Numerical investigation of the thermal behavior of heated natural composite materials

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Abstract. In the present work numerical investigation was carried out for laminar natural convection heat transfer from natural composite material (NCM). Three types of natural materials such as seed dates, egg shells, and feathers are mixed separately with polyester resin. Natural materials are added with different volume fraction (10%, 20%, and 30%) are heated with different heat flux (1078W/m^2, 928W/m^2, 750W/m^2, 608W/m^2, and 457W/m^2) at (vertical, inclined, and horizontal) position. Continuity and Navier-Stocks equations are solved numerically in three dimensions using ANSYS FLUENT package 12.1 software commercial program. Numerical results showed the temperature distribution was affected for all types at volume fraction 30% and heat flux is 1078 W/m^2, for different position. So, shows that the plumes and temperature behavior are affected by the air and the distance from heat source. Numerical results showed acceptable agreement with the experimental previous results.

1. Introduction

Natural convection heat transfer depends on the geometry of the surface as well as its orientation. It also depends on the variation of temperature on the surface and the thermo physical properties of the fluid involved. The heat transfer from generators, transformers and electronic circuits in the electrical and electronic applications is natural convection heat transfer [1,2]. Hassan and Mohammed [3], studied experimentally of laminar natural convection heat transfer from rectangular plates at horizontal, vertical and inclined heated at constant temperature. The plate fabricated from brass dimensions (0.504 m X 0.2 m) heated by hot water upward to constant temperature. They obtained that the mean of heat transfer in vertical position is higher than horizontal in both cases. Pera and Gebhart [4], studied numerically and experimentally the boundary layer flow for laminar natural convection heat transfer at semi-infinite horizontal plates and inclined at constant temperature and heat flux, with range of Prandtl number ($0.1<Pr<10$). Miyamoto et al.[5], studied numerically the heat transfer from rectangular surfaces at vertical and horizontal position. It is heated with constant heat flux and temperature. They obtained the relation between the mean Nusslet number and Grashof number at Prandtl number ($Pr = 0.72$). Rafah [6], studied experimentally the natural convection heat transfer from isothermal heated upward – facing square horizontal plates and has square hole at range of Grashof number is ($0.5 \times 10^6 < Gr < 6.28 \times 10^6$) and for range of temperatures (T_w=40, 61, 82.5, and 112.8℃). Fujino and Honda[7], described the features of PWFA (Plastic Waste / Fly Ash) composite, which is made mostly from plastic waste and fly ash, is one of the materials developed for the purpose of recycling. A small amount of glass fiber as reinforcement and a fire retardant was added in the ingredient of the composite. The thermal conductivity data for the specimen (100×100) mm^2 is determined and it decreased with increasing the specimen temperature. Faieza [8], studied the effect of volume fraction on the thermal conductivity of some composite materials consisting of epoxy/carbon fibers and epoxy/Kevlar fibers experimentally using Lee's disc method. The results showed that the composites when reinforced with carbon fiber have a higher thermal conductivity than Kevlar composites. Also, for both composites the thermal conductivity increases as the volume fraction increase. In the present work numerical study of laminar natural convection heat transfer from NCM with different heat flux at different position.

2. Physical Model

The heat flux can be determined by the following law [9];

$$q = \frac{Q}{A_s} \tag{1}$$

where q is heat flux(W/m^2)

Heat transfer coefficient can be computed as follows:

$$I.P = Q = Q_{cond.} + Q_{conv.} + Q_{rad} \tag{2}$$

$$Q_{cond.} = \frac{(T_w - T_x)}{R_{ins.}} = \tag{3}$$

$$R_{ins.} = \frac{L_{ins.1}}{K_{ins.1}A_{ins.1}} + \frac{L_{ins.2}}{K_{ins.2}A_{ins.2}} \tag{4}$$

$$Q_{rad.} = FA_s\,\varepsilon\sigma\left(T_w^4 - T_{surr}^4\right) \tag{5}$$

Where F=1,Ɛ=0.9

In the present work Q_{cond} and $Q_{rad.}$ are neglected.

$$Q_{conv.} = \bar{h} A_s (T_w - T\infty) \tag{6}$$

Where A_s is area of element (m^2), h is average heat transfer coefficient (W/m^2K),and Q_{conv} is heat transfer by convection(W).

$$\bar{h} = \frac{Q_{conv.}}{A_s(T_w - T_\infty)} \tag{7}$$

The properties of air can be evaluated at reference temperature

$$T_e = T_w - 0.25\,(T_w - T_\infty) \tag{8}$$

Where T_w and T_∞ are wall temperature and ambient temperature respectively (C).

The coefficient of expansion (β) is determined as:

$$T_f = 0.5\,(T_w + T_\infty) \tag{9}$$

$$\beta = \frac{1}{T_f} \tag{10}$$

where β; is expansion volumetric coefficient (1/K)

3. Mathematical Model and Numerical Solution

The geometry of physical model is consists of a solid plate represents natural composite materials plate and have dimensions of (30cm x20cm x0.6 cm). The natural composite materials plates are setting in horizontal, vertical, and inclined with different angles. They are heated with different constant heat flux. A SOLID WORK PREMIUM 2012 is used to draw the geometry of plate as shown in figure 1**.** ANSYS FLUENT 12.1 package has been conducted for performing numerical simulation across the NCM plate using three dimensional model. The assumptions for the present work are; steady state, Newtonian fluid, incompressible laminar flow, three dimensional, free convection, external flow. The conservation equations for continuity, momentum, and energy can be written as follows [9]:

Continuity Equation:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \tag{11}$$

Momentum Equations (x, y, z components):

$$\rho\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}\right) = \mu\left(\frac{\partial_u^2}{\partial x^2} + \frac{\partial_u^2}{\partial y^2} + \frac{\partial_u^2}{\partial z^2}\right) - \frac{\partial p}{\partial x} + \rho g_x \tag{12}$$

$$\rho\left(u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z}\right) = \mu\left(\frac{\partial_v^2}{\partial x^2} + \frac{\partial_v^2}{\partial y^2} + \frac{\partial_v^2}{\partial z^2}\right) - \frac{\partial p}{\partial y} + \rho g_y \tag{13}$$

$$\rho\left(u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z}\right) = \mu\left(\frac{\partial_w^2}{\partial x^2} + \frac{\partial_w^2}{\partial y^2} + \frac{\partial_w^2}{\partial z^2}\right) - \frac{\partial p}{\partial z} + \rho g_z \tag{14}$$

Energy Equation:

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + w\frac{\partial T}{\partial z} = \alpha\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) + \beta T\left(\frac{dp}{dt} + u\frac{dp}{dx} + v\frac{dp}{dy} + w\frac{dp}{dz}\right) + \mu\phi + q''' \tag{15}$$

Unstructured mesh is used to discretized the computational domain by using the finite volume scheme. The model was meshed by GAMBIT software and figure 2 shows the mesh. In the present study, an average of three million cells is used. The maximum number of iterations performed to get the solver terminate are 500 iteration as shown in figure 3. Boundary conditions are specified for each zone of computational domain as shown in figure 4.

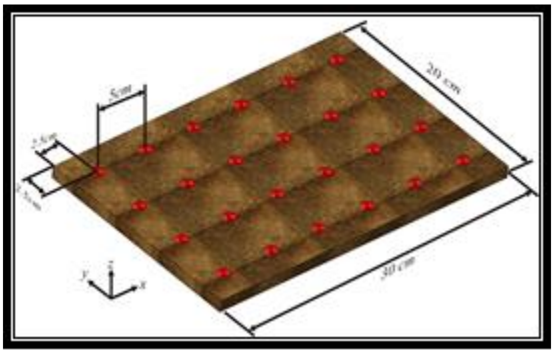


Figure 1. Plate geometry of NCM.

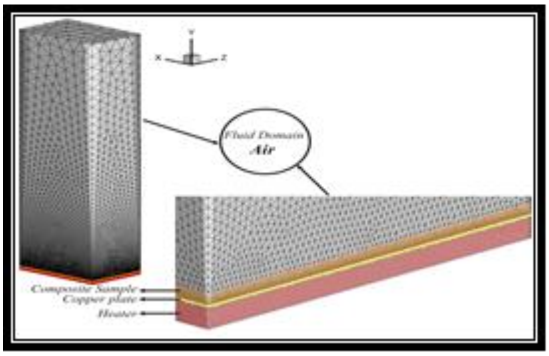


Figure 2. Tetrahedral meshing of the samples and the fluid Domain (Air).

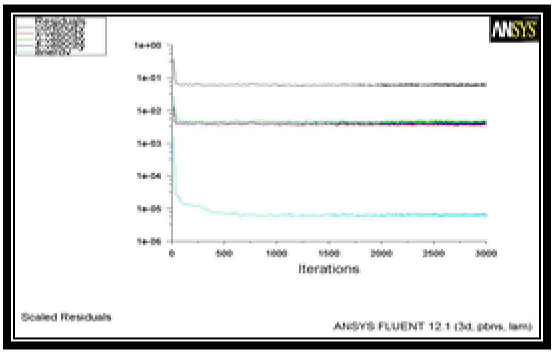


Figure 3. Convergence history for continuity, momentum, and energy equations.

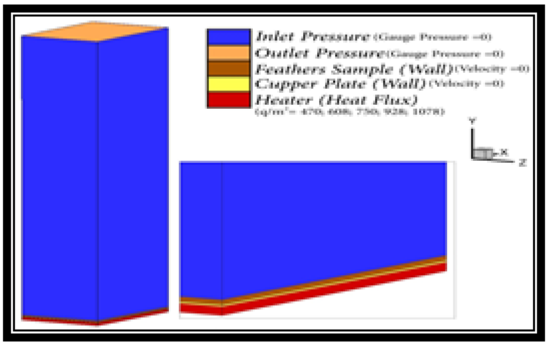
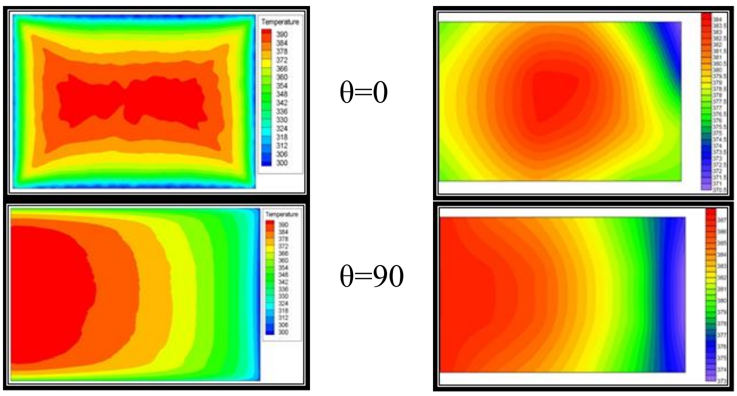


Figure 4. Boundary conditions of the computational domain.

4. Results and Discussion

In order to validate present numerical simulation, a comparison has been carried out with experimental results achieved by Mohammed [10]. Good agreement of behavior between these results has been found which indicates the acceptable validation of present simulation as shown in figure 5 and figure 6. Figures show that the temperature is concerned at mid of NCM plate for different volume of fraction and different type of NCM at horizontal position. But the temperature concerned at the leading edge of plate for vertical position because of air effect.



Numerical results (present work) **Experimental results [10]**

Figure 5. Validation of numerical results with reference results for egg shells composite material plate , $q=1078W/m^2$, $V_f=30\%$, temperatures at (K).

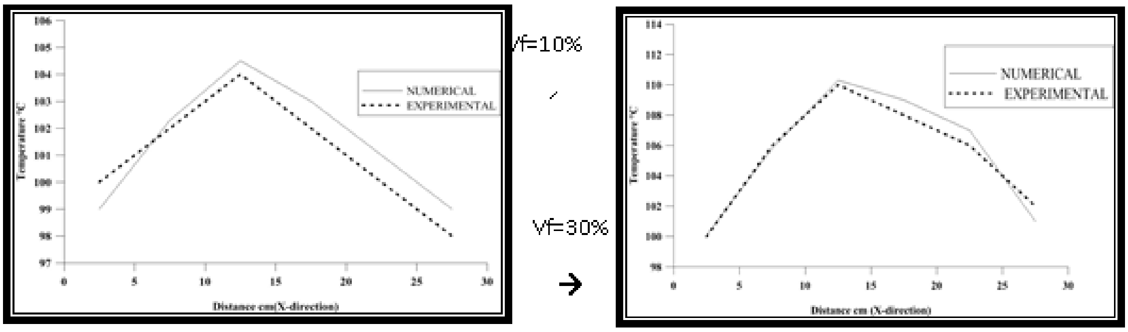


Figure 6. Comparison between numerical and reference experimental results [10] for seed dates composite materials, q=1078W/m^2, θ=0°, (X=12.5 cm, Y=12.5 cm).

Figure 7 and figure 8 show the distribution of temperature for two types of NCM (seed dates and feathers) at different positions. Same behavior show in previous figures but different heating temperature. This is because of different properties for NCM (thermal conductivity, specific heat, and thermal diffusivity), which causes difference in the behavior of temperatures. Figures 9, 10 and 11 show the temperature contours at middle Y- plane of three types of NCM with 30% volume of fraction. NCM plates are heated with constant heat flux (1078 W/ m^2) at horizontal position. Figures show different shape of plumes above the plate. This is because of the distribution of temperature related with different properties. Figure 12 shows that the heat transfer from the plate is increases with increasing the angle of position and the heat flux depending on the properties on NCM.

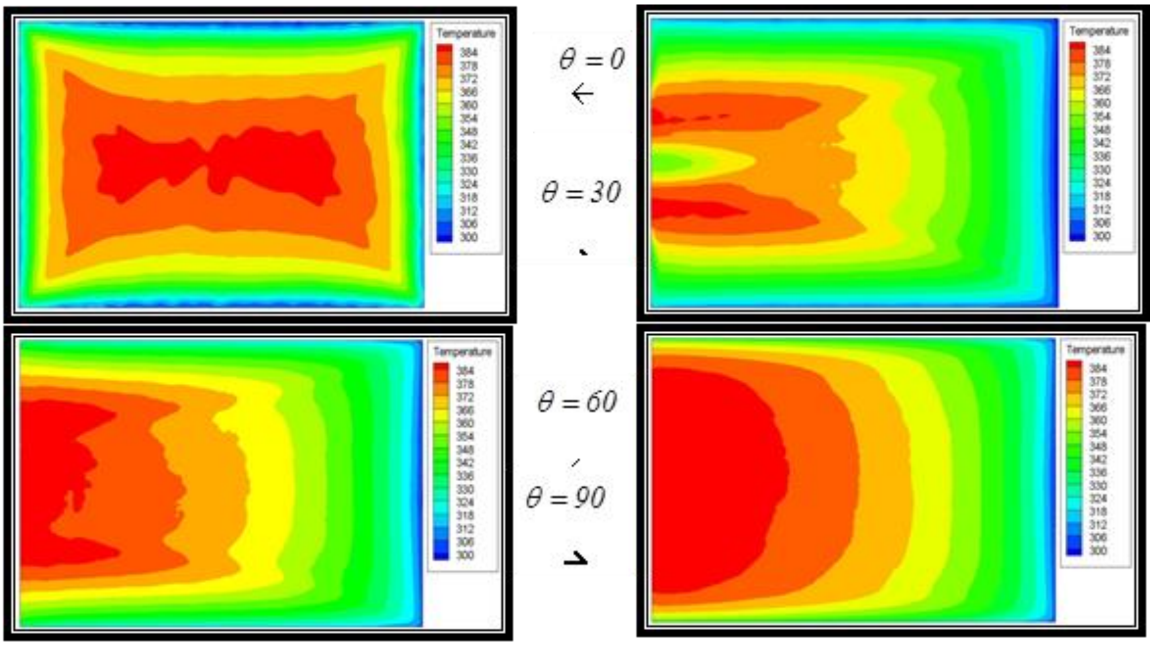


Figure 7. Temperature contours at the plate for seed dates composite material, q=1078W/m^2, V_f=30%.

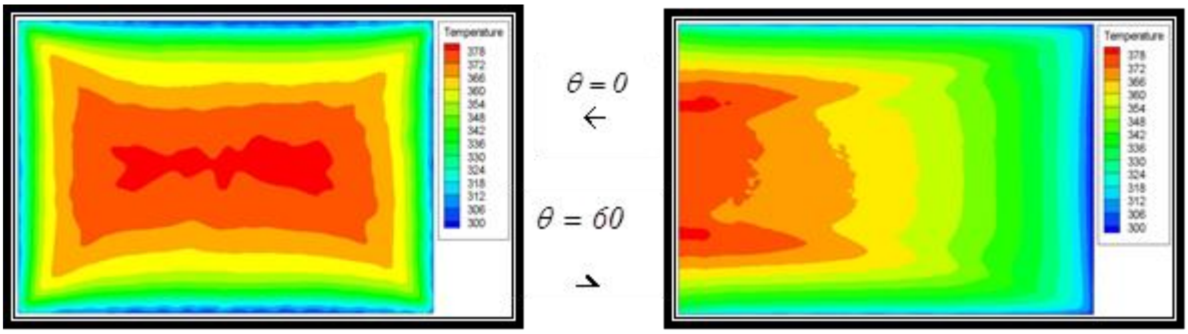


Figure 8. Temperature contours at the plate for feathers composite material, q=1078W/m^2,V$_f$=30%.

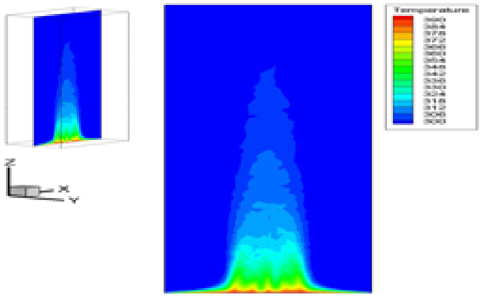


Figure 9. Temp. contour at XZ-plane for egg shells composite material q=1078W/m^2, V$_f$ =30%, θ=0̊.

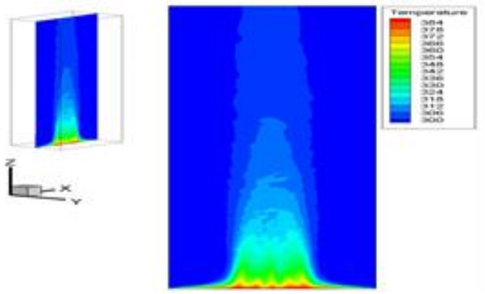


Figure 10. Temp. contour at XZ-plane for seed dates composite material q=1078W/m^2, V$_f$=30%, θ=0̊.

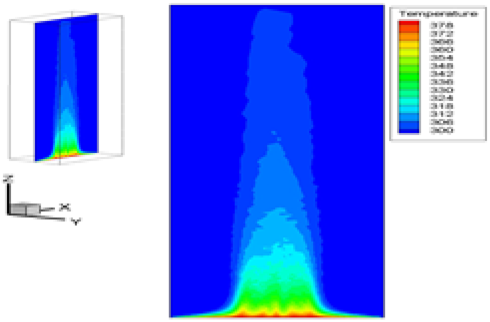


Figure 11. Temp. contour at XZ-plane for feathers composite material q=1078W/m^2, V$_f$ =30%, θ=0̊.

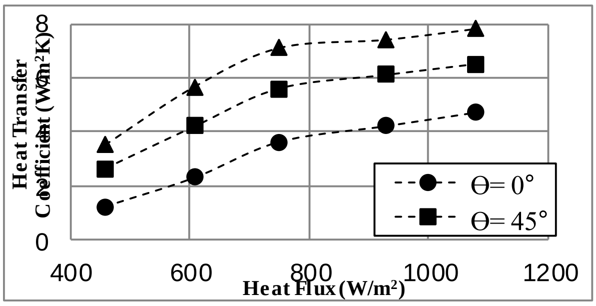


Figure 12. Effect of heat flux on heat transfer coefficient for seed dates composite material V$_f$=30%.

5. Conclusions

The main concluded points of this study may be summarized as follows:

- The temperature is concentrated at the central of NCM plate in horizontal position. But it is start to deviate toward the edge of plate at any angle of inclination especially vertical position.

-Increasing the volume of fraction of (seed dates, egg shells, and feathers) in the composite materials lead to different properties for NCM such as (thermal conductivity, specific heat, and thermal diffusivity).

-The temperature distribution is different due to the properties of NCM.

- The heat transfer coefficient increases due to the increases in heat flux for different type of NCM and position of plate.

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