



## *Analysis of Combined Conduction- Radiation Heat Transfer in Multilayer Insulations*

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### **ABSTRACT**

Modeling the combined conduction-radiation heat transfer in multilayer insulation has been done. Governing equations of the problem are integro-differential and there is no exact solution for them. So numerical procedure with the approximate solutions have been used. Main governing equations were energy equation and two-flux equations using the finite volume and finite differences have been discretized, respectively. Numerical solution is validated with Ozisik's solution and the experimental results were published. Total heat flux and effective thermal conductivity obtained via steady state results. Dimensionless temperature distribution and dimensionless radiative and conductive heat fluxes along the sample thickness were obtained. Near the hot boundary, dominating mode is radiation, so it is suggested that the reflective screens are located near hot boundary. For the lower temperature differences, the dominating mode is conduction, so the number of reflective screens does not influence effective thermal conductivity so much. In all steps of validation, the numerical results have good agreements with the published data in the references. Finally, it is suggested that just the foils near the hot boundary, are coated with gold for the sake of cost cutting. In addition, it is understood that layer density has an optimum value and this value does not change if the boundary conditions and the material remain unchanged.

### **KEYWORDS**

Multilayer Insulation, Thermal Conductivity, Thermal Protection System, Combined- Mode Heat Transfer.

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### 1- INTRODUCTION

Multilayer insulator has been introduced in cryogenics for the first time [1]. Some theoretical and experimental research has been done for the modeling of heat transfer in the multilayer insulators. One of the earliest research on high temperature MLI has been done by German scientist [2]. They used optically thick approximation. Keller analyzed the role of each of heat transfer modes and also the layer density on MLI performance [3]. In another work, the dependency of heat transfer to the pressure and the temperature variations have been considered, in latter research, optically thick approximation has been used for the radiation modeling and parallel approximation has been used for the conduction modeling [4].

Using two-flux approximation for the radiation modeling has been led to better results for the multilayer insulations simulation, because the other approximations are valid for the limited range of optical thickness and in their equations, the radiative properties of surfaces are not considered. In numerical solution, the finite volume method has been used which led to better convergency.

### 2- METHODOLOGY

Heat transfer mechanisms in multilayer insulators include; conduction in solid phase, conduction in gas phase and radiation. because of existence of porous medium in layers convection heat transfer can be neglected. Obtaining temperature distribution in a multilayer insulator is feasible by solving energy conservation equation (eq.1);

For the radiation modeling in current research, two-flux approximation has been applied (eqs. 2,3);

$$\rho c \frac{\partial T}{\partial t} = \frac{\partial}{\partial x} \left( k \frac{\partial T}{\partial x} \right) - \frac{\partial q_r}{\partial x} \tag{1}$$

$$\frac{\partial q_r}{\partial x} = \beta(1-\omega)(4\pi I_b - G) \tag{2}$$

$$q_r = -\frac{1}{3\beta} \frac{\partial G}{\partial x} \tag{3}$$

$$-\frac{1}{3\beta^2(1-\omega)} \frac{\partial^2 G}{\partial x^2} + G = 4\sigma T^4 \tag{4}$$

$$-\frac{2}{3\beta \left( \frac{\varepsilon_1}{2-\varepsilon_1} \right)} \frac{\partial G}{\partial x} + G = 4\sigma T_1^4 (@ x=0) \tag{5}$$

$$-\frac{2}{3\beta \left( \frac{\varepsilon_2}{2-\varepsilon_2} \right)} \frac{\partial G}{\partial x} + G = 4\sigma T_2^4 (@ x=L) \tag{6}$$

In above formulas  $G$  in incident radiation,  $\varepsilon$  is emissivity,  $q_r$  is radiative heat flux,  $\beta$  is extinction coefficient and  $I_b$  is radiation intensity of black body.

The final equations for an incident radiation and its boundary conditions are shown in equations 4 to 6.

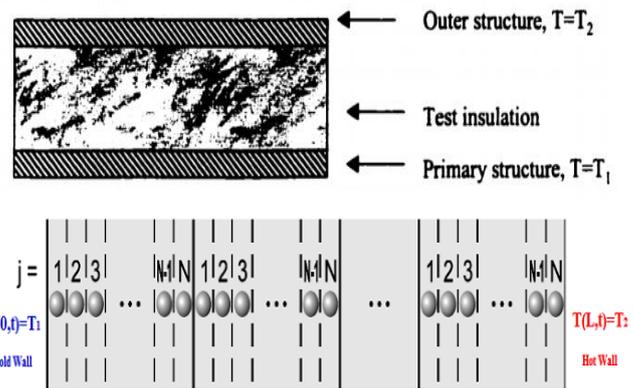


Figure 1- scheme of a multilayer insulator solution domain

For numerical simulation finite volume method with adaptive grid has been implemented. A general scheme of solution domain is shown in figure 1.

For better simulation, analysis is done by dimensionless parameters that is described in equations 7 and 8;

$$x^* = \frac{x}{L} \tag{7}$$

$$\Phi = \frac{T(x) - T(L)}{T(0) - T(L)} \tag{8}$$

where  $x^*$  is dimensionless length and  $\Phi$  is dimensionless temperature.

Samples used for the analysis contains four foils and spacers between them; foil material is inconel coated with thin layer of gold and spacers are Polycrystalline ceramic

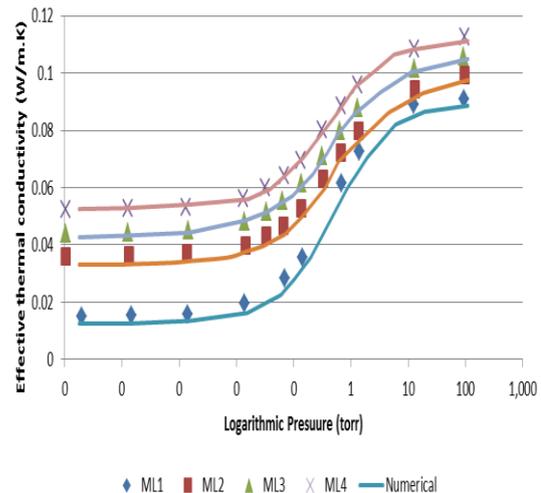
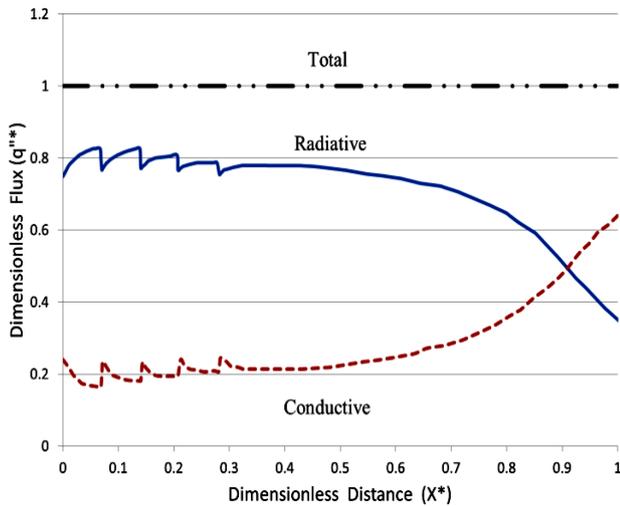


Figure 2- Effective thermal conductivity of MLI samples respect to pressure named Saffil. This material melts in 2000 degrees of



**Figure3- Variations of contribution of conductive and radiative fluxes respect to dimensionless length of an insulator**

centigrade. Nominal density for sample is  $48 \text{ kg/m}^3$  and specific heat is  $880 \text{ J/kg.K}$ .

### 3- SIMULATION RESULTS

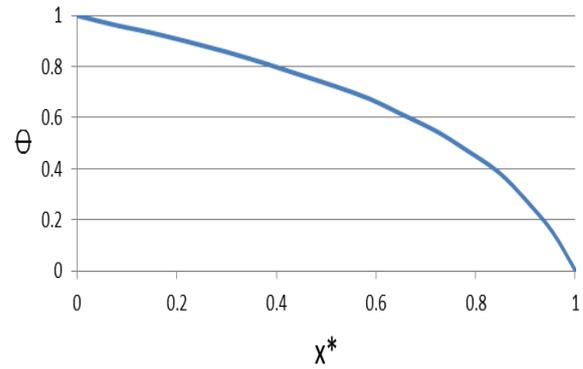
In current study numerical solution has been done using dimensionless energy equation. Also two-flux approximation has been applied for radiation modeling. Transient solution has been used participating 34 nodes and 0.001 dimensionless time. convergence criteria has been set to 0.01K.

As shown in figure 2, gradient of effective thermal conductivity is negligible in low pressures. By increasing pressure, a sudden jump is observed in thermal conductivity values. the cause of this phenomenon is that in lower pressures free molecular flow is dominated in molecular regime. As pressure increases above a certain value molecular collisions begin and help the thermal conductivity to increase suddenly. Generally through common mechanism by increasing pressure gas conduction increases and hereon effective thermal conductivity increases.

Also by increasing pressure contribution of radiation heat transfer decreases respect to gas conduction. By plotting contribution of heat transfer modes mentioned before (figure 3) some discontinuities appear that is due to impose of conduction heat transfer near heat shields (foils).

In figure 3  $X^*=0$  indicates hot boundary and  $X^*=1$  indicates cold boundary. In dimensionless length of 0.91 radiative and conductive fluxes become equal. the curve labeled "Total" is a test for result accuracy. (the sum of fractions of radiative and conductive fluxes should be equal 1 along insulation thickness.)

According to figure 4 temperature gradient along insulation thickness is non-linear and also gradients are steeper near cold boundary.



**Figure 4- Dimensionless temperature along dimensionless length of insulation**

### 4- CONCLUSION

Modeling the combined conduction-radiation heat transfer in multilayer insulation has been done. Also dependency of effective thermal conductivity to temperature and pressure has been investigated. Increasing pressure, effective thermal conductivity increases. Temperature variations are non-linear along sample thickness and gradients are greater near cold boundary. By parametric study and using the results, better arrangement has been suggested. Because of the dominated contribution of the radiative flux near hot boundary, layer density shall be increased in this region.

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