Comprehensive Assessment of Heat Loads in Ground-Based Cryogenic Applications

Damini Singh[1],* Kapil Saraswat[2], Avijit Kumar Ganguly[3], and Venktesh Singh[4]
[1] *Department of Physics, Gujarat Arts and Science College, Ellisbridge, Ahmedabad, Gujarat, 380006, India.*
[2] *Institute of Physics, Academia Sinica, Taipei, 115201, Taiwan.*
[3] *Department of Physics, MMV, Banaras Hindu University, Varanasi, UP., 221005, India. and*
[4] *Department of Physics, School of Physical & Chemical Science, Central University of South Bihar, Gaya, 428236, India.*

Introduction

The analysis of heat loads is critical in various engineering applications, particularly in fields such as cryogenics, aerospace, and thermal management systems. Multilayer Insulation (MLI) is a crucial technology for achieving energy efficiency and effective thermal management in various high-performance applications, composed of low-emissivity radiation shields and a low thermal conductivity spacer materials. Its unique ability to minimize heat transfer while remaining lightweight and compact makes it an essential component in modern engineering and design. MLI is perfect for sustaining low temperatures in cryogenic situations because it can attain extremely low thermal conductivity by reflecting radiant heat and restricting conductive pathways [1, 2]. Insulation performance is affected by layer density, number of layers, and thermal boundary temperature. The various heat transfer relationships (radiation heat transfer, solid conduction and gas conduction) between the layers were not taken into consideration in the early research on MLI systems, which focused only on the insulation material itself. In a MLI Blanket construction, the individual heat flux varies with thermal boundary temperatures even when the total heat flow of each layer remains the same.

*Electronic address: `damini0physics@gmail.com`

Results and Discussion

The following was carried out in order to optimize insulation efficiency based on various methods for transferring heat with the thermal boundaries temperatures. After the understanding that how thermal boundary temperatures influence the three types of heat transfer mechanisms, it is easy for the engineers to design more efficient systems and optimize performance. In the current work, the Modified Lockheed equation [1, 2] has been considered to be the most flexible model to study the thermal performance of MLI technology. In this work, two distinct spacer materials- Glass−tissue, and Silk−net with radiation shields, are adopted as the separating medium. In this analysis, we have kept the thickness of the MLI blanket constant and after taking the values of all constants used in Modified Lockheed equation [1, 2], the results are presented in Figure 1 and Figure 2. The initial investigation presented in the Figure 1 indicates that when the hot wall boundary temperature increases, all three heat loads increase. However, the radiation heat transfer for the two specified spacer materials shows an upward trend rather than a linear response. The hot wall boundary temperature has a significant impact on radiation heat load, but solid conduction heat load has a minor shift in comparison. The gas conduction heat load is basically unchanged compared to the other two heat loads. Hence it makes clear that, in higher temperature regions, it's important to reduce radiation heat load. The second thing we have observed that the increment in the heat load is maximum for the Glass-Tissue

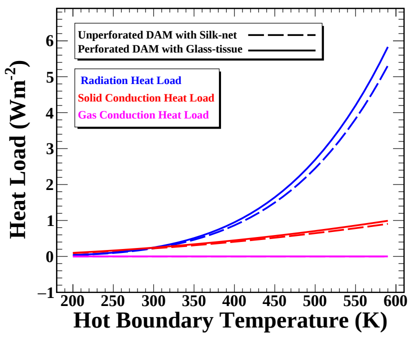

FIG. 1: The variation in heat flux with Hot wall boundary temperature.

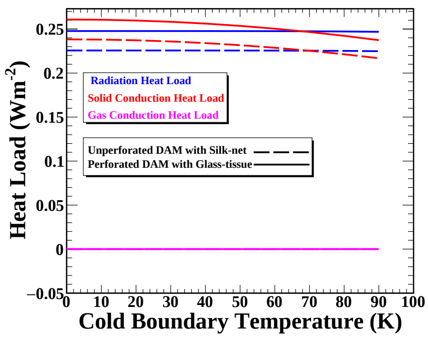

FIG. 2: The variation in heat flux with Cold wall boundary temperature.

spacer as compared to the Silk-Net spacer material. The value of gas conduction heat load is same for the two selected spacer materials. Therefore, while choosing from the two radiation shield and spacer material combinations, we should decide on Unperforated Dam with Silk-Net to make the MLI blanket.

When we try to compare all the heat loads with cold wall boundary temperature as pointed out in the Figure 2, we found that solid conduction heat load for the two materials drops promptly in the cold wall boundary region as compared to the two other heat loads. When it comes to radiation heat load, the value of radiation heat load changes minimally in the cold wall boundary region, while the value of gas conduction heat load is not affected considerably. From the second figure we observe that the decrement in the solid conduction heat load for the two selected material combinations are in the same proportion but while choosing the material combination for MLI blanket design, we have to focus on Unperforated Dam with Silk-Net because of having the lower value of heat load as compared to Perforated Dam with Glass-Tissue.

Acknowledgments

We are thankful to the support provided by CSIR, New Delhi in terms of JRF and SRF. I would like to express my heartfelt gratitude to everyone who contributed to this study on heat load analysis with thermal boundary temperatures.

References

[1] D. Singh et. al., JINST 15 P07032 (2020).
[2] D. Singh et. Al., 59, 1365 - 1378 (2023).