

Root Cause Assessment of Pressure Drop Rise of a Packed Bed of Lithium Hydroxide in the International Space Station Trace Contaminant Control System

Tatiana Aguilera
Carnegie Mellon University

Jay L. Perry
National Aeronautics and Space Administration

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ABSTRACT

The trace contaminant control system (TCCS) located in the International Space Station's (ISS) U.S. laboratory module employs physical adsorption, thermal catalytic oxidation, and chemical adsorption to remove trace chemical contamination produced by equipment offgassing and anthropogenic sources from the cabin atmosphere. The chemical adsorption stage, consisting of a packed bed of granular lithium hydroxide (LiOH), is located after the thermal catalytic oxidation stage and is designed to remove acid gas byproducts that may be formed in the upstream oxidation stage. While in service on board the ISS, the LiOH bed exhibited a change in flow resistance that leading to flow control difficulties in the TCCS. Post flight evaluation revealed LiOH granule size attrition among other changes. An experimental program was employed to investigate mechanisms hypothesized to contribute to the change in the packed bed's flow resistance. Background on the problem is summarized, including a discussion of likely mechanisms. The experimental program is described, results are presented, and implications for the future are discussed.

INTRODUCTION

CONTAMINATION CONTROL ON BOARD ISS – The trace chemical composition of the International Space Station's (ISS) cabin atmosphere is maintained by employing both passive and active means. Passive

means involve screening materials, equipment, and supplies delivered to orbit to ensure that their chemical offgassing characteristics comply with materials selection and control standards as well as safety standards. While passive methods are effective for limiting the magnitude of trace chemical offgassing sources, they do not eliminate them. Therefore, active methods must be employed to prevent chemical contamination buildup in the cabin atmosphere.[1]

Two active trace contaminant control processes purify the cabin atmosphere on board the ISS. The trace contaminant control system (TCCS) is located in the ISS U.S. On-orbit Segment's (USOS) laboratory module and the micropurification unit known by its Russian acronym, BMP, is located in the Russian On-orbit Segment's (ROS) service module. Together, the TCCS and BMP purify the ISS cabin atmosphere by removing a broad spectrum of chemical contaminants through physical adsorption and catalytic oxidation processes. The BMP has been functioning since the ROS service module's activation in December 1998 and the TCCS has been functioning since the USOS laboratory module's activation in February 2001. References 2 and 3 provide more details on the TCCS and BMP process designs and their basic functions.

USOS ACTIVE TRACE CONTAMINANT CONTROL – The TCCS equipment consists of a carbon bed assembly (CBA), catalytic oxidizer assembly (COA), and sorbent bed assembly (SBA) connected by ducting and supported by electrical and process control systems.

The CBA removes non-methane volatile organic compounds (VOCs) from the cabin atmosphere. Light VOCs such as methane, carbon monoxide, formaldehyde, and hydrogen which are not removed by activated carbon are oxidized over a catalyst in the COA. The COA operating temperature is 400 °C. The SBA contains granular lithium hydroxide (LiOH) that reacts with any acidic oxidation products that may be produced in the COA. A blower located downstream of the CBA provides cabin atmospheric gas flow through the TCCS equipment. The process flow splits downstream of the blower and approximately one-third of the process gases pass through the COA and SBA subassemblies. The balance of the process flow bypasses the COA and SBA. The split flows recombine downstream of the SBA just before the TCCS exhaust. A flow meter located just upstream of the COA provides feedback control to the blower to adjust the motor speed such that the proper flow is maintained through the COA. Figures 1 and 2 show a simplified process flow diagram of the TCCS and views of the TCCS equipment, respectively.

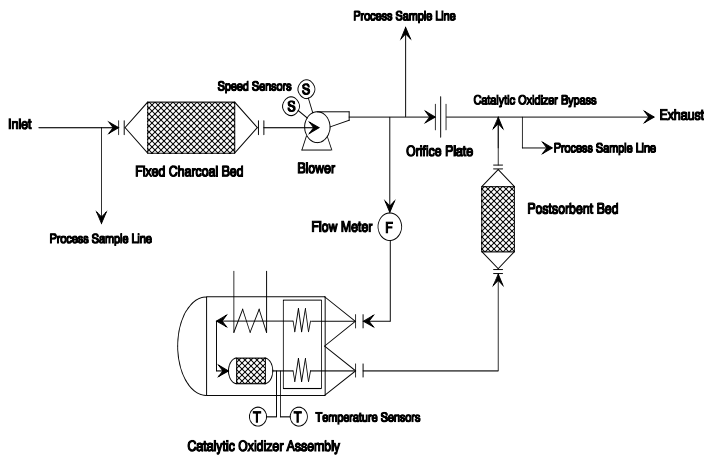


Figure 1. Simplified TCCS Process Flow Diagram

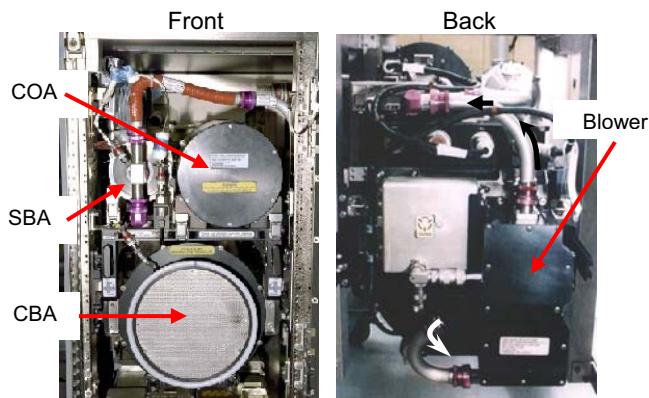


Figure 2. Views of the TCCS Equipment

TCCS Preventive Maintenance Cycles – The CBA, COA, and SBA are on-orbit replaceable units (ORU) and undergo scheduled preventive maintenance. The ORUs are returned to Earth where they are refurbished and

readied for the next maintenance event. Assessment of cabin atmospheric quality established preventive maintenance cycles of 4.5 years, “wear-out”, and 6 years for the CBA, COA, and SBA, respectively.[4] These maintenance cycles are reviewed periodically as operational experience is gained. In particular, post-flight ORU refurbishment provides a wealth of information that is vital to managing the preventive maintenance cycle. Recent in-flight assessment and post-flight ORU evaluation found that difficulties associated with in-flight TCCS process gas flow control resulted from increasing flow resistance through the SBA.[5] A summary of the SBA equipment and flight operational experience follows.

Sorbent Bed Assembly Characteristics – The SBA provides important post-processing of the atmospheric gas flow in the TCCS downstream of the COA by removing undesirable oxidation products such as hydrogen chloride (HCl) and hydrogen fluoride (HF) that can be produced if halogenated compounds enter the COA. The normal process gas flow through the SBA is 70.8 standard L/minute (2.7 standard ft³/minute).[6] Bed components are constructed from 321 and 347 stainless steel alloys. The bed packing containment assemblies located at each end of the SBA consist of a 316L stainless steel screen and polypropylene mesh filters. Figure 3 shows the exterior of the SBA and Figure 4 shows an exploded view of the SBA assembly.



Figure 3. TCCS SBA Equipment

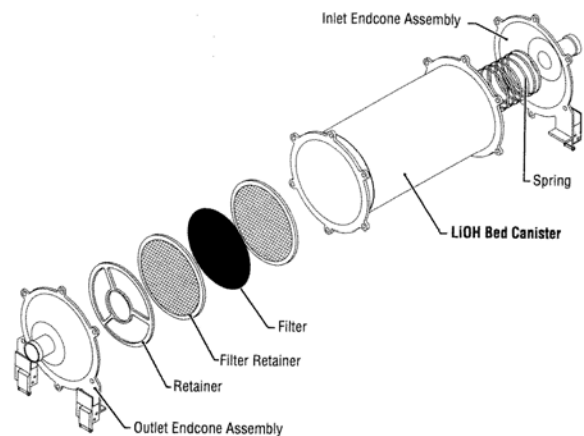


Figure 4. TCCS SBA Assembly Components

Sorbent Bed Assembly Flight Operations Experience – Assessment of telemetry and in-flight investigation discovered that flow resistance through the COA and SBA flow path increased over time. While the TCCS flow control algorithm's operational margin was sufficient to compensate for the degrading condition for approximately 3.5 years, the proper flow eventually could not be maintained resulting in frequent TCCS shutdowns. The SBA was replaced in February 2006, approximately 2 years earlier than scheduled, and normal TCCS flow control was restored indicating that the SBA was the source of the increased flow resistance. Post-flight evaluation of the CBA, COA, and SBA units established without doubt that increased flow resistance within the SBA caused the flow control problem. Further investigation has been conducted to better understand the mechanism leading to increased flow resistance.

A ROOT CAUSE HYPOTHESIS

Observations from both TCCS developmental testing and post-flight SBA refurbishment provide insight for developing a root cause hypothesis for the mechanism that leads to increased flow resistance through the bed. The following discussion presents these observations.

DEVELOPMENTAL TESTING OBSERVATIONS – Two developmental tests provide early insight to observations from the SBA's post-flight evaluation.

TCCS Functional System Test – A 45-day functional test documented in 1992 found a “brownish” discoloration of the LiOH at the SBA inlet during post-test inspection. The “reddish-brown” material was found on the inlet retainer screen, LiOH granules, and the cannister's top interior surfaces. Elemental analysis found lithium (Li), iron (Fe), nickel (Ni), and chromium (Cr) as major components of the discolored material. Manganese (Mn), magnesium (Mg), molybdenum (Mb), tin (Sn), copper, (Cu), and titanium (Ti) were found as minor and trace elements. It was concluded that the discoloration resulted from iron oxide (Fe_2O_3) produced by exposure of the retainer screen and other metallic parts to LiOH and acid gases. [7]

Predevelopment Operational Systems Test – A second test conducted in early 1991 incorporated a pre-development TCCS unit into an early integrated life support system test for the space station program. During post-test inspection, the SBA bed materials were found to be “caked” and discolored at the inlet. The discoloration was attributed to Fe_2O_3 and ferrous oxide (FeO). The nature of discoloration was not described but Fe_2O_3 is dark red while FeO is black. [8]

Other Developmental Testing – A number of media were evaluated in the late 1960s for removing acid gases from a spacecraft cabin atmosphere. Lithium carbonate (Li_2CO_3) was investigated as a candidate and was

concluded to be the most effective media for removing HCl from a cabin atmosphere. Documentation of the investigation noted no granule size attrition or color changes associated with the chemical reaction between Li_2CO_3 and the HCl challenge. [9]

More recently, LiOH granules that had been subjected to 4 years of operation downstream from a developmental TCCS COA unit that was undergoing life testing were inspected. Some of the LiOH granules were found to have become stuck together but no size attrition was noted. Likewise no discoloration at the bed inlet was observed. It should be noted that the COA unit was not subjected to a halocarbon load during the life testing because the primary objective was to demonstrate long-term thermal stability of the catalyst.

SBA POST-FLIGHT OBSERVATIONS – Specific observations during the SBA's post-flight refurbishment are four-fold. First, the granular LiOH broke down into smaller particles. This breakdown was observed through the first 8 cm of bed depth. The remaining bed material was unchanged. Second, discoloration of the inlet filter media indicated a chemical change. Third, the chemical analysis of the bed material indicated that all the chlorine, fluorine, and water were contained in the first 8 cm of the bed depth. The remaining bed material contained only trace amounts of halogens and moisture. And fourth, all of the LiOH was found to be converted to carbonate. Figure 5 shows the LiOH granule size attrition and inlet filter media discoloration observed during the post-flight SBA refurbishment. As noted previously TCCS developmental testing reported similar discoloration with some evidence of possible size attrition.

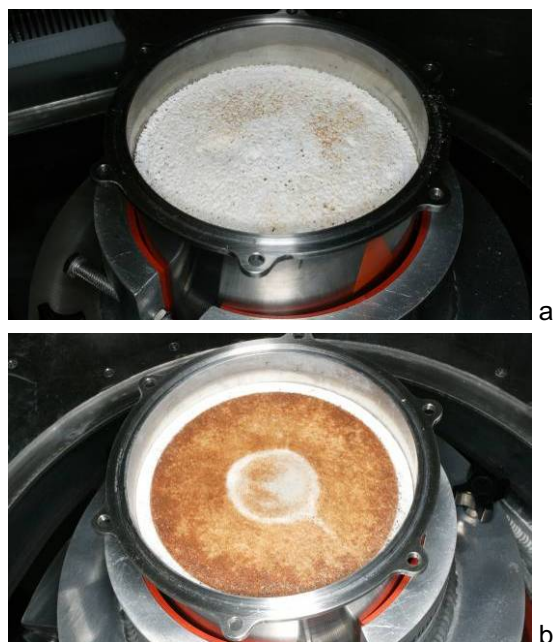


Figure 5. Powdered SBA Bed Material (a) and Inlet Filter Discoloration (b)