassware Preparation

All glass containers, pipets, and wettable tubing and components used for this procedure must be scrupulously cleaned of organic residues. Glassware may be cleaned by any of a number of effective methods, including the following:

- Detergent treatment, followed by Reagent Water rinse, followed by 3% hydrogen peroxide soak, and followed by extensive final rinsing with Reagent Water.
- Chromic acid treatment as detailed in USP <1051> *Cleaning Glass Apparatus.*
- Other suitable means to remove trace organic impurities such as CIP solutions.

8. Tubing Connections

- To purge Process Water through the system, set the tubing to the configuration shown in Figure 1.
- To send Reagent Water(**BYPASS OUT** valve is fully open initially) or test solution(**BYPASS OUT** valve is closed) through the TOC analyzer, set the valve and tubing to the configuration shown in Figure 2

Figure 1: Water Flush Configuration

*Consult your pharmacopeia for current requirements. Contact Thornton Technical Services for any questions

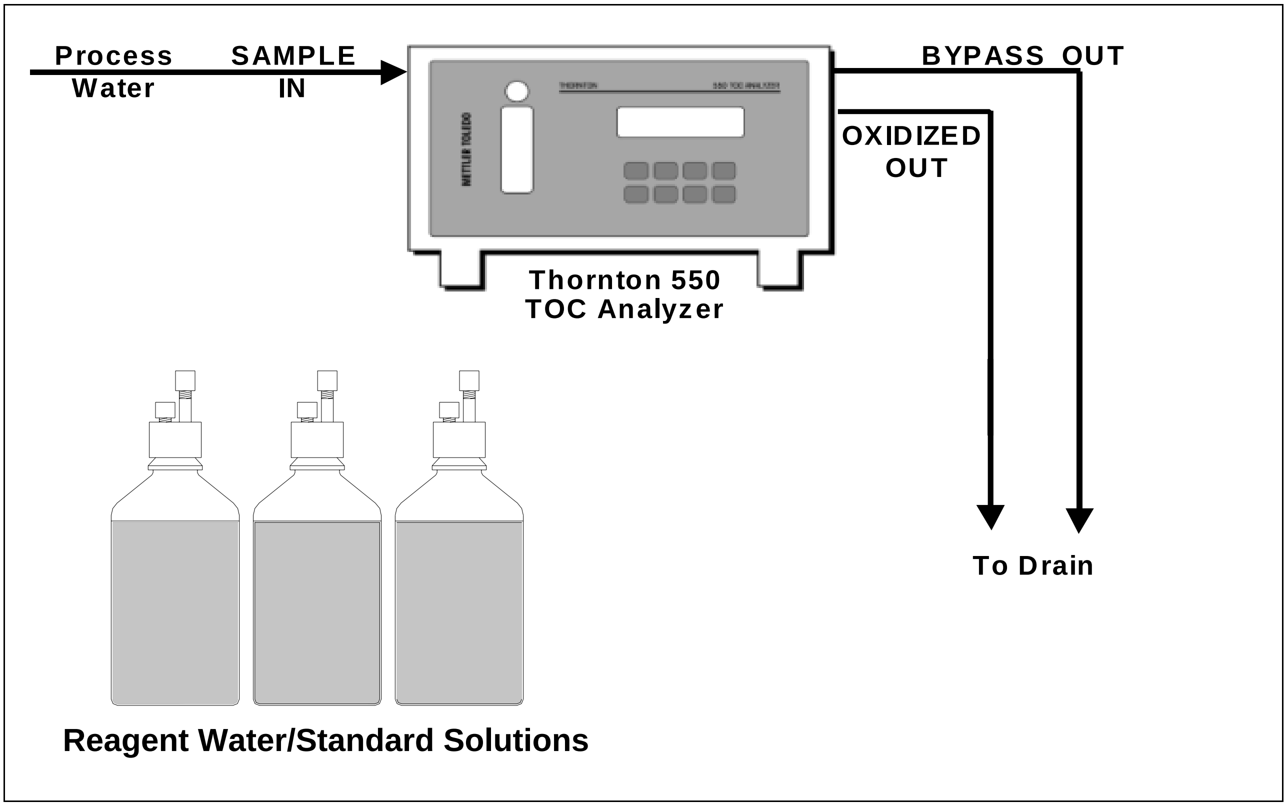
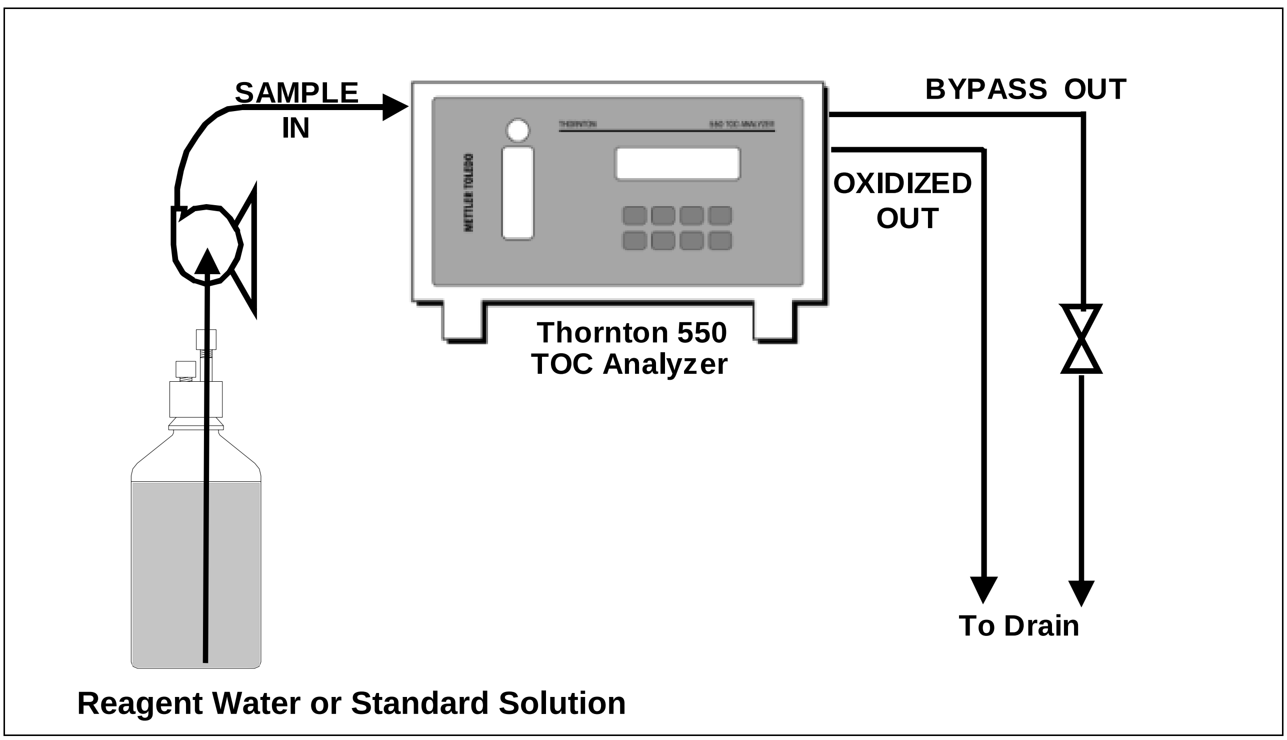


Figure 2: Test Solution Measurement Configuration



9. Test Solutions

9.1. Reagent Water Sample

The Reagent Water is the water used to prepare the solutions described below.

1. Rinse and fill a 1 L flask or other glass storage container with Reagent Water. The container shall have been cleaned and stored in a similar manner as the test solution containers.
2. Stopper and set aside. Do not use any greases or organic stoppers to seal the container.
3. Use this water container as a Reagent Water control sample.

9.2. Sucrose Stock Solution

The purpose of the concentrated Sucrose Stock Solution is to be the source solution for the preparation of the 500 ppb Sucrose Standard Solution. Alternative volumes are acceptable.

This procedure describes the preparation of a Sucrose Stock Solution at a concentration of ~50,000 ppb Carbon. Alternative concentrations may be made up to 10 times more or less concentrated. However, less concentrated solutions will require less sucrose. Be sure that your balance has the desired accuracy and resolution to weigh the sample.

1. Unless otherwise directed by a monograph, accurately weigh ~0.12 g of sucrose, $C_{12}H_{22}O_{11}$ (molecular weight 342.3 g/mole) to the nearest 0.001 g. Record the exact weight in the System Suitability Worksheet (table 2, row 3).
2. Quantitatively transfer the sucrose to a clean Class A 1000 mL volumetric flask that has been rinsed with Reagent Water.
3. Add some Reagent Water to completely dissolve the sucrose.
4. Dilute to the 1000 mL mark with Reagent water, and seal the flask. Record the solution volume in the System Suitability Worksheet (table 2, row 4).
5. Label the solution with its contents ("50,000 ppb* C as sucrose" or equivalent), sucrose lot number, preparer's initials, and date. Use eq 1 to determine the concentration.

$$\mathrm{TOC}\,(\mu\mathrm{g\ C/L}) = \frac{\left(\dfrac{\mathrm{wt\ C_{12}H_{22}O_{11}\ (g)}}{\mathrm{MW\ C_{12}H_{22}O_{11}\ (g/mole)}}\right)\left(\dfrac{\mathrm{12\ mole\ C}}{\mathrm{mole\ C_{12}H_{22}O_{11}}}\right)\left(\dfrac{\mathrm{12.011 g\ C}}{\mathrm{mole\ C}}\right)\left(\dfrac{10^{6}\ \mu\mathrm{g\ C}}{\mathrm{g\ C}}\right)}{\mathrm{volume\ solution\ (L)}} \quad \textbf{Eq 1}$$

* It is common practice to discuss the TOC concentration in terms of "ppb". "ppb" is not an SI recognized unit. The accurate term is "µg/L", but the term "ppb" is often used in its place.

For example, if 0.1163 g of sucrose were dissolved in a 1000 mL volumetric flask, the concentration of Carbon would be

$$\frac{\left(\frac{0.1163\ \text{g}}{342.3\ \text{g/mole}}\right)\left(\frac{12\ \text{mole C}}{\text{mole } C_{12}H_{22}O_{11}}\right)\left(\frac{12.011\ \text{g C}}{\text{mole C}}\right)\left(\frac{10^{6}\ \mu\text{g C}}{\text{g C}}\right)}{1.000\ \text{L}} = 48{,}970\ \mu\text{g C/L} \quad \textbf{Eq 1a}$$

Note: *Alternative Sucrose Stock Solution concentrations, volumes, and dilutions are permissible. The only requirements are the concentration of sucrose in the final Standard Solution and sufficient volume to do the testing.*

9.3. 500 ppb Sucrose Standard Solution

This solution is prepared from the Sucrose Stock Solution. A final concentration of 500 ppb TOC is the target. It is prepared from an analytical dilution of the Sucrose Stock Solution.

1. Before preparing the Sucrose Standard Solution, gently agitate the Sucrose Stock Solution to homogenize the solution.
2. Quantitatively transfer the appropriate volume of the Sucrose Stock Solution to a clean Class A 1000 mL volumetric flask that has been rinsed with Reagent Water. Use eq 2 to determine the volume to deliver. *Use delivery glassware with an accuracy of 1% or better*. Typical laboratory Class A pipets exceed this requirement.

$$\text{transfer volume (mL)} = \text{final solution volume (mL)} \times \left(\frac{\text{final solution conc (ppb)}}{\text{initial solution conc (ppb)}}\right) \quad \textbf{Eq 2}$$

3. Record the volume transferred in the System Suitability Worksheet (table 2, row 7).

In this example, the target volume would be

$$1000\ \text{mL} \times \left(\frac{500\ \text{ppb}}{48{,}970\ \text{ppb}}\right) = 10.2\ \text{mL} \quad \textbf{Eq 2a}$$

4. Dilute to the 1000 mL mark with Reagent Water, vigorously agitate to homogenize the solution. Vigorous agitation, for example, is accomplished by transferring the solution to a 5000 mL flask and shaking for at least 5 minutes. Return the solution to the 1000 mL flask. Seal the flask.
5. Record the final solution volume in the System Suitability Worksheet (table 2, row 8).
6. Label the solution with its contents (“500 ppb C as sucrose” or equivalent), sucrose lot number, preparer’s initials, and date.

9.4. 1,4-Benzoquinone Stock Solution

The sole purpose of the concentrated 1,4-Benzoquinone Stock Solution is to be the source solution for the preparation of the 500 ppb 1,4-Benzoquinone Standard Solution. Alternative volumes are acceptable.

This procedure describes the preparation of a 1,4-Benzoquinone Stock Solution at a concentration of ~50,000 ppb Carbon. Alternative concentrations may be made up to 10 times more or less concentrated. However, less concentrated solutions will require less 1,4-benzoquinone. Be sure that your balance has the desired accuracy and resolution to weigh the sample. Also, more concentrated solutions become more difficult to solubilize the 1,4-benzoquinone.

Note: 1,4-benzoquinone is also known as *p*-benzoquinone.

1. Accurately weigh 0.07 to 0.08 g of 1,4-benzoquinone ($C_6H_4O_2$, molecular weight 108.1 g/mole). Record the exact weight in the System Suitability Worksheet (table 3, row 3).
2. Quantitatively transfer the 1,4-benzoquinone to a clean Class A 1000 mL volumetric flask that has been rinsed with Reagent Water.
3. Add approximately ½ the volume of Reagent Water and dissolve the 1,4-benzoquinone. It may be necessary to mix or sonicate this solution to dissolve completely.
4. Dilute to the 1000 mL mark with Reagent water, gently agitate to homogenize the solution, and seal the flask. Record the solution volume in the System Suitability Worksheet (table 3, row 4). Note: *The solution readily reacts with light. The solution should be stored in a flask with low light transmittance. It should be stored in a dark area when not in use.*
5. Label the solution with its contents ("50,000 ppb C as 1,4-benzoquinone" or equivalent), 1,4-benzoquinone lot number, preparer's initials, and date. Use eq 3 to determine the concentration.

$$\text{TOC } (\mu\text{g C/L}) = \frac{\left(\dfrac{\text{wt } C_6H_4O_2 \text{ (g)}}{\text{MW } C_6H_4O_2 \text{ (g/mole)}}\right)\left(\dfrac{6 \text{ mole C}}{\text{mole } C_6H_4O_2}\right)\left(\dfrac{12.011 \text{ g C}}{\text{mole C}}\right)\left(\dfrac{10^6\ \mu\text{g C}}{\text{g C}}\right)}{\text{volume solution (L)}} \quad \textbf{Eq 3}$$

For example, if 0.0826 g of 1,4-benzoquinone were dissolved in a 1000 mL volumetric flask, the concentration of Carbon would be

$$\frac{\left(\dfrac{0.0826 \text{ g}}{108.1 \text{ g/mole}}\right)\left(\dfrac{6 \text{ mole C}}{\text{mole } C_6H_4O_2}\right)\left(\dfrac{12.011 \text{ g C}}{\text{mole C}}\right)\left(\dfrac{10^6\ \mu\text{g C}}{\text{g C}}\right)}{1.000 \text{ L}} = 55{,}066\ \mu\text{g C/L} \quad \textbf{Eq 3a}$$

Note: *Alternative 1,4-Benzoquinone Stock Solution concentrations, volumes, and dilutions are permissible. The only requirements are the concentration of 1,4-benzoquinone in the final Standard Solution and sufficient volume to do the testing. However, Stock Solutions in excess of the procedure described above will be difficult to prepare due to the low solubility of 1,4-benzoquinone.*

9.5. 500 ppb 1,4-Benzoquinone System Suitability Solution

This solution is prepared from the 1,4-benzoquinone Stock Solution. A final concentration of 500 ppb TOC is the target. It is prepared from an analytical dilution of the 1,4-benzoquinone Stock Solution.

1. Before preparing the 500 ppb 1,4-Benzoquinone System Suitability Solution, gently agitate the Benzoquinone Stock Solution to homogenize.

2. Quantitatively transfer the appropriate volume of the Benzoquinone Stock Solution to a clean Class A 1000 mL volumetric flask that has been rinsed with Reagent Water. Use eq 2 to determine the volume to deliver. *Use delivery glassware with an accuracy of 1% or better*.
3. Record the volume transferred in the System Suitability Worksheet (table 3, row 7).

In this example, the target volume would be

$$1000\text{ mL} \times \left(\frac{500\text{ ppb}}{55{,}066\text{ ppb}} \right) = 9.08\text{ mL} \qquad \textbf{Eq 4}$$

4. Dilute to the 1000 mL mark with Reagent Water, vigorously agitate to homogenize the solution. Vigorous agitation, for example, is accomplished by transferring the solution to a 5000 ml flask and shaking for at least 5 minutes. Return the solution to the 1000 ml flask. Seal the 1000 ml flask. Record the final solution volume in the System Suitability Worksheet (table 3, row 8).
5. The solution should be stored in a dark area when not in use.
6. Label the solution with its contents ("500 ppb C as 1,4-benzoquinone" or equivalent), 1,4-benzoquinone lot number, preparer's initials, and date.

10. Test Procedure

Note: *Always use freshly prepared Reagent Water and TOC Solutions.*
Note: *To simplify data acquisition do the following.*

1. Set the print time interval to desired interval.
2. When collecting 3 consecutive readings push the **NEXT** *button once to display the last 3 readings.*

Note: *Purge air from the inlet tubing before starting section 10.2***.** *This can be done by pumping reagent water through the tubing before connecting to* **SAMPLE IN.** Use a pump setting between 100-200 for purging air from the inlet tubing.

10.1. Purge TOC Analyzer

1. Connect the Process Water to the Thornton 550/550-HT inlet. Use the valve configuration as shown in Figure 1. This will allow the Process Water to flow through the Analyzer. Allow the unit to equilibrate in place with power switch ON for at least 30 minutes before collecting data. Disconnect from process water. Ensure that in **MAINTENANCE**, **OTHER SETUP** the TOC Curve on the 550/550-HT is set to Curve 1. Also check that the flow rate is set to 20 ml/min. For most applications, the appropriate range of operation is 20 ml/min.

10.2. Set up equipment

1. Connect **SAMPLE IN** as shown in Figure 2. Install a needle valve in the **BYPASS OUT** line. Make sure **BYPASS OUT** valve is closed. Fully open the 550 flowmeter needle valve.
2. Set dial on pump between 10 – 20.
3. Turn on the pump to push the fluid through the Analyzer. Turning the pump dial counterclockwise, set flowrate between 40-50 ml/min. Let residual air leave the

550 meter. Do not exceed maximum scale (450) on pump at anytime during the procedure. Typically a new pump does not require settings above 150. With normal use settings may increase over time.

4. Open the bypass valve until the flowmeter ball falls close to 20 ml/min. **(do not fully open the bypass valve)**.
5. View the resistivity/conductivity of the Reagent Water by going to the 1st screen of **SENSOR VIEW**. When S1 and S2 are stable return to title screen and push **START** to initiate the System Check and Measurement process.
   a. The analyzer does an automatic zero to correct for any zero drift. The unit will display "SYSTEM CHECK" blinking. At the conclusion, the unit will display "SYSTEM CHECK PASSED" after about 3 minutes.
   b. Next the message "UV WARMING UP" blinks as the UV lamp warms up. Go to step 6 immediately.
   c. Finally the TOC, Resistivity/Conductivity, and Temperature are displayed on the Measurement Display. The measurement is updated every 2 seconds.
6. Close the **BYPASS OUT** valve. Turn pump dial clockwise until flowrate is 20 ml/min. If necessary use flowmeter knob to make fine adjustments only after using pump dial to make rough flowrate adjustments.

10.3. Reagent Water Blank Measurement

1. Allow the water to be pumped through the instrument for at least 10 minutes before collecting data for use in the calculations.
2. Collect three consecutive TOC readings, at least 10 seconds apart, and record in the System Suitability Worksheet for the Reagent Water TOC value. These values are used to calculate R_w.
3. Record the resistivity or conductivity in the System Suitability Worksheet.
4. Turn the pump off.

10.4. Standard Solution Measurement

1. Using the configuration shown in Figure 2, insert the sample in tubing into the Sucrose Standard Solution.
2. Turn on the pump.
3. Pump this solution through the Thornton 550/550-HT at 20 ml/min.
4. Allow the solution to be pumped through the instrument for at least 10 minutes before collecting data for use in the calculations.
5. Collect three consecutive TOC readings, at least 10 seconds apart, and record in the System Suitability Worksheet, for the 500 ppb Sucrose Standard Solution. These values are used to calculate R_s. The three measurements are typically within 1% of each other.
6. Turn off the pump.

10.5. System Suitability Solution Measurement

1. Clean the tubing with Reagent Water used in the previous step. Do not use the same container of Reagent Water due to the risk of contamination.
2. Using the configuration shown in Figure 2, insert the tubing into the 500 ppb 1,4-Benzoquinone System Suitability Solution.
3. Turn on the pump.
4. Pump this solution through the Thornton 550/550-HT at 20 ml/min.

5. Allow the solution to be pumped through the instrument for at least 10 minutes before collecting data for use in the calculations.
6. Collect three consecutive TOC readings, at least 10 seconds apart, and record in the System Suitability Worksheet for the 500 ppb 1,4-Benzoquinone System Suitability Solution. These values are used to calculate R_{ss}. The three measurements are typically within 1% of each other.
7. Turn the pump off.

10.6. Repeat Reagent Water Blank Measurement

1. Repeat the Reagent Water Blank TOC Measurement to verify that the background TOC has not significantly changed. Record the measurement in the System Suitability Worksheet. Be sure to rinse the tubing thoroughly before immersing it in the Reagent Water.
2. Press the **STOP** button on the 550/550HT.

11. Calculations

11.1. Limit Response

All calculations can be performed in the System Suitability Worksheet.

1. Calculate the corrected Sucrose Standard Solution response, which is also the ***limit response***, by subtracting the Reagent Water TOC response from the response of the Sucrose Standard Solution. This is R_s - R_w.
2. Record the value R_s - R_w in the System Suitability Worksheet.

11.2. System Suitability Response

1. Calculate the corrected System Suitability Solution response by subtracting the Reagent Water TOC response from the System Suitability Solution TOC response. This is R_{ss} - R_w.

2. Calculate the Response Efficiency from the following formula:

$$\text{Response Efficiency (\%)} = 100 \times \left(\frac{R_{ss} - R_w}{R_s - R_w} \right)$$

3. Record the Response Efficiency in the System Suitability Worksheet
4. The system is suitable if the Response Efficiency is not less than 85% and not more than 115%*.

12. References

- “<643> Total Organic Carbon”, United States Pharmacopeia
- “<1051> Cleaning Glass Apparatus”, United States Pharmacopeia

* These values are correct at the time of printing. Consult your pharmacopeia for current requirements

13. System Suitability Worksheet

Table 1. TOC Analyzer

Date	
Instrument Model Number	
Instrument Serial Number	

Table 2. Sucrose ($C_{12}H_{22}O_{11}$) Data

1. Sucrose Lot Number	
2. Date of Preparation of Stock Sucrose Solution	
3. Weight of Sucrose for Stock Solution (m_1)	g
4. Volume of Sucrose Stock Solution (v_1)	ml
5. TOC Concentration in Stock Sucrose Solution (S_{stock}) $$TOC = \left(\frac{m_1 \text{ grams sucrose}}{v_1 \text{ liters solution}} \right) \times 421069$$	μg/L
6. Date of Preparation of Standard Sucrose Solution	
7. Volume transferred from Stock to Standard Sucrose Solution (v_2)	mL
8. Volume of Standard Sucrose Solution (v_3)	mL
9. TOC Concentration in Standard Sucrose Solution $$TOC = S_{stock} \times \left(\frac{v_2}{v_3} \right)$$	μg/L
Performed By:	**Date:**
Reviewed By:	**Date:**

Table 3. 1,4-Benzoquinone ($C_6H_4O_2$) Data

1. 1,4-Benzoquinone Lot Number	
2. Date of Preparation of Stock Benzoquinone Solution	
3. Weight of Benzoquinone for Stock Solution (m_2)	g
4. Volume of Benzoquinone Stock Solution (v_6)	ml
5. TOC Concentration in Stock Benzoquinone Solution (SS_{stock}) $$TOC = \left(\frac{m_2 \text{ grams benzoquinone}}{v_6 \text{ liters solution}} \right) \times 666660$$	µg/L
6. Date of Preparation of Standard Benzoquinone Solution	
7. Vol transferred from Stock to Standard Benzoquinone Solution (v_7)	mL
8. Volume of Standard Benzoquinone Solution (v_8)	mL
9. TOC Concentration in Standard Benzoquinone Solution $$TOC = SS_{stock} \times \left(\frac{v_7}{v_8} \right)$$	µg/L
Performed By:	**Date:**
Reviewed By:	**Date:**

Table 4. Data from TOC Measurements

Reagent Water (R_w)		Sucrose (R_s)		1,4-Benzoquinone (R_{ss})	
Reading	**ppb**	**Reading**	**ppb**	**Reading**	**ppb**
1		1		1	
2		2		2	
3		3		3	
Average R_w		Average R_s		Average R_{ss}	

Reagent Water Quality ______MΩ-cm or ________μS/cm

Final reading Reagent Water TOC________ ppb

Table 5. User Limit Response Calculation

$\text{User Limit (ppb)} = R_s - R_w$ =_________ppb -_________ppb =_________ppb

Table 6. Response Efficiency Calculation

$\text{Response Efficiency (\%)} = 100 \times \left(\frac{R_{ss} - R_w}{R_s - R_w} \right)$ =________%	
Performed By:	**Date:**
Reviewed By:	**Date:**

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