Simulation Helps Improve Atmosphere Revitalization Systems for Manned Spacecraft

Life support systems for manned spacecraft must provide breathable air and drinkable water for the astronauts. Through the Atmosphere Revitalization Recovery and Environmental Monitoring (ARREM) project, engineers at NASA are developing atmosphere control devices for the safety of the onboard crew.

The atmosphere in a manned spacecraft needs to be regularly revitalized in order to ensure the safety of the astronauts and the success of the space mission. For missions lasting a few months, this means air is continuously dehumidified, water collected for re-use, and carbon dioxide (CO_2) ejected. One component of the onboard atmosphere control system is a water-saving device that Jim Knox, aerospace engineer at NASA, is optimizing through the Atmosphere Revitalization Recovery and Environmental Monitoring (ARREM) project. He is leading a team at the Marshall Space Flight Center (Huntsville, Alabama) that is aiming to make the assembly more cost-effective and efficient by reducing its power usage and maximizing the water saved; their goal is to save 80-90% of the water in the air. They hope to offer flight system developers at NASA an integrated approach to atmosphere revitalization and water collection that will ultimately increase the time and distance space missions can travel.

Figure 1. The atmosphere revitalization computer simulation team at the NASA MSFC. Left to right: Rob Coker, Carlos Gomez, Greg Schunk, and Jim Knox.

Separating Water and CO_2 through Efficient Adsorption

Revitalizing the atmosphere inside a spacecraft requires separating water, removing CO_2, and returning the water to the air before it is condensed into liquid form. The water-saving system that the team developed (see Figure 2A) is called an Isothermal Bulk Desiccant (IBD). It consists of a chassis with enclosed channels called packed beds, each of which is lined with silica gel pellets to promote water adsorption (a "dry" bed to draw water out) or desorption (a "wet" bed to return water to the air). Each pair of beds straddles an aluminum foam lattice used for transferring heat.

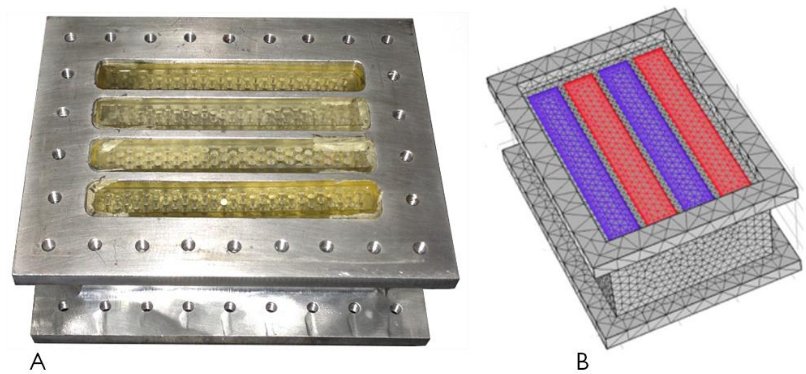

Figure 2. (A) Photograph of IBD with four columns. (B) Meshed COMSOL model of the IBD. Purple regions indicate wet beds, red indicate dry.

The water-saving process occurs in simultaneous half-cycles, with some air entering the dry beds while some leaves the wet beds. In a dry bed, water in the air is exothermally adsorbed onto the silica gel, drying the gas to save the water, before the air travels to a CO_2 removal system. The CO_2-free air flows back to the wet bed. Meanwhile, the heat caused by adsorption in the dry bed is transferred to the wet bed via the aluminum lattice, causing water to desorb from the silica gel and return to the air. This heat transfer has the added benefit of lowering the temperature in the dry bed, allowing adsorption to continue longer. The water is pumped back into the cabin, and the CO_2 is expelled into space. After flowing out of the IBD, the cabin air will enter a heat exchanger and centrifugal separator that condense and separate the liquid water, collecting it for re-use.

Simulating Gas Flow and Optimizing Bed Conditions

Using COMSOL Multiphysics®, Knox's team modeled a 4-column IBD to calculate the efficiency of the device (his model is shown in Figure 2B). The IBD geometry was created in Pro/ENGINEER® and imported using the LiveLink™ *for* Pro/ENGINEER®. "COMSOL let us perform this kind of multiphysics simulation on such an intricate geometry," Knox remarked. "We needed to simulate porous media flow in the beds and heat transfer in multiple materials, include pressure boundaries, and find sorption rates." They noted that dry beds gain heat as gas flows downward, due to exothermic adsorption. Conversely, the wet beds lose heat as gas flows upward (see Figures 3 and 4).

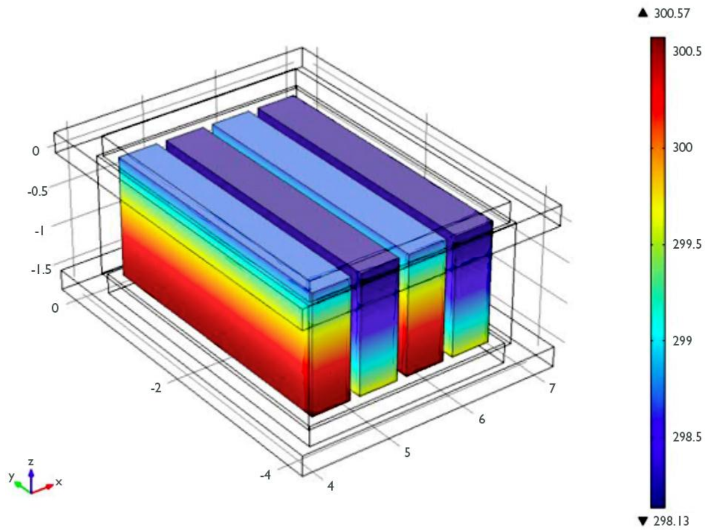

Figure 3. Simulation results showing temperature (K) in each bed. The first and third columns contain wet air flowing downward, the second and fourth dry air flowing upward.

Rob Coker calculated the efficiency of the IBD using a breakthrough test where air was pumped through a dry bed. Initially, the air leaving the bed was completely dry; all the water vapor had adsorbed onto the silica gel. As more air flowed through, the water vapor concentration in the air at the exit increased; eventually, it had the same humidity as the air entering – the silica gel pellets could hold no more water. Observing this process allowed the team to gather parameter values for the IBD model, and they compared the breakthrough and experimental results (see Figure 4). The capabilities of COMSOL let them track the water concentration, flow rates, and pressure, with the boundary conditions for inflow, outflow, and wet and dry air changing for each half-cycle.

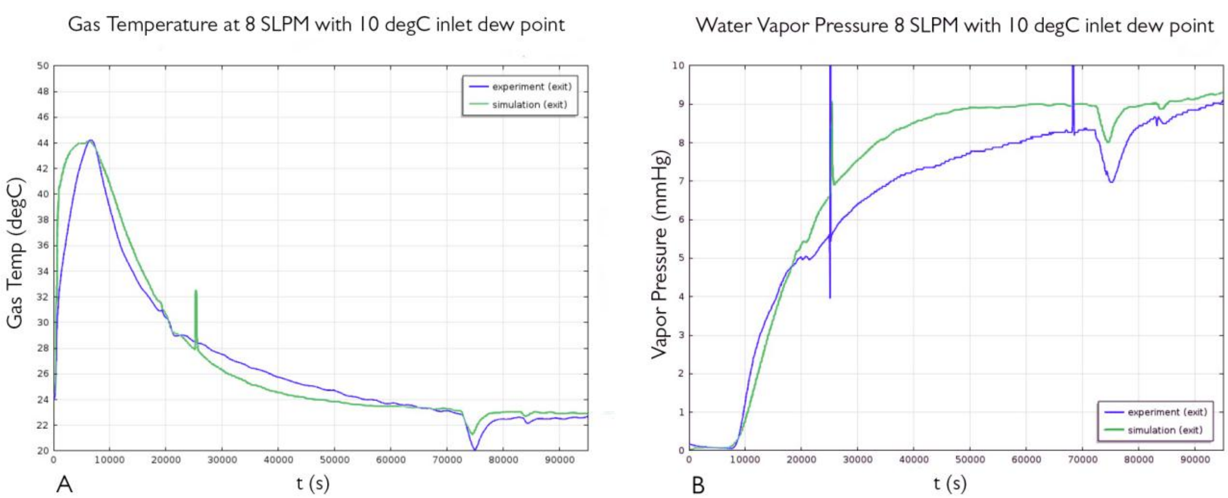

Figure 4. Simulation results for air at the exit showing (A) gas temperature, (B) water vapor pressure.

According to the simulation results, the IBD successfully removed 85% of the water in the air and returned it to the atmosphere for collection. The model successfully predicted the efficiency of the IBD; from here they will be able to further refine the design for a thermally linked bed.

Offering NASA a Reliable Approach to Atmosphere Regulation

The team's COMSOL simulation provided invaluable optimization and design guidance for the water-saving assembly. They are increasing the IBD efficiency by minimizing power requirements and maximizing the water saved before CO_2 is ejected. This is one of many important parts of a revitalization system which they hope will extend the reach of space missions. They are also using COMSOL simulations to design new systems suited for longer missions, which enable the separation of oxygen from CO_2 and reduce the amount of O_2 that must be brought from earth. With these innovative designs and the powerful capabilities of simulation, we'll soon have manned spacecraft traveling farther than ever before.