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Numerical Thermal Analysis of Insulated Laminated Cookware

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Abstract- Multi-layer-plate (MLP) provides improved thermal properties. Heat capacity of utensil material is significant in cooking. In this study the main objective is about reducing heat loss of cookware. We analyzed the Temperature Distribution (TD) all over the insulated and non-insulated pan by electrical resistivity as heat source. We compared the insulated pan with non-insulated pan. Based on results the insulator improved the thermal properties of pan. It reduces the energy consumption. To achieve this aim were employed Finite Element Method (FEM) for analyzing transient thermal behavior of insulated and non-insulated pan.

Keywords-, *Saving energy, Heat storing, Laminated late, Temperature distribution, Insulator, Utensil*

I. INTRODUCTION

Multi-layer structure can be effective on improving Temperature Distribution (TD) and heat storing. It can reduce the energy consumption by improving thermal properties of utensil [1].

When the cooking task requires the ability to maintain consistent and ample amount of heat, even after you remove your utensil from the heat source, heat retaining ability will play mainly role.

In the other hand, especially if we use electrical resistivity as heat source, the heat is transferred to ambient from pan side easily. Hence we insulated the side of pan for saving the energy.

Reference [2] studied on Multi-Layer Plate (MLP) as cookware. It demonstrated that MLP provides improved thermal and chemical properties of cookware. MLP causes regular TD on the top while bottom heated irregularly [1], [3], [4]. In addition thermal, mechanical and chemical behaviors of Cu/SSt MLP make it completely excellent structure for cookware production [5].

Reference [6] has optimized thickness and material of the bottom layer containing different alloys of aluminum or copper. It showed that the optimum thickness is 8 (mm) for copper.

In this paper the heat loss from pan is studied then we compared it with insulated pan. We concerned about heat loss from heated cookware. We reduced the heat loss by insulting the cookware up to about 20 degrees. In this study, we have employed FEM to calculate the temperature profile all over the pan and we showed how much wall of pan affects in heat loss.

TABLE I. SYMBOLS AND THICKNESSES

Metals	Symbols	Thicknesses
Copper	Cu	8 (mm)
Stainless Steel	SSt	2 (mm)

II. MODELING

A. Boundary Condition and Geometry

As we want to model irregularly heating we constrained annular part of the circular surface of bottom side pan, which illustrated in Fig. 1 as Δr, by constant temperature about 773 (K). There is a geometrical symmetry so the system can be modeled by rectangle plane with length of the pan radius and a thin and long rectangle as wall of pan. Because of the symmetry, the temperature gradients at the centre of plate along the y-axis have zero value. Hence there is no heat flux at the centre of plate along the y-axis. Side of pan has convection heat transfer with air in ambient temperature. We have taken thickness of layers according to Table I. The ambient temperature and the coefficient of heat transfer have been assumed as 293 (K) and 17 (W/ (m².K)), respectively. In addition, it is also assumed that the pan is filled up by water with boiling temperature, and the coefficient of heat transfer between the pan and the water is 50 (W/ (m².k)).

First the pan is heated to reach steady state. Then we cooled the heated pan to ambient temperature for studying on the heat loss of the insulated and non-insulated pan. Hence we modeled the heated pan to transfer the heat just with air at ambient temperature for cooling. We considered the pan has a cap in cooling step so it has not any heat loss in inner space of pan. The analysis is transient.

B. Meshing

The model was meshed with PlANE55.this element can be used as a plane element or as an axis-symmetric ring element with a 2-D thermal conduction capability and it capable to modeling the axis-symmetric geometry. The element has four nodes with a single degree of freedom, temperature, at each node. The element is applicable to a 2D, steady-state or transient thermal analysis.

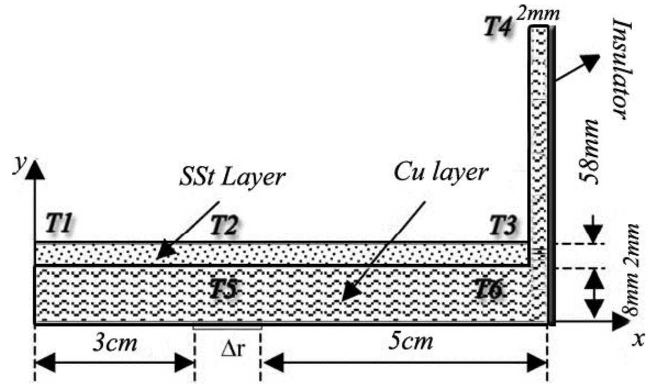

Figure 1. 2D bi-layer model in numerical analysis and positions of different selected nodes, named T1-T6

III. FINITE ELEMENT METHOD

In the finite element method, a given computational domain is subdivided as a collection of a number of finite elements, subdomains of variable size and shape, which are interconnected in a discrete number of nodes. The solution of the partial differential equation is approximated in each element by a low-order polynomial in such a way that it is defied uniquely in terms of the solution at the nodes. The global solution can then be written as series of low-order piecewise polynomials with the coefficients of series equal to the approximate solution at the nodes [8].

With the advent of digital computers, discrete problems can generally be solved readily even if the number of elements is very large. As the capacity of all computers is finite, continuous problems can only be solved exactly by mathematical manipulation. The available mathematical techniques for exact solutions usually limit the possibilities to over-simplified situations [9].

Various discretization methods have been used in the past for numerical solution of heat conduction problems. It must be emphasized that – particularly in the case of nonlinear heat transfer problems – the numerical solution must always be validated [8].

Use to solve the transient heat conduction process is governed by:

$$\frac{\partial}{\partial x}(k_x \frac{\partial T}{\partial x})+\frac{\partial}{\partial y}(k_y \frac{\partial T}{\partial y})=\rho c(\frac{\partial T}{\partial t}) \quad (1)$$

The finite element method can be applied as:

$$KT + C\dot{T} = P \quad (2)$$

The ρ denotes the material density, *c* the specific heat of material at constant pressure, and C the damping matrix of the thermal system. In the finite element analysis, the numerical integration is carried out through *N* time steps. Between two adjacent time steps, the *j*th and (j-1)th, we can have the following approximation:

j= (1, 2, …, N)

$$T = (1-\lambda)T_j + \lambda T_{j-1}$$

$$\frac{dT}{dt} = \frac{T_j - T_{j-1}}{\Delta t} \quad (3)$$

The λ is the relaxation parameter. The finite element equation (2) becomes:

$$\left[(1-\lambda)K + \frac{C}{\Delta x}\right]T_j = \left[\frac{C}{\Delta x} - \lambda K\right]T_{j-1} + F \quad (4)$$

By solving (4), temperature fields T at different time steps are found [1].

TABLE II. DENSITY AND THERMAL PROPERTIES OF METALS

Symbol	Density (kg/m^3)		K (W/m.K) C (J/Kg.K)		
		T=200K	**T=400K**	**T=600K**	**T=800K**
Cu	8933	413 356	393 397	379 417	366 433
SSt	8055	15.1 480	17.3 512	20 559	22.8 585

The properties of applied metals are according to **[7]**.

IV. FINITE ELEMENT ANALYSIS

We analyzed the model in transient behavior to reach steady state. In this part we want to analyze TD all over the insulated and non-insulated pan when it is being heating. After that we changed the boundary conditions and again we analyzed transient behavior to reach ambient temperature. We compared the insulated pan with non-insulated pan to understand the importance of insulating. We employed finite element method with ANSYS program to calculate the TD. Different positions of pan at different time during analysis have different temperature degree so we chose 6 nodes at various point of pan called T1-T6 that illustrated in Fig.1.

V. RESULTS

We analyzed heating and cooling of the Cu/SSt MLP for finding the importance of insulating. Time variations of temperature for different points of pan are illustrated in Fig 2-17. Figures 2, 4, 6, 8, 10, 12 shows the comparison of insulated pan temperature with temperature of non- insulated in T1-T6 nodes. Differences between insulated and non-insulated pan temperature in T1 node in 20th minutes during cooling step is up to 20 K shown in Fig 3. These differences are illustrated for T1-T6 nodes in Fig 3, 5, 7, 9, 11, 13.

In all them we observed that insulated pan has higher temperature degree than non-insulated pan. It is obviously, insulated pan can storage the heat better than non-insulated.

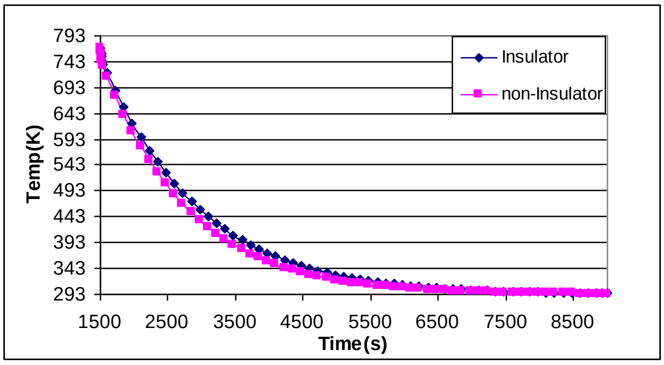

Figure 2. Time variation of T1 node temperature in insulated and non-insulated pan

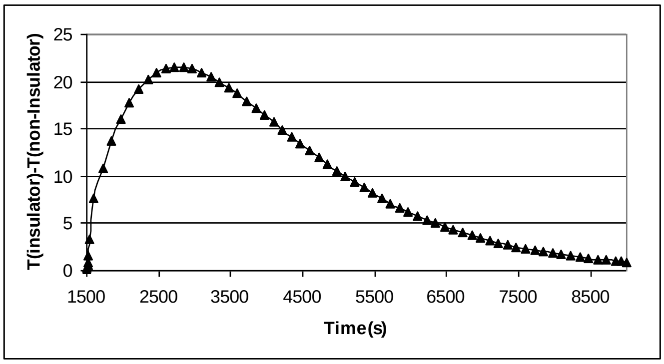

Figure 3. Time variation of differences between insulated and non-insulated pan temperature in T1 node

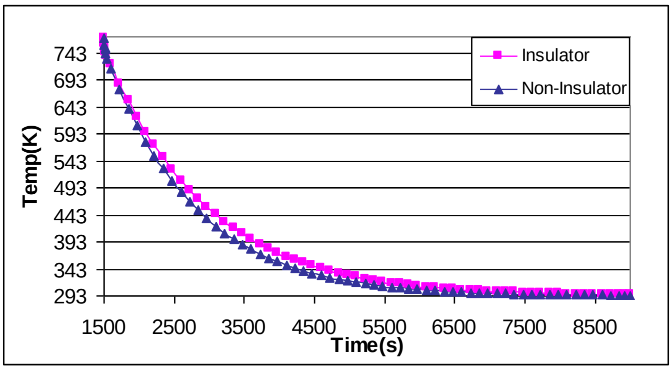

Figure 4. Time variation of T2 node temperature in insulated and non-insulated pan

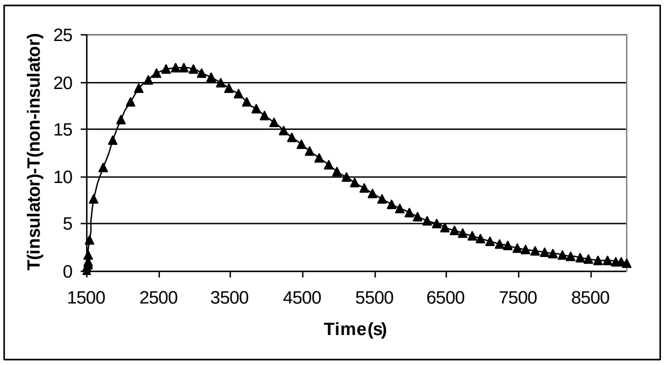

Figure 5. Time variation of differences between insulated and non-insulated pan temperature in T2 node

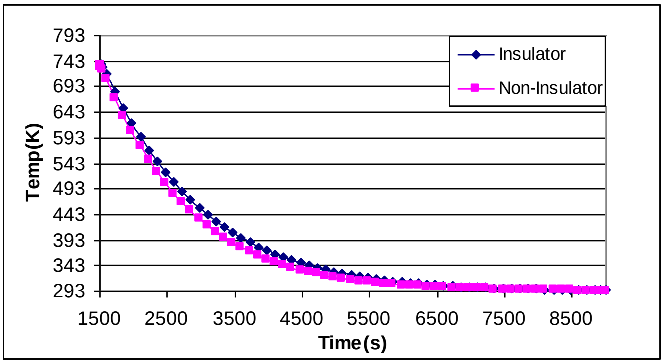

Figure 6. Time variation of T3 node temperature in insulated and non-insulated pan

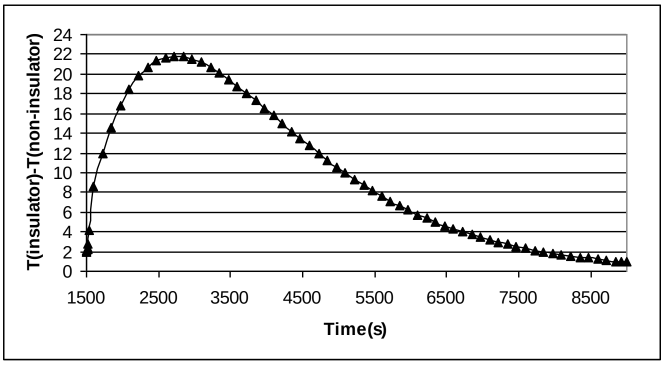

Figure 7. Time variation of differences between insulated and non-insulated pan temperature in T3 node

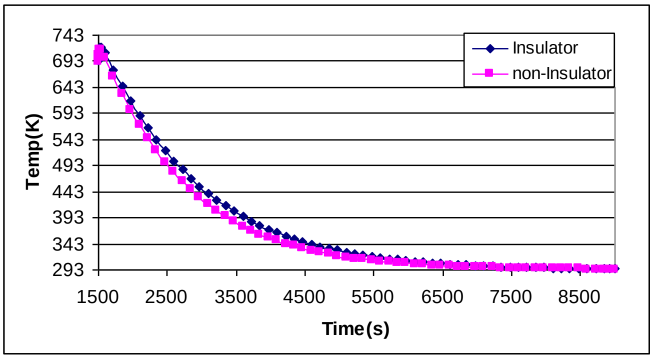

Figure 8. Time variation of T4 node temperature in insulated and non-insulated pan

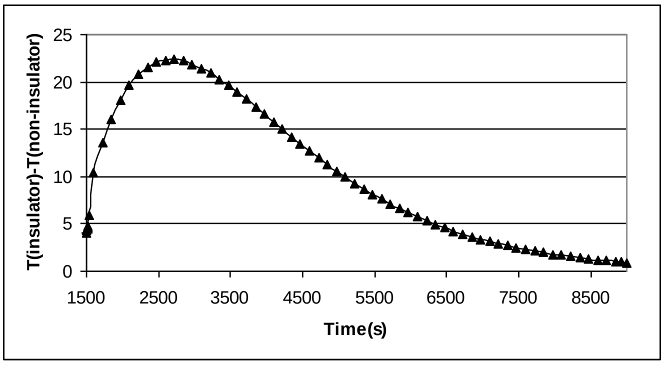

Figure 9. Time variation of differences between insulated and non-insulated n temperature in T4 node

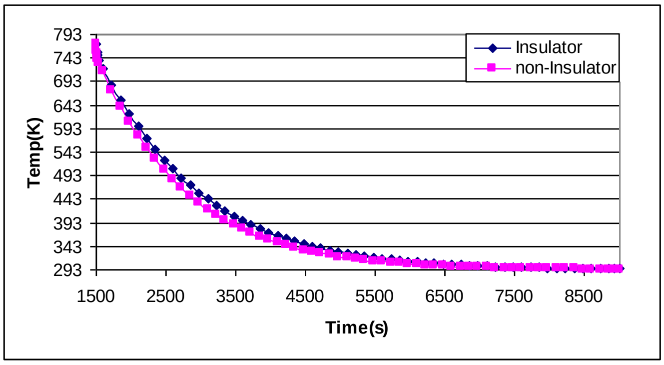

Figure 10. Time variation of T5node temperature in insulated and non-insulated pan

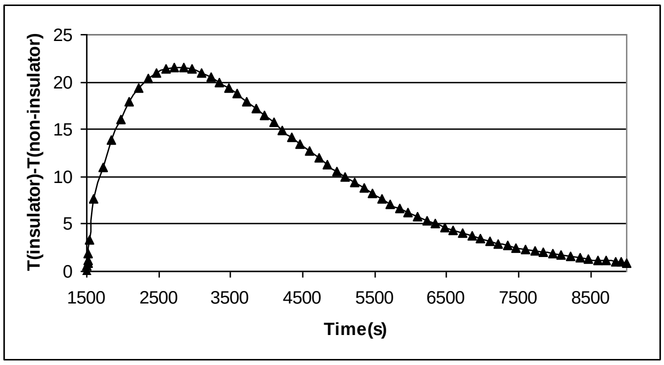

Figure 11. Time variation of differences between insulated and non-insulated pan temperature in T5 node

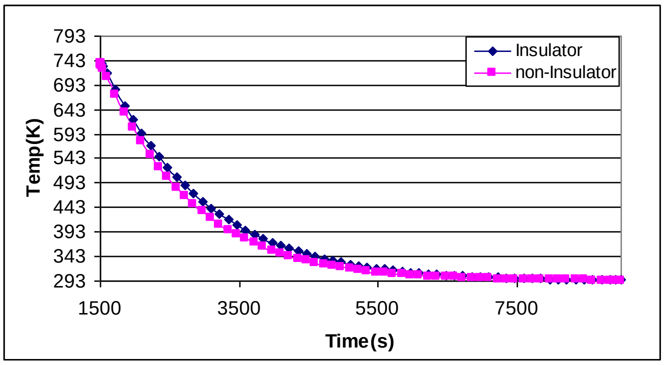

Figure 12. Time variation of T6 node temperature in insulated and non-insulated pan

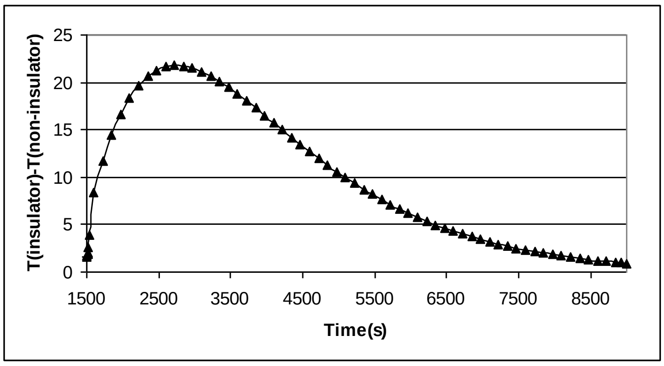

Figure 13. Time variation of differences between insulated and non-insulated pan temperature in T6 node

Figure 14 shows the heating and cooling steps of analysis together in insulated pan for T1-T6 nodes. First the pan heated to reach steady state shown in Fig 14, 15. Then we eliminated heat source and the heated pan is exposed to air at ambient temperature. The heated and insulated pan reached to ambient temperature during 7500 seconds shown in Fig 15.

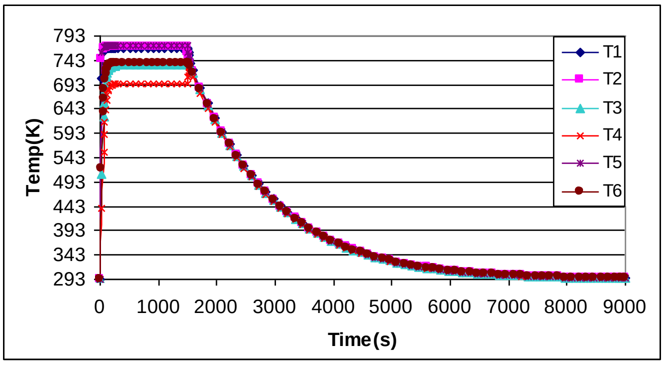

Figure 14. Time variation of T1-T6 nodes temperature in insulated pan during heating and cooling steps

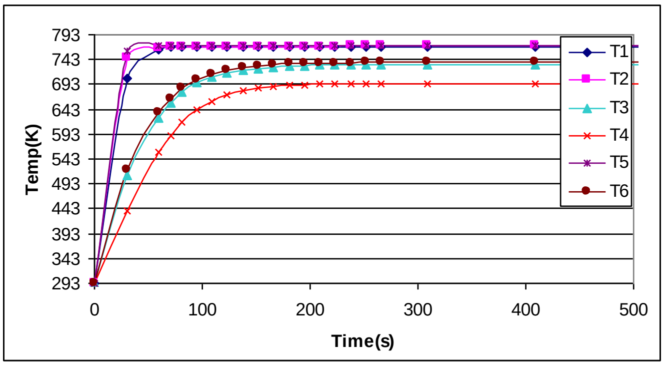

Figure 15. Time variation of T1-T6 nodes temperature in insulated pan during first 500 seconds in heating step

MLP provides higher temperature degree in heating step is represented in Fig. 17. The temperature degree on cooking surface for T1 and T2 nodes of non-insulated pan, a degree is greater than insulated case before steady state. After steady state this difference became zero. Whereas T3 node has higher temperature degree than non-insulated pan about 2 degree. This behavior in insulated pan provides more uniform TD on preparation surface of pan than non-insulated model.

Figure 16 shows the differences between insulated and non-insulated pan temperature in T1-T6 nodes together during heating and cooling steps.

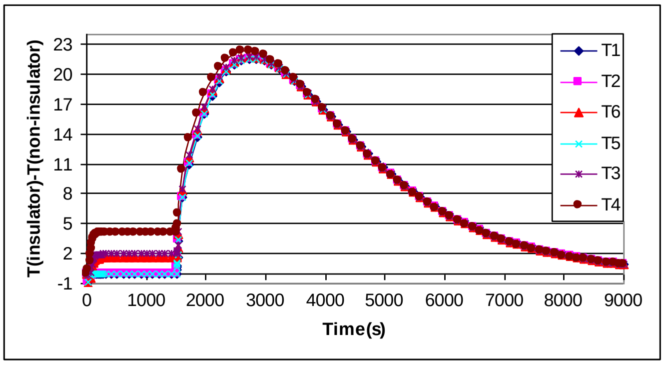

Figure 16. Time variation of differences between insulated and non-insulated pan temperature of T1-T6 nodes in heating and cooling steps

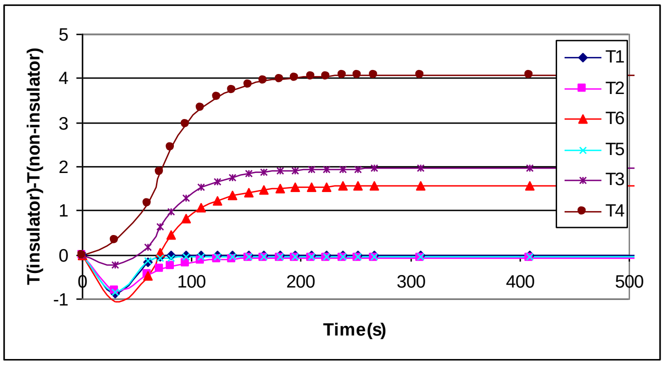

Figure 17. Time variation of differences between insulated and non-insulated pan temperature of T1-T6 nodes in heating step

VI. CONCLUSION

In this paper we studied on the heat loss from pan. The numerical, finite element method, analysis of transient thermal behaviors of the MLP heated irregularly is described. First we heated the model to reach steady state then the pan was cooled. The results of insulated pan is compared with non-insulated. According to results insulated model have better thermal performance in heating and especially in cooling. It provides the energy saving. It's obviously that the insulated model can storage heat better than non-insulated.

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