Simulation of Complex Heat Transfer Phenomenon across the Composite Wall by Using COMSOL Multiphysics

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***Abstract*- Steady state complex heat transfer phenomenon across a cold storage composite wall has been studied by using COMSOL 5.0 Multiphysics simulation software. The layers of composite wall are built with three different materials, pine, cork board and concrete. Inside and outside surface temperatures of composite wall are T1 = 255K and T4 = 298 K respectively. Without including convective resistance heat flux value is 17.15 W/m2 and with convective resistance it is reduced to 12.12 W/m2. The temperature profiles in each composite layer are linear at constant thermal conductivities. But it has been observed that this trend is changed when thermal conductivities are the function of temperature. COMSOL Multiphysics simulator results are compared with analytical results.**

Keywords: Composite Wall, COMSOL, Heat Flux, Temperature Profile.

I. Introduction

Rate of heat loss through composite wall have attracted significant attention in various field such as multiwall thermal projection system, unit operation, cold storage rooms, and furnaces. Operating and capital cost have resilient relation with rate of heat loss. Greater the heat loss larger will the operating cost. It can be reduced by increasing the thickness of wall but this will increase the capital cost. Therefore, to optimize the operating and capital cost it is important to analyze the thermal behavior across composite wall. It is very difficult to precisely analyze the thermal behavior of composite wall because it contains more than one constitute with different thermal properties.

Whenever there is a temperature difference occur heat transfer will take place. The amount of heat transfer depends upon deriving force (temperature difference) and thermal resistances. There are three modes of heat transfer, conduction, convection, and radiation. The conduction heat transfer

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phenomenon take place by vibration of molecules within the object and convection heat transfer phenomenon appears due to movement of molecules from one position to another. In case of radiation heat transfer take place by electromagnetic radiations [1].

Wei Chen analyzed the heat transfer rate through composite solar wall with porous medium and observed that porous medium behaves like as thermal insulator when no solar shining [2]. Abdulaziz Almujahid, explained the heat loss across building wall and extensive consequences on energy consumption and energy conservation in buildings [1, 4]. J. Raymond, studied heat transfer behavior in composite walls and evaluated the effect of wall channel width and surface emissivities at heat transfer rate [7].

In this paper complex heat transfer phenomenon has been studied through composite wall of cold storage room. It was constructed by three different materials pine, cork board, and concrete. Heat loss was analyzed by COMSOL Multiphysics and results were compared with analytical results.

II. Problem Statement

Cold storage room wall was constructed with layers of pine, cork board and concrete. Inside surface temperature was less than the outside surface temperature. Hence, heat transfer was took place across the wall due to temperature gradient. Properties of wall materials are summarizing in the Table I.

TABLE I
PROPERTIES OF MATERIALS

Layer	Material	Thickness of Layer (L = mm)	Thermal Conductivity (k = W/m.K)
A	Pine	15	0.151
B	Cork board	100	0.0433
C	Concrete	75	0.762

Figure 1 Show the systematic diagram of cold storage wall. Heat will flow from outside surface to inside surface. Temperatures at each boundary layer were T1, T2, T3, and T4. The outside air temperature was T5. The interior and exterior surface temperatures were 255 K and 298 K respectively. Heat transfer has occurred due to temperature gradient. It was required to reduce the heat flux up to 50% by increasing the corkboard thickness or with some other material. The temperature profile was also studied by changes the corkboard with new material having thermal

conductivity K = 2.5exp (-1225/T). Heat flux and temperature profiles were also examined with natural convection heat transfer coefficient ($h = 1.37[(T_5 - T_4)/6]^{1/4}$) at the outside of the wall.

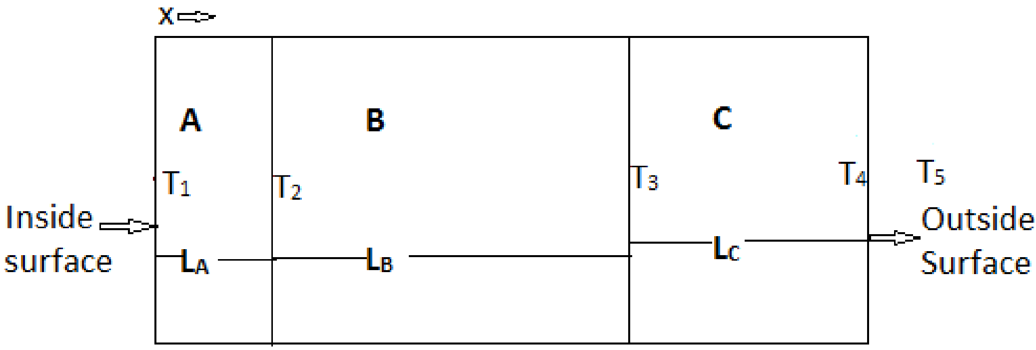

Figure 1. Heat transfer through cold storage wall.

III. Mathematical Model

The heat transfer was occurred by conduction mode across the solid wall. Furrier law will be applicable:

$$\text{Heat flux} = q_x = \frac{\text{Deriving force}}{\text{Resistance}} ------ 1$$

$$\text{Deriving force} = \text{Temperature change} = \Delta T ---- 2$$

$$\text{Thermal resistance} = \frac{\text{Thickness of material}}{\text{Thermal conductivity}} = \frac{L}{K} ---- 3$$

Thermal resistance = R = Resistance of Pine + Resistance of cork board + Resistance of concrete

Convective resistance will also encounter in case of convective heat transfer.

$$R = R_A + R_B + R_C = \frac{L_A}{K_A} + \frac{L_B}{K_B} + \frac{L_C}{K_C} ---- 4$$

Heat flux through layer A, Layer B, and Layer C will be

$$q = \frac{\Delta T}{\frac{L}{K}} ---- 5$$

$$T_1 - T_2 = -\frac{L_A}{K_A} q_A ---- 6$$

$$T_2 - T_3 = -\frac{L_B}{K_B} q_B ---- 7$$

$$T_3 - T_4 = -\frac{L_C}{K_C} q_C ---- 8$$

Total temperature difference

$$\Delta T = T_1 - T_2 + T_2 - T_3 + T_3 - T_4 = T_1 - T_4 ---- 9$$

Total heat flux through composite wall is

$$q_x = \frac{\Delta T}{R_A + R_B + R_C} = \frac{T_1 - T_4}{\frac{L_A}{K_A} + \frac{L_B}{K_B} + \frac{L_C}{K_C}} ----- 10$$

In case of convection

$$q_x = \frac{\Delta T}{R_A + R_B + R_C} = \frac{T_1 - T_4}{\frac{L_A}{K_A} + \frac{L_B}{K_B} + \frac{L_C}{K_C} + \frac{1}{h}} ---- 11$$

IV. METHODOLOGY

COMSOL 5 multiphysics software was used to study the heat transfer phenomenon. 2 D heat transfer module has been selected for this particular case. Composite wall geometry has been sketched first with the help of data. To analyze the problem material data from table 1 and Furrier law equation has been selected. Boundary conditions were defined from problem statement. The required parameters for simulation were used from the table 1. Run the simulator after completion of all simulation requirements. The obtained results were compared with mathematical method.

V. RESULTS AND DISCUSSION

The temperature profile was linear in each layer of composite wall at constant thermal conductivities. At steady state condition temperature was raised from 255 K to 256.7 K at interface of pine and cork board. Temperature profile trend was linear in pine layer. It was increased from 256.7 K to 296.3 K in cork board layer. The temperature at interface of corkboard and concrete was 296.3 K. The outside surface temperature was found 298 K. From these results it can be concluded that heat was transferred from outside surface to inside surface. The heat flux value was found 17.150389 W/m2. In case 2, when the cork board was changed with other material which thermal conductivity is function of temperature. It has been analyzed that the temperature profile with in layer of that martial was not linear. It was changed along the temperature change within that layer. When convective heat transfer (h) was considered heat flux and temperature at interfaces were also changed. The heat flux value was reduced to 12.12 W/m2. Pine and corkboard interface temperature was remained unchanged. The corkboard and concrete interface temperature was 289.68 K and the concrete and air interface temperature was 290.88 K. It has been observed that the heat flux value was decreased with increased in thermal resistances. It is required to decrease the value of heat flux up to 50%. It was achieved by increasing the thickness of corkboard from 0.1 m to 0.2 m. This increase in thickness will increase the thermal resistance and hence reduce heat loss up to 50%.

Simulated temperature profiles were shown in Fig. 2 and fig. 3. In Fig.1 graph (A) and Fig.2 (C) it has been observed that when the thermal conductivity of corkboard was function of temperature then the temperature profile has little curve. The temperature profile was linear in pine (0-0.015 m) and concrete (0.1-0.75 m) layers but little curved can be seen in middle layer (0.015-0.1 m). This trend shows that temperature profile in composite material depend upon thermal conductivity and consequently thermal resistance of the material.

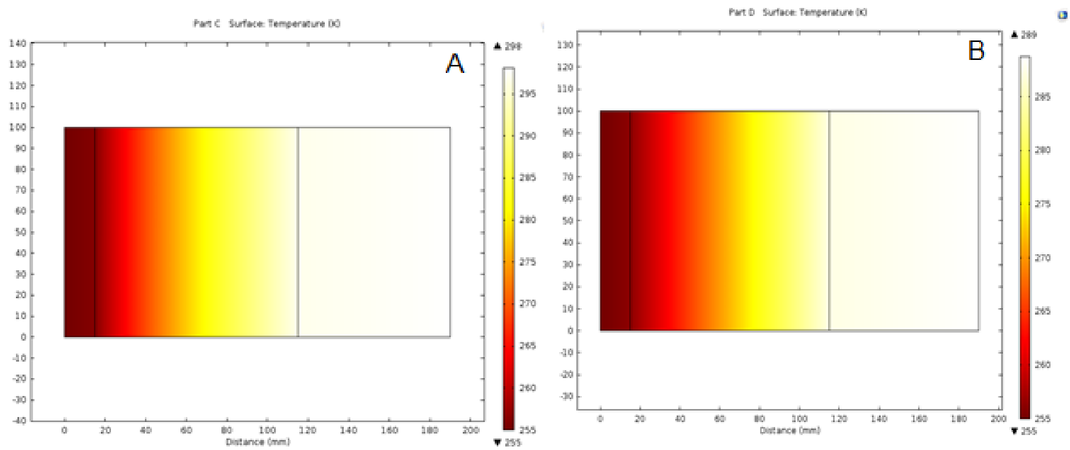

Figure 2. COMSOL Multiphysics 5 simulation results: (A) Temperature variations within composit layers when material thermal conductivity (K = 2.5exp (-1225/T).) was the function of temperature. (B) Temperature profile with convective resistance.

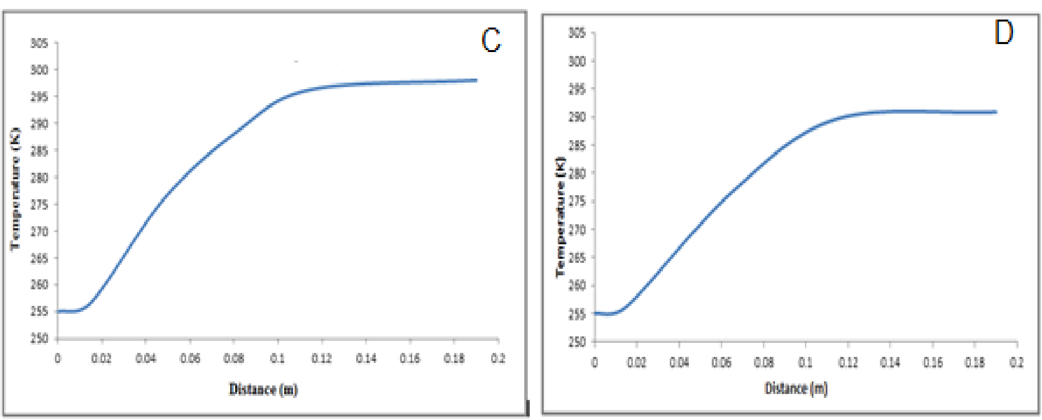

Figure 3. Temperature profiles within composite layer layers when material thermal conductivity (K= 2.5exp (-1225/T).) was the function of temperature (C); Temperature profile with convective resistance (D)

VI. Conclusions

Complex steady state heat transfer phenomenon across a cold storage composite wall has been studied with the help of COMSOL 5.0 Multiphysics. In this article it has been observed that temperature profiles within the composite wall are linear but temperatures value at the interface depend upon the thermal resistances of composite materials. Heat loss through the wall can be reduced by increasing the thermal resistance of composite materials used to construct wall. It is concluded that heat loss across the wall is depend on the thickness of composite material layers and temperature gradient across the composite layers.

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