

International Space Station United States Orbital Segment Oxygen Generation System On-orbit Operational Experience

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ABSTRACT

The International Space Station (ISS) United States Orbital Segment (USOS) Oxygen Generation System (OGS) was originally intended to be installed in ISS Node 3. The OGS rack delivery was accelerated, and it was launched to ISS in July of 2006 and installed in the US Laboratory Module. Various modification kits were installed to provide its interfaces, and the OGS was first activated in July of 2007 for 15 hours. In October of 2007 it was again activated for 76 hours with varied production rates and day/night cycling. Operational time in each instance was limited by the quantity of feedwater in a Payload Water Reservoir (PWR) bag. Feedwater will be provided by PWR bag until the USOS Water Recovery System (WRS) is delivered to ISS in fall of 2008. This paper will discuss operating experience and characteristics of the OGS, as well as operational issues and their resolution.

INTRODUCTION

The U.S. regenerative Environmental Control and Life Support Systems (ECLSS) have been developed to enable the ISS to expand its crew size from three to six crewmembers. These regenerative systems include the WRS and the OGS. The OGS includes the Oxygen Generation Assembly (OGA), the Power Supply Module (PSM) that supports the OGA, an Area Smoke Detector (ASD), an Avionics Air Assembly (AAA) to move cabin air through the OGS smoke detector and minimize oxygen concentration buildup within the OGS rack, and scars to accommodate the later addition of a Sabatier Carbon Dioxide Reduction Assembly (CRA). Iodinated feedwater is pumped from a 10 liter PWR bag to the OGS by an externally mounted Water Delivery System (WDS) that has a gear pump and accumulator. The temporary PWR and WDS feedwater source will not be needed once the WRS racks are activated and the OGS connects to the pressurized LAB potable water bus.

Prior to the OGS activations, the ISS LAB port water vent was replaced with a new hydrogen vent line and non-propulsive vent that was installed during Flight 13A EVA3. Earlier development activities and the LAB modifications required to accommodate the OGS are summarized in references 1-8.

OXYGEN GENERATION SYSTEM

OGA OVERVIEW - A simplified schematic of the OGA is shown in Figure 1 and its installation in the OGS rack is shown in Figure 2. Iodinated feed water from either a PWR supplied WDS accumulator or the pressurized potable water bus enters the assembly through the Water Orbital Replacement Unit (ORU) and flows through an Inlet Deionizing Bed, which serves as an iodine remover as well as a coalescer for any gas bubbles that may be present in the feed water. If gas bubbles are detected by the gas sensor downstream of the DI bed, the feed water is rejected to the waste water bus. This serves to prevent any oxygen that may be present in the feed water from mixing with generated hydrogen. Water is electrolyzed into oxygen and hydrogen in the Hydrogen ORU, which contains the electrolysis cell stack. Oxygen produced by the cell stack passes through the Oxygen Outlet ORU containing a water absorber, which protects the three downstream hydrogen sensor dies from liquid moisture. These sensor dies are in the Hydrogen Sensor ORU, which monitors the product oxygen for the presence of hydrogen. Detected hydrogen would indicate a problem with the cell stack and signal the controller to shut down the OGA. The Rotary Separator Accumulator (RSA) within the H₂ ORU separates the product gaseous hydrogen from the water which is re-circulated by the Pump ORU. The gaseous Hydrogen separated from the recirculation water by the RSA along with some water vapor is vented directly from the OGA subambient dome through a dedicated ISS vent line connected to a heated, non-propulsive overboard vent. The Nitrogen Purge ORU serves to purge system lines upon shutdown with

nitrogen, and the Process Controller ORU is responsible for OGA System command/control and communication with the ISS Multiplexer/Demultiplexer (MDM).

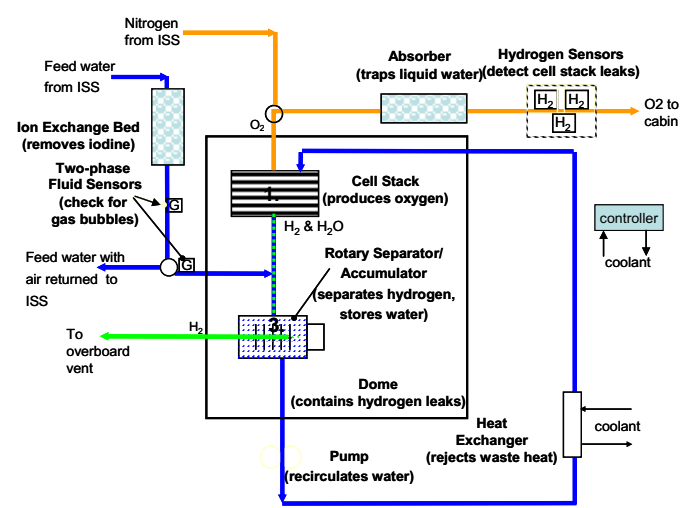


Figure 1. OGA Simplified Schematic

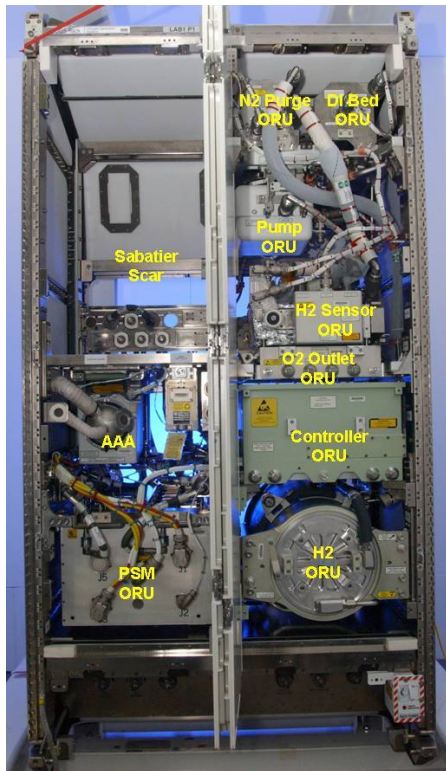


Figure 2. Oxygen Generation System

The OGA is designed to generate oxygen at a maximum nominal rate of 5.4 kg/day (12 lb/day) when operated on day/night orbital cycles, and also at a selectable rate between 2.3 and 9.2 kg/day (5.1 and 20.4 lb/day) when operated continuously. At the maximum nominal day/night cycle rate, the OGA can support the oxygen needs for six crew and biological specimens, and atmosphere leakage, while at the maximum continuous rate it can support eleven crew, biological specimens, and atmosphere leakage. The OGS consumes 2971 W when processing at the maximum oxygen production

rate and 469 W during standby at beginning of cell stack membrane life. At the end of cell stack membrane life, OGS power consumption increases to 3955 W during maximum process mode and 497 W during standby. The product oxygen meets quality specifications for temperature, free water, dewpoint, and hydrogen content.

POWER SUPPLY MODULE OVERVIEW – The PSM is shown in the lower left of the OGS rack in Figure 2. The PSM provides 10-55 amps current to the OGA cell stack during Process mode and 1.0+/-0.2 amps during Standby mode, with a minimum efficiency of 91% in Process mode. The PSM is designed for 60,000 process/standby cycles, and a 10-year life.

ON-ORBIT OPERATION

The OGS has been activated three times since its July 2006 installation in the ISS. During the first activation, the OGS operated in Standby (~2% of maximum oxygen production) for 6.8 hours and in Process (25% to 100% of maximum oxygen production) for 15.8 hours, which converts to approximately 13.4 Equivalent Full Power Hours (EFPH). During the second activation, the OGS operated in Standby for 26.8 hours and in Process for 47.1 hours, which converts to approximately 31 EFPH. During the third activation, the OGS operated in Standby for 29.6 hours and in Process for 82.9 hours, which converts to approximately 45.3 EFPH. The following sections describe the activations in more detail.

FIRST ACTIVATION, ON-ORBIT DAY 2007:192 (JULY 11) - When the first activation of the OGS was attempted on July 11, 2007, it was understood that there could be some problems with startup. The system had been dormant—apart from periodically powering the controller, the recirculation pump, and exercising some valves—since December 2005. It was known that the water in the hydrogen side of the cell stack would permeate to the oxygen side, and the nitrogen in the oxygen side would permeate to the hydrogen side. As a result, the RSA would be low in water quantity and would likely cause a shutdown. Also, since water permeates to the oxygen side of the stack, this water would then be pushed into the hydrogen dome during the initial nitrogen purge of the cell stack, which would extend the needed time to dry out the dome.

In light of this information, it is not surprising that there were 11 fast shutdowns caused by system conditions during the first attempted activation of the OGS. Fault limit overrides were implemented to overcome many of the difficulties of starting the system. The timeline for the first activation is shown in Figure 3.

In addition to the anticipated startup issues, on GMT 192 (prior to the first OGS activation) a closed LAB element hydrogen vent line valve was observed to be leaking before opening the valve in preparation to vent the OGA hydrogen dome to space vacuum. A Vent Dome command is issued to evacuate any water from the

dome in a controlled manner so that freezing of the water does not occur. The hydrogen vent line pressure decayed from 440 to 310 mmHg over an interval of 290 minutes. This equated to a leak rate of 0.53 mmHg/minute through the valve (with no thermal variances taken into account.)

On GMT 192 the LAB Hydrogen Vent Valve was cycled open and closed once to allow a soft seat seal blow-by flow in an attempt to clear any postulated contamination using an 820 ml volume of nitrogen gas, initially pressurized to 362 mmHg, then vented to space vacuum. A 10 minute hydrogen vent line/dome leak check was performed with 259 mmHg pressure on the closed Hydrogen valve's inlet and the OGA hydrogen dome's absolute pressure sensor (7314) showed no pressure loss to space vacuum. Leakage was not observed, but the dome pressure was already very low.

After the successful LAB Vent Valve leak check and prior to the first OGS startup, a 110 minute hydrogen vent line leak test was initiated by the OGA Line Check command. The startup leakage test of the hydrogen vent line requires both the LAB element internal hydrogen vent valve and the internal OGA dome vent valve to both be closed in order to isolate the evacuated vent line volume from space vacuum and the OGA dome volume. Safety mandated a confirmation of the previously measured, pre-13A installation leakage during this activity since a final connection of the vent line jumper hose to the OGS was to be performed just prior to activation. The 110 minute OGA Line Check acceptance criteria of < 2 mmHg (pressure increase) was established to equate to the hazard control leakage for a worst-case double failure scenario of cell stack rupture and the LAB vent valve failed closed. The 110 minute Line Check was successfully conducted on GMT 193 and tested for cabin air leaking into the contained, evacuated vent line volume. OGA CSCI monitored the hydrogen vent line pressure sensor (P_7312) and it was determined that 0.11 mmHg pressure increase was below the success criteria of < 2 mmHg over 110 min.

Before the OGS can start, the hydrogen dome must be evacuated and dried of any water. The dome must be dry to allow for leakage detection. Sufficient time must be given to evacuate the dome to vacuum to evaporate any resident water so that the dome pressure will not rise above the pressure trip-point after the evacuation procedure is complete.

Not enough time was allowed for the software-controlled dome vent evacuation procedure, so high hydrogen dome pressure caused the first two fast shutdowns. As mentioned above, these shutdowns were caused by the fact that the system was dormant for so long that water accumulated in the oxygen side of the cell stack, which was then purged into the hydrogen dome. The first startup attempts dried the dome enough so that, by the third attempt, the dome had dried enough so another high dome pressure failure was avoided.

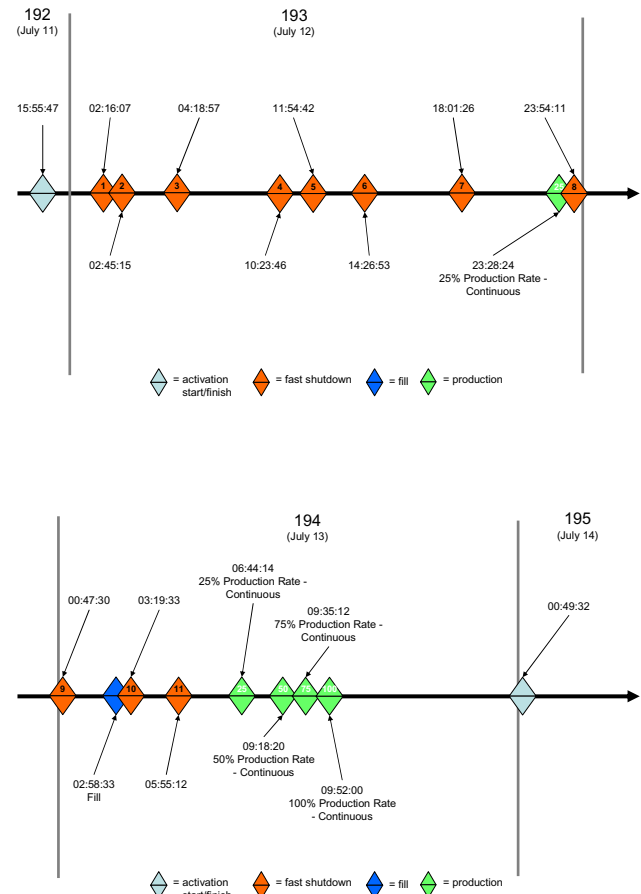


Figure 3: 1st Activation Timeline

Low RSA quantity caused the third fast shutdown. This was expected to be a problem due to water crossover in the cell stack. Overrides were prepared for the RSA quantity and speed trip points so that the system could continue with the startup procedure and eventually fill the RSA with water.

High water flow rate in the OGS water recirculation loop appeared to be the cause of the fourth and fifth shutdowns. However, it is speculated that it was not, in fact a high flow rate that caused the shutdown, but an anomaly with the Venturi used to measure the flow rate. Since the RSA speed was increased after the third shutdown to remedy the low RSA water condition, it was speculated that the extra speed in the RSA caused an increase in water flow. However, a similar condition was observed in ground testing, and was attributed to gas bubbles in the Venturi pressure taps causing errors in the readings. The solution implemented in the ground tests was to push high flows of water through the Venturi to purge the bubbles. This solution worked, and so the bubble theory was accepted. The on-orbit condition could have occurred due to redistribution of gas by launch loads. In order to continue beyond this failure, the shutdown trip-point was overridden to a higher flow rate. Higher recirculation flow rates were used during