Characteristics of Post-Sorbent and High Temperature Catalytic Oxidizer Beds After Long-Term On-Orbit Use

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ABSTRACT

Trace contaminants are produced on-orbit by human metabolic processes and equipment off-gassing. These potentially hazardous contaminants are removed by the Trace Contaminant Control Subassembly (TCCS) in the US segment of the International Space Station (ISS). The TCCS has been operating since February 2001. Analysis of on-orbit telemetry data indicated a slow increase in the TCCS system flow resistance over the five years of operation. Two of the packed beds within the TCCS were replaced to return the TCCS to its nominal operation conditions; the high temperature catalytic oxidizer and the post-sorbent bed. Results from the examination of the returned beds are presented along with a discussion about changes to bed service life.

INTRODUCTION

The Trace Contaminant Control Subassembly (TCCS) has been operating within the Atmosphere Revitalization Rack in the International Space Station (ISS) Laboratory Module since February 2001. The TCCS removes potentially hazardous gaseous trace contaminants generated by equipment off-gassing and crew metabolic processes. It consists of three packed beds: an activated charcoal bed, a high temperature catalytic oxidizer, and a post-sorbent bed.

Figures 1 and 2 show a simplified schematic and a drawing representation of the TCCS. The Blower Assembly nominally moves 15.3 m^3/hr (9.0 cfm) of cabin air through the Charcoal Bed Assembly (CBA). The CBA removes most high molecular weight components, ammonia and volatile organic compounds (VOCs). The airflow is then divided and approximately one third, 4.6 m^3/hr (2.7 cfm), flows through the catalytic oxidizer flow branch of the TCCS. This flow branch consists of the Flow Meter Assembly, Catalytic Oxidizer Assembly (COA), and Sorbent Bed Assembly (SBA). The COA is a high temperature catalytic oxidizer which removes low molecular weight components such as formaldehyde, methane, hydrogen and carbon monoxide, while the SBA removes any acid gasses produced in the COA by halocarbon oxidation. The remaining process air that bypasses the catalytic oxidizer flow branch combines with the effluent from the SBA and is returned to the Temperature and Humidity Control (THC) ducting.

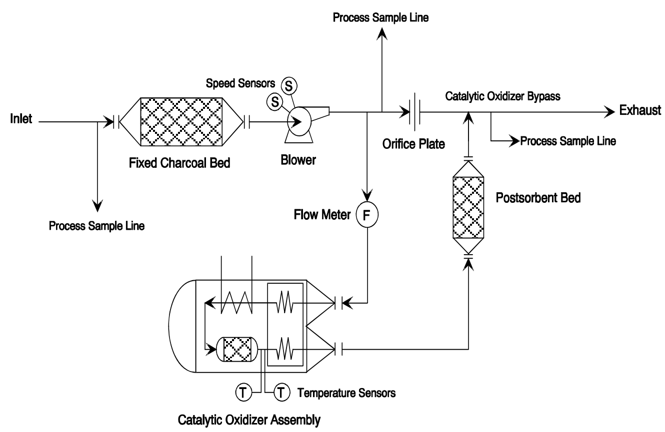

Figure 1: TCCS Schematic

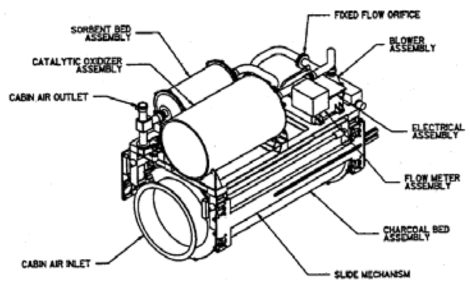

Figure 2: TCCS

ON-ORBIT OBSERVATIONS

An analysis of on-orbit telemetry data is performed to ensure the health of the TCCS. The flow rate through the flow meter and therefore through the catalytic oxidizer branch of the TCCS is maintained via a flow control algorithm between the flow meter and blower. Adjustments to the blower speed will compensate for any changes in cabin temperature, cabin pressure or THC ducting pressure.

The regenerative heat exchanger in the COA maintains the catalyst temperature by cycling the heater at a specific duty cycle. Any changes in the flow through the COA will change the heater duty cycle. When the flow rate decreases, the heater duty cycle is reduced since less heating is required to maintain the catalyst bed temperature. Monitoring the heater duty cycle along with the flow rate through the flow meter ensures that the flow rate through the catalytic oxidizer flow branch is being maintained. It is also a check to see if the flow meter is functioning properly.

Analysis of on-orbit telemetry data showed a slow increase in flow resistance in the TCCS over approximately five years of operation (figure 3). From February 2001, until August 2004, the blower was able to compensate for the increased resistance. Eventually, the blower reached its maximum speed, and the flow rate through the catalytic oxidizer branch varied with changes in cabin pressure and Carbon Dioxide Removal Assembly (CDRA) operation. Examination of heater duty cycle, as shown in figure 4, shows that when the blower remained at 17.3 m3/hr (10.2 cfm), the duty cycle adjusted with the flow meter: when the flow through the flow meter decreased the duty cycle decreased, and when the flow throughout the flow meter increased the duty cycle increased. This indicates a functional flow meter, since a lower flow through the catalytic oxidizer flow branch would require less heating to maintain the catalyst bed temperature. In addition to analyzing telemetry data, ground testing and on-orbit troubleshooting was performed. Results from this additional testing indicated that the increased resistance was due to one or more of the beds in the catalytic oxidizer flow branch.

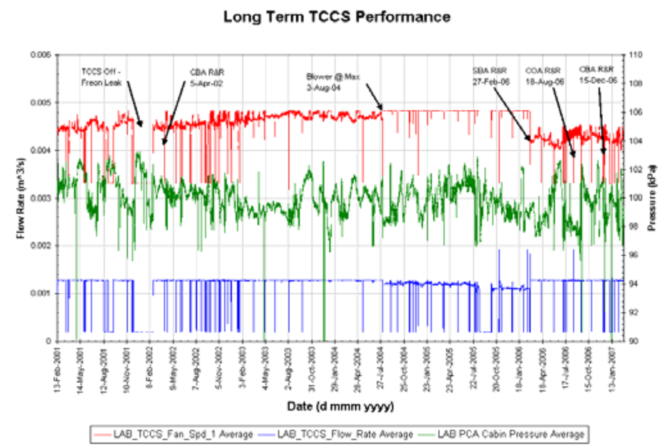

Figure 3: Long Term TCCS Performance

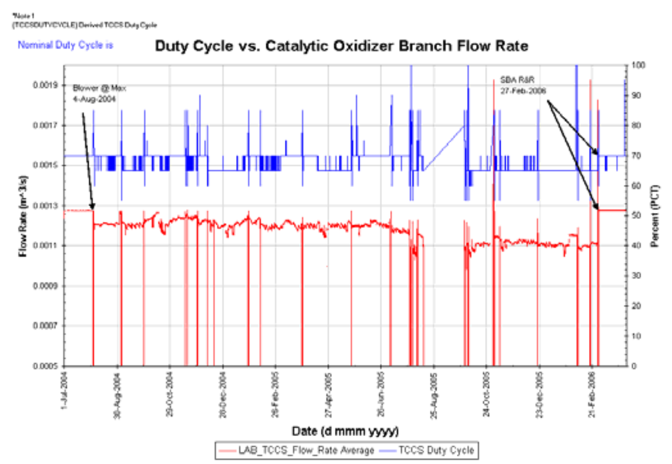

Figure 4: TCCS Duty Cycle

After the SBA was replaced in February 2006, nominal flow conditions returned to the TCCS, pointing to the SBA as the cause of the increased resistance. Additional evidence came when the COA was replaced in August 2006 and the TCCS flow rate did not change.

TEST TEARDOWN AND EVALUATION (TT&E)

There were three hypotheses as to the cause of the increased SBA resistance going into the TT&E of the beds: lithium hydroxide caking, blockage from migrating catalytic oxidizer catalyst pellets, and particulate fines clogging the outlet screen in the bed. In January 2007, the SBA and COA underwent a TT&E to determine the cause of the increased resistance in the SBA. In addition to the visual inspection of the lithium hydroxide and screens, pressure drop tests were performed on the bed in the horizontal and vertical positions to simulate a microgravity environment. Similar pressure drop tests were performed on the COA.

The results of the pressure drop tests with the beds in the vertical position matched the results from the tests in the horizontal position. The delta pressure on the returned SBA was higher than the maximum delta P used for acceptance testing of the unit. This confirms that the increased resistance of the on-orbit TCCS resided within the SBA. The delta pressure on the returned COA was consistent with the pre-launch data, providing additional evidence that the SBA was the sole cause of the increased system resistance.

Contamination was found on the inlet of both packed beds. The contamination at the inlet of the SBA completely covered the inlet filter. There was also some contamination on the lithium hydroxide (LiOH) beneath the filter. The outlet filter of the SBA contained no visible contamination. Additional pressure drop tests were performed to determine whether the contamination build up on the inlet filter contributed to the increased resistance in the bed. Analysis of the contaminated filter when compared to a new filter showed a negligible increase in delta pressure of the bed.

During the TT&E, it was discovered that the first several inches of the bed at the inlet, had become powdered. The SBA is packed with lithium hydroxide (LiOH) that has been sieved to 6 x 14 mesh. The first two to five centimeters (one to two inches) of the returned bed were completely powdered, with the amount of powder decreasing through the length of the bed. At about four inches from the inlet and throughout the remainder of the approximately 25 cm (10 in.) bed, the LiOH granule size was consistent with newly packed LiOH. There was also discoloration/corrosion of the stainless steel canister that corresponded to the powdered sections of the LiOH. This powdering of the LiOH is believed to be the cause of the increased resistance in the SBA.

Examination of the COA showed mechanical degradation of the catalyst pellets. Many of the cylindrical pellets had become rounded and misshapen. There was also an increase in the gap between the top of the pellets and the retaining screen. Nominally the catalyst is packed within 1.3 cm (0.5 inches) of the top of the interior wall of the canister. The returned bed had a gap of almost 2.5 cm (1 inch), indicating catalyst settling. An increased gap in the packed bed allows for movement during shipping and launch conditions, increasing the possibility of catalyst damage.

Chemical composition analysis of the contamination on both beds is still being performed. In addition, chemical composition, percent moisture, and particle size analyses will be performed on the LiOH samples from the returned SBA.

CAUSE OF LIOH POWDERING

The cause of the LiOH powdering is still under investigation. Preliminary analysis data is showing that the samples at the inlet of the bed have a moisture content that is higher than at the outlet of the bed. Moisture can be introduced into the bed in a variety of ways: long term introduction from humidity in cabin air, as an oxidation product in the COA, and as a byproduct from the conversion of lithium hydroxide to lithium carbonate in the SBA itself.

DISCUSSION

On-orbit telemetry data shows that the increased resistance in the SBA occurred over a period of several years. The blower was able to compensate for the increased resistance until August 2004, three and a half years after the unit was initiated on-orbit. After that, although the flow rate through the catalytic oxidizer branch of the TCCS decreased, the air quality aboard the ISS was maintained.

Currently the service life of the SBA is 6.3 years while the COA is scheduled to run to failure. Failure criteria for the COA would be Resistance Temperature Detector (RTD) or heater failure. These service life schedules are based on airborne contaminant removal alone. Increased resistance in the SBA due to powdering of the LiOH in the bed appears to occur over the course of several years of on-orbit operation. There has also been mechanical breakdown of the catalyst pellets within the packed catalyst bed within COA. Since these mechanical limitations of the beds have been noted, bed lifetimes will be reevaluated based on the mechanical characteristics of the post-sorbent and high temperature catalytic oxidizer beds.

CONCLUSION

After approximately five years of operational use on-orbit for the post-sorbent bed and five and a half years for the high temperature catalytic oxidizer bed, these TCCS beds were returned for examination. These beds were returned before their scheduled replacement due to increased bed resistance observed on-orbit. During the post-flight analysis of the beds, it was confirmed that the Sorbent Bed Assembly (SBA) was the cause of the increased resistance in the TCCS. This increased resistance was caused by powdering of the LiOH in the SBA. In addition, the Catalytic Oxidizer Assembly (COA) experienced mechanical breakage of the catalyst pellets within its packed bed. Although the beds have exhibited mechanical limitations, the TCCS has been able to maintain air quality aboard the International Space Station.

RECOMMENDATION

Based on the physical characteristics of the returned SBA and COA beds, it is recommended that the service life of these beds be determined based on the physical limitation of the beds and not on contamination removal alone. At this time there is no intention to change the design of the beds, as these characteristics may be intrinsic to the beds themselves and should not necessarily be considered failures.

ACKNOWLEDGMENTS

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