Performance Work Statement
For
International Space Station (ISS) Water Processor Assembly (WPA) Ambient Catalytic Reactor Catalyst Development

April 2, 2014

1.0 ABSTRACT

This performance work statement encompasses the development of high efficiency water processing oxidation catalyst capable of operation at ambient pressure and a temperature below the boiling point. In summary, water is reclaimed on the International Space Station (ISS) from crew latent, crew urine, and Sabatier reactor product water. The Water Processor Assembly (WPA) uses adsorption and ion exchange to remove the majority of dissolved contaminants; however, volatile organic chemicals are not effectively removed via adsorption. These contaminants are treated with a Catalytic Reactor that oxidizes the organics at elevated temperature (above the normal boiling point of water) and with a gaseous oxygen feed. Operation at elevated temperature results in a more complex system design compared to a reactor that could operate at ambient pressure. However, catalysts currently available have insufficient activity to achieve complete oxidation of the organic load at a temperature less than the boiling point. The purpose of this research is to develop an improved catalyst that can completely oxidize the desired organic load at ambient pressure and a temperature < 200°F. The contaminant level defined as the "requirement" represents the nominal concentrations observed on ISS, whereas the "goal" level represents the specification levied on the current flight catalyst. Complete oxidation to carbon dioxide is preferred, but the requirement is to achieve < 3 mg/L of non-ionic Total Organic Carbon (TOC).

2.0 PERFORMANCE WORK STATEMENT

The contractor shall proceed with the catalyst development in accordance with the constraints and requirements described herein. In addition, the contractor shall outline appropriate quarterly milestones for their proposed catalyst development plan.

2.1 Constraints and Requirements

Operating Conditions

The developmental catalyst is required to operate under the following process conditions:

- Temperature: < 200°F (93.3°C)
- Pressure: Ambient cabin pressure, 14.7 psia
- Nominal Feedwater Flowrate: 13 lb_m/hr
- Oxygen Feed Rate: 0.011 lb_m/hr
- Reactor Volume: 1,100 cm^3

- Acceptable Bed Pressure Drop: < 5 psi*

*Note: Pressure drop must be measured in flow configuration matching that in which the full oxidation performance of the catalyst was achieved.

Benchmarking

High single-pass oxidation efficiency is desirable to prevent accumulation of contaminants over time with water recycling. If possible, individual component oxidation efficiencies should be reported as defined by Equation 1. Note that the reported reactor effluent concentration for each contaminant shall be relative to the analytical instrumentation method detection limit used for analysis.

$$\text{Oxidation efficiency for component } i = \frac{(C_{i,IN} - C_{i,OUT})}{C_{i,IN}} \times 100\% \quad (1)$$

Required Performance

Non-ionic Total Organic Carbon level must be **< 3 mg/L**. Separation, quantification, and identification of reactor effluent/oxidation products are preferred. Secondary TOC contamination should be quantified.

Feedstock Ersatz

The challenge load ersatz shall be an aqueous solution of volatile organic chemicals as described by Table 1 used to simulate the nominal reactor feedwater. Deionized water shall be used as a solvent for the challenge feed stock.

REQUIRED	
Chemical Name	**mg/L**
Acetaldehyde	1.8
Acetone	4.6
Ethanol	25.4
Methanol	5.3
Propylene glycol	23.5
Ethylene glycol	4.1
Formaldehyde	3.8
1-propanol	0.3
2-propanol	2.7
1-butanol	1.0

GOAL	
Chemical Name	**mg/L**
Acetaldehyde	2.74
Acetone	4.4
Ethanol	39.2
Methanol	7.94
Propylene glycol	35.4
Ethylene glycol	5.5
Formaldehyde	5.9
1-propanol	0.45
2-propanol	1.6
1-butanol	1.5
Formic acid	49.9
Urea	3.55

Table 1 - Ersatz Contaminant Listing at the (left) Required Load and (right) Goal Load

Analysis and Characterization

- The contractor shall perform appropriate analytical techniques (e.g. HPLC-MS, TOC, trace) as deemed required to analyze both the inlet ersatz feedstock to the catalytic reactor as well as the reactor effluent. Instrument calibration curves shall exceed the ersatz loading level and terminate at the determined method detection limit. Appropriate standardized methods shall be utilized and documented. From this analysis, oxidation efficiencies for each chemical in the challenge load are to be determined.
- Catalyst apparent density shall be determined to aid in bed filling. If possible for material, specific surface area shall be determined.

Mechanical Stability

The developmental catalyst is required to limit dusting associated with mechanical vibration and shock of space flight. Historical ground test data indicated downstream particulate levels to be **< 10 ppb volume** [Micro Measurement Laboratories, Inc.; IL, USA] under nominal reactor operating conditions. An alternate standardized testing method such as ASTM D4058 should be proposed by the contractor. Feedwater flash evaporation or shock tests may also be proposed.

2.2 Quarterly Milestones

As an example, some suggested quarterly milestones shall include procurement of raw chemicals and materials, calibration and documentation of analytical instrumentation performance, assembly and check-out of reactor test-stand, proposal of test or genealogy matrix, formulation trial catalyst aliquots defined by test matrix, production of full-scale candidate material formulation, characterization of performance (per DRD 1504MA-001), and delivery of final report and materials.

3.0 TASK PLAN & DELIVERABLES

At the completion of the baseline task effort the developed catalyst material and final report shall be delivered to National Aeronautics and Space Administration (NASA)-Marshall Space Flight Center (MSFC) for performance demonstration and evaluation.

The Contractor shall report and document this work and fulfill the requirements of associated Data Requirement Descriptions (DRD's) as outlined in Data Procurement Document (DPD) 1504 (Attachment J-2). The contractor shall determine the data restriction that applies to each data deliverable and mark or transmit the data restriction in accordance with section 2.3.3 of the Data Procurement Document.

3.1 Baseline Task Description

The contractor shall perform research and development work required to design high efficiency water processing oxidation catalyst in accordance with the constraints and demands outlined in Section 2.0 herein. At the completion of this effort, the prototype developmental catalyst and detailed report shall be delivered to NASA-MSFC for performance demonstration and

evaluation. The report shall adhere to the requirements of Section 3.1.1 herein. If needed, the contractor shall provide technical support during the integration and testing at NASA-MSFC by telephone and/or email.

3.1.1 Baseline Reporting and Deliverables

- Teleconferences shall be held to update NASA-MSFC of the development status at the discretion of the MSFC technical lead.
- Quarterly status reports provided to the NASA-MSFC technical lead shall serve as milestones prepared in accordance with DRD 1504MA-002. At the discretion of the MSFC technical lead either PowerPoint or e-mail is acceptable.
- At the conclusion of the base period the following shall be delivered to NASA-MSFC:
    1) A developmental catalyst material capable of filling **1,200** cm^3 of well-packed cylindrical reactor volume.
    2) A final scientific and technical report in accordance with DRD 1504MA-001 in MS Word and PDF formats that complies with the requirements of NFS 1852.235-73. The report shall include (at a minimum) sections on:
        - Catalyst material description and available properties
        - Catalyst storage, safe handling, and operating instructions
        - Projection of shelf life, as delivered
        - Functional test data indicating, if possible based on analysis method, single-pass oxidation efficiency for each species
        - Characterization of organic species in reactor effluent
        - Analytical analysis of ersatz challenge load composition
        - Appendix information listing chemical vendor, CAS #, grade, lot # (when applicable), etc. of ersatz composition
        - Appendix section displaying calibration curves and detection limits used for analysis
        - Appendix entry including analysis of feed oxygen purity
        - Appendix entry on feed water purity
        - Routine analysis of ersatz chemical composition if solution stored over time and used to assess performance throughout development work
        - Discussion of any lessons learned that would apply to the integration into a flight reactor
- The contractor shall provide technical information concerning any invention, discovery, improvement, or innovation made by the contractor in the performance of work under this contract. Technology Reports shall be prepared in accordance with DRD 1504CD-001.

- The contractor shall report mishaps and safety statistics to the MSFC Industrial Safety Branch in accordance with DRD 1504SA-001. The contractor shall submit directly into the NASA Incident Reporting Information System (IRIS) or shall use the forms listed in section 15.4 of DRD 1504SA-001 or electronic equivalent to report mishaps and related information required to produce the safety metrics.

4.0 TRAVEL

NASA-MSFC reserves the right to site visit in order to review the development progress, audit analytical equipment, and ensure safe practices are being carried out.

5.0 POINT OF CONTACT

The point of contact(s) for this effort:

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