

Development of the Second Generation International Space Station (ISS) Total Organic Carbon Analyzer (TOCA)

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ABSTRACT

The second generation International Space Station (ISS) Total Organic Carbon Analyzer's (TOCA) function is to monitor concentrations of Total Organic Carbon (TOC) in ISS water samples. TOC is one measurement that provides a general indication of overall water quality by indicating the potential presence of hazardous chemicals. The data generated from the TOCA is used as a hazard control to assess the quality of the reclaimed and stored water supplies on-orbit and their suitability for crew consumption. This paper details the unique ISS Program requirements, the design of the ISS TOCA, and a brief description of the on-orbit concept-of-operations. The TOCA schematic will be discussed in detail along with specific information regarding key components.

INTRODUCTION

HIGH LEVEL CONCEPT DESCRIPTION - The ISS Regenerative Water Processing Assembly (WPA) will purify all forms of waste water into potable water for consumption and oxygen generation on the ISS. Water reclamation is required for ISS Logistics when the crew expands from 3 to 6 persons.

The purpose of the TOCA is to take samples of WPA water at crew use locations and analyze them for the presence of TOC. Several principles of TOC analysis are listed below:

- Total Carbon (TC) = Total Inorganic carbon (TIC) + Total Organic Carbon (TOC)
- TIC interferes with the direct measurement of TOC and must be removed prior to measuring TOC
- TOCA converts and removes TIC by creating a pH shift with a slightly acidic buffer which forces inorganic carbon species into carbon dioxide (CO₂) gas
- TOCA oxidizes organic carbon species remaining in the sample water to CO₂ gas
- TOCA produced CO₂ gas is measured using a very precise Infra-red CO₂ detector
- General process steps for the on-orbit instrument include:
 1. Flush and purge liquid and gas loops
 2. pH shift and convert and remove TIC
 3. Detect CO₂ from TIC
 4. Oxidize TOC
 5. Detect CO₂ from TOC
 6. Analyze and report

UNIQUE ISS DESIGN REQUIREMENTS AND CONSTRAINTS - Terrestrially, TOC analyzers employ various methods to determine TOC. Most notably, ground based units involve wet chemistry techniques that use hazardous reagents or high temperature combustion. The first generation¹ ISS TOC analyzer employed phosphoric acid (H₃PO₄) and ammonium persulfate ((NH₄)₂S₂O₈), both designated as toxicity level 2 chemicals. The reagents resulted in design complexity and required two verifiable levels of containment. The lessons learned from the first generation TOCA resulted in the ISS Program requesting the new unit not utilize hazardous liquid reagents.

The analytical range also posed a challenge. The ISS Program required a 1,000 to 25,000 µg/L range with an accuracy of ± 25%. The need for a large analytical range was driven by the various international supplies of potable water. The go/no-go decision on water potability is 3,000 µg/L for WPA supplied water and 20,000 µg/L for Russian Segment Water.

Other unique application issues are shown in Table 1.

Table 1: Unique Constraints and Design Implications

Spaceflight Constraint	Design Implication
Reagent toxicity	Use non-toxic oxidation process
Microgravity	Special handling of two phase flow
Crew safety	Redundancy, numerous sensors and controls
Size limitations	Very tight packaging
Maintainability	Open architecture of replacement modules
Small water sample	Miniaturization of system wetted volumes

Taken together, these constraints resulted in an initial design concept for a non-toxic TOC analyzer to be deployed in a flight-ready package that is robust to the special considerations of microgravity and the on-orbit cabin environment. This basic concept was developed through laboratory component level testing, two moderate fidelity integrated system breadboard prototypes, a flight-like full scale prototype, and the final TOCA unit. Throughout the development, system interactions and sensitivities were discovered and characterized to define the desired performance operating envelop. Some specific development challenges are shown in Table 2.

Table 2: System Sensitivities and Design Implications

System Sensitivity	Design implication
Interference from cabin CO2	Purge subsystems, attention to permeation, use of adsorber to remove residual CO2 in ISS N2
H2, O2 byproduct generation	Recombination of H2 and O2 back to water using Platinum Catalyst
Condensate generation	Moisture exchanger
Bubble trapping	Internal flow geometries Flow rates
Pressure, temperature	Pressure regulator, mass flow controller Precision flow orifices thermoelectric chiller to control water temp VCA to control pressure
Contamination, reactivity	Inert wetted materials, filters, Foreign Object Debris (FOD) protection

The overall TOCA layout consists of a custom integrated chassis with an electronics and fluids module as shown in Figure 1. Commercial-Off-the-Shelf (COTS) components for internal hardware were selected where appropriate and integrated based on lessons learned during development. The electronics module contains power supplies, power distribution circuits, a computer, and a touchscreen interface. With the exception of wire feed throughs, the fluids module is separate in terms of structure and chassis cooling. The fluids module chassis consists of front and rear compartments separated by a mid-plane bulkhead. Access to both compartments is made via large access panels where the front panel allows access to several modules requiring servicing throughout nominal operations [e.g., sample bag, acidic buffer container, waste bag, an oxidizer reactor, and a gas-liquid-separator (GLS)].

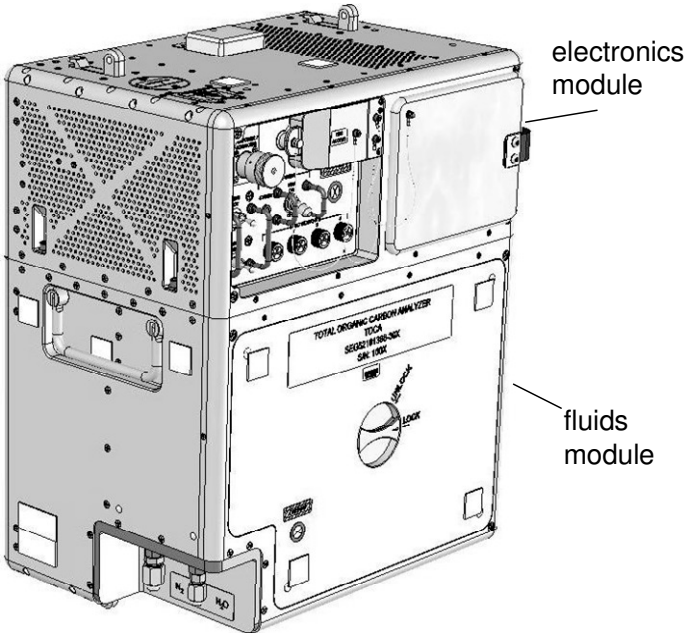


Figure 1. TOCA Layout

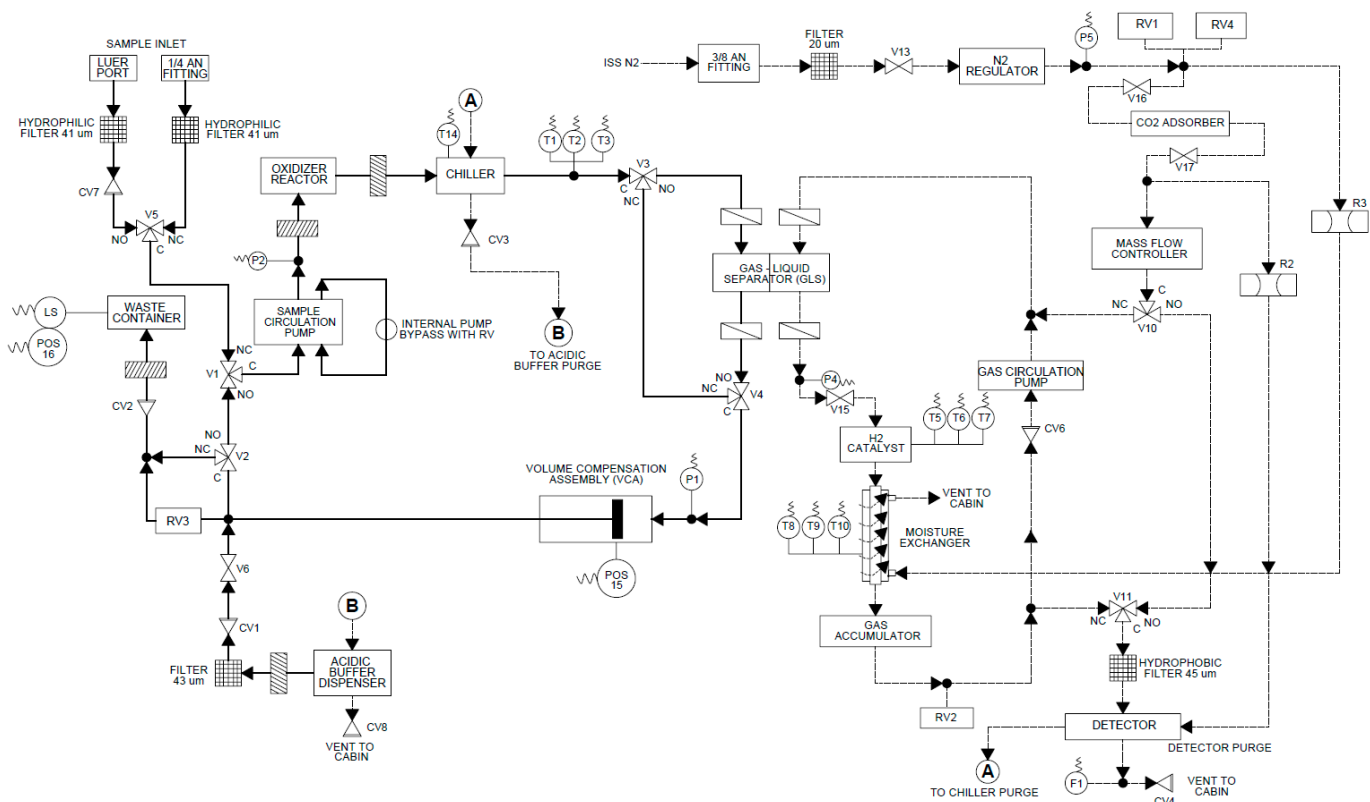


Figure 2. TOCA Process Schematic

TOCA SCHEMATIC AND HARDWARE DESCRIPTION

The major elements of the TOCA schematic are shown in Figure 2. Several underlying core technologies of the analyzer including the Boron Doped Diamond (BDD)-coated electrode oxidizer^{2,3}, Volume Compensation Assembly (VCA), and CO₂ detector⁴ were developed at OI Analytical. The analyzer uses an innovative BDD-based electrolysis reaction to oxidize the organic carbon. The TOCA consists of two loops that perform the TOC analysis: a water sample loop and a gas loop. The water sample loop's primary function is to introduce and prepare the water sample for analysis. The sample loop contains valves and a pump to direct sample flow, a gas/liquid separator to remove gas from the water sample, a Volume Compensation Assembly (VCA) to provide for sample loop volume adjustability as gas is eliminated (either by de-bubbling the initial sample draw or as TIC and TOC conversion are accomplished), an acid buffer solution container for TIC conversion, and an oxidizer reactor to oxidize TOC.

The gas loop requires the use of ISS Nitrogen (N₂) as a sweep gas. It contains valves and orifices to control and direct gas flow, an adsorber to remove residual CO₂ from the ISS N₂, a hydrogen catalyst to reduce Hydrogen (H₂) and Oxygen (O₂) byproducts from the oxidizer's electrolysis process, a Nafion® tube based moisture exchanger to remove moisture within the gas loop, and a Non-Dispersive – Infrared (ND-IR) detector to detect CO₂ from the TIC and TOC conversions.

The next several sections of this paper will detail component specifics, including primary function and contribution to the overall system during the various operating stages.

SAMPLE CIRCULATION WATER PUMP - The sample circulation pump is a COTS, brushless, DC magnetically-coupled gear pump. A key operating parameter for the TOCA is controlling the water flow rate. A relatively high sample flow rate is needed to prevent bubble trapping inside the liquid lines. An insufficient flow rate allows bubbles to be trapped (especially detrimental to the BDD electrodes) while an excessive flow rate results in unnecessarily high operating pressures that limit choices of hardware selections. The sample pump allows the sample loop to operate at different flow rates by varying the flow control voltage. The TOCA default flow rate is about 140 mL/min. The flow rate is throttled down to approximately 110 mL/min during the TIC Detect operating mode to provide an enhanced gas transfer across the GLS as observed on breadboard level testing. The flow rate then increases to approximately 190 mL/min during the TOC react operating mode to enhance bubble removal on the surfaces of the BDD electrodes used in the oxidizer. The sample pump has an internal relief valve that allows internal recirculation to occur if a downstream failure in sample loop were to produce a deadhead or blocked flow condition on the pump.

GAS LIQUID SEPARATOR - Ground-based instruments operating with wet chemistry often use gravity assisted