Compact, Lightweight and Effective Heat Exchanger for Liquid Oxygen Storage for Sustainable Lunar Exploration

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Storage of oxygen is essential for a sustainable consumable transfer station for use on the lunar surface. NASA KSC [1] proposed a novel cryogenic system that incorporates integrated refrigeration with a Brayton cycle and oxygen storage to meet the envisioned architecture requirements as well as increased mission capabilities. The cold head heat exchanger in the storage tank is an important component to maintain the integrated system at a high operational coefficient of performance (COP), thereby reducing energy consumption. In the application of a cryocooler to liquefy oxygen, the dominant thermal resistance at the cold head heat exchanger is on the gas side. We propose to use carbonate foams manufactured by a recently developed technology at ORNL to reduce this resistance and to satisfy the stringent requirements of the cold head heat exchanger – heat transfer with a very small temperature difference between the cold gas and oxygen, compactness and lightweight. As a new material for heat transfer, carbon has extremely high thermal conductivity compared to other materials such as copper and aluminum. The open cell structure of the foam provides an extremely large surface area to volume ratio. All these would provide a heat transfer coefficient more than 5 times higher compared to conventional fin structures. The low density of carbon leads to the light weight of the heat exchanger.

Experiments will be conducted to characterize the thermal-hydraulic performance of different carbonate foams with various configurations. Data for each foam configuration will be correlated and the physical mechanisms that affect the performance will be analyzed. New design such as a sandwich structure will be included with the purpose of reducing the flow resistance (pressure drop). The final heat exchanger will be an optimized design to minimize the log mean temperature difference (LMTD) required and maximize the heat transfer effectiveness under the constraint of a fixed number of transfer units (NTUs). Performance tests will also be conducted to evaluate the cold head heat exchanger as a condenser for gaseous oxygen. Figures of merit will be provided for heat transfer versus pressure drop, size, mass and cost compared to other fin structures such as straight fins, offset fins, wavy fins, louvered fins, pin fins as well as other metal foams. The results will provide guidance for further development of the cold head heat exchangers for the specific application. This research will also be beneficial to designers of compact heat exchangers in aerospace and automotive industries.

[1] William U. Notardonato, "Development of Consumable Transfer Systems for Sustainable Lunar Exploration," AIAA Aerospace Sciences Meeting, Reno, Nevada, January 1997.