COMSOL thermal simulations of a Mars environment facility

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Introduction

Environmental chambers are used to simulate planetary environment and to perform qualification tests. Our simulating facility, the SpaceQ chamber [1] (Figure 1), has an operating temperature range of 163–423 K and a pressure range from < 0.01 Pa (high vacuum) to ambient pressure. We observe the thermal profile and validate the model against the experiments.

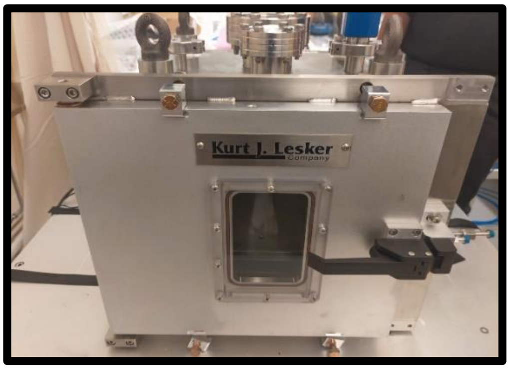


Figure 1. View of the SpaceQ chamber facility

This work demonstrates the potential of COMSOL to simulate the thermal gradients within the chamber and the time scales required to reach quasi-equilibrium. This method can be used to design future tests of space instrumentation in simulating facilities and to decide where to install thermal control sensors.

Computational Methods

This application is a Multiphysics based problem, so we use the Heat transfer module's Conjugate Heat Transfer Laminar Flow model. This is coupled with surface to surface radiation to account for the radiative heat flux within the chamber and to quantify their influence on the net heat exchange.

The chamber has a certain level of symmetry and to reduce the computational time we use a 2D model (Figure 2). In this work we simulate two different conditions.

- **Mars conditions:** This simulation is a time-dependent model, here we refrigerate the working table inside the chamber to 250 K and a pressure of 700 Pa of carbon dioxide, CO_2, gas. We observe the thermal profile and validate the model against the experimental measurements.
- **Vacuum conditions:** Here we simulate a time-dependent model where we heat the chamber with an external heating jacket made of glass wool fitted on the walls of the chamber. The initial condition is 293.15 K and 10^{-3} mbar and the input power, 700 W, is supplied through the jacket.

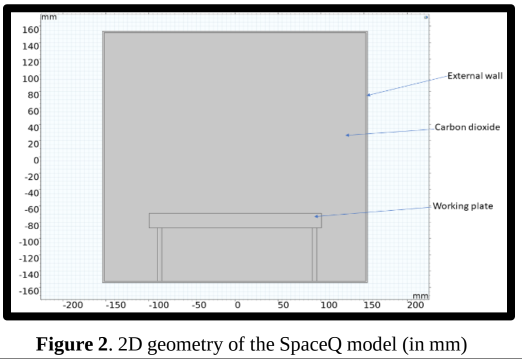
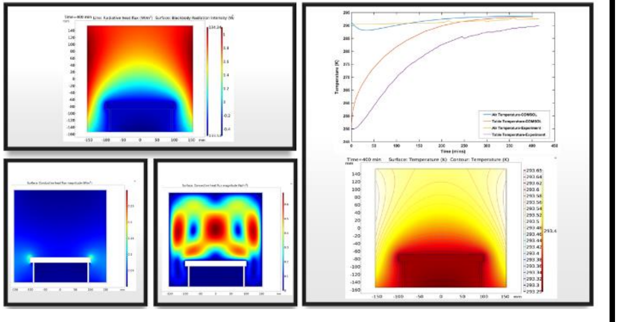


Figure 2. 2D geometry of the SpaceQ model (in mm)

Results

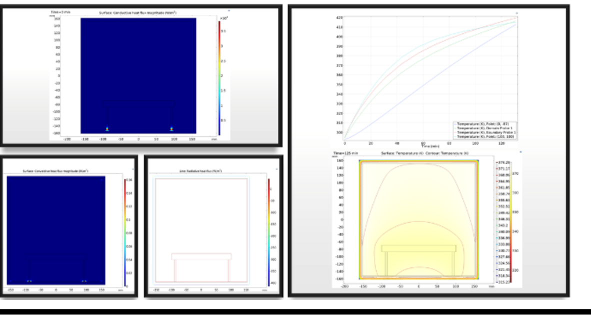
Mars Conditions:

- We observe that radiative interchange is the dominant energy transfer mode, see the four figures underneath.
- Both the simulation and experimental values follow the same trend reaching the ambient temperature after about 400 min.
- The simulation table temperature shows a different trend from the experimental one. This is probably due to the existence of a liquid nitrogen pipe in the chamber which is not included in the simulation and has strong thermal inertia.



Vacuum Conditions:

- We observe that the most significant mode of energy transfer in the vacuum conditions is also through radiation.
- The simulation shows that under this configuration it takes two hours to reach a high temperature equilibrium, and that with this power, the expected upper temperature limit is about 420 K (i.e. about 150° C). If the chamber is used for Thermal Vacuum Tests or Dry Heat Microbial Reduction, then due to the extra mass of the instrumentation, this test will presumably require longer time and the upper temperature limit will be reduced.



Conclusions

- This simulation helps us to evaluate the time required to reach a quasi-equilibrium situation and the expected thermal gradients within the SpaceQ chamber. It is therefore useful to plan the experiments and find the hot and cold spots of the chamber.
- Our future studies will simulate the 3D behavior and incorporate the simulation of other elements like the nitrogen pipe and added instruments, which have strong thermal inertia.

REFERENCES

1.Vakkada Ramachandran, A.; Nazarious, M.I.; Mathanlal, T.; Zorzano, M.-P.; Martín-Torres, J. Space Environmental Chamber for Planetary Studies. Sensors, 2020, 20, 3996.

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