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CONJUGATE HEAT TRANSFER IN RUBBERWOOD DRYING BY HOT AIR

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ABSTRACT

In this study, we present numerical study with experimental validation of the thermal temperature treatment of three-dimensional wood, the heat transfer in rubberwood drying using hot air convection. The aim of the experiment is to verify the model for the kinetics of drying process by means of the characteristic of drying curve method. The time variations of internal temperature inside rubberwood between experiment and simulation were compared. Comsol Multiphysics finite element analysis software was used to obtain results via conjugate heat transfer model. Simulation results of temperature distribution are presented for 80, 90 and 100°C conditions. The result shows that the drying of rubberwood using the two methods reveals acceptable level of agreement.

Keywords: conjugate heat transfer; rubberwood drying; temperature; finite element

INTRODUCTION

Southern Thailand is home to a large area for rubber tree which is a major source of timber. The tree is commonly harvested when it is between 20 to 30 years of age depending on the specie of the tree and if the diameter is less than 200 mm [1]. Rubber tree is naturally short in lengths and has to be glued during to crafting process in order to make useful wooden plank. One of the most method of wood maintenance is drying which has to do with the complex combination of the application of heat transfer and the removal of moisture content[2]. In general, the conventional drying process of rubberwood in Thailand takes 5-8 days [3] due to the low thermal efficiency of dryer. The aim of drying is simply to elimination liquid from the dried sample without generating any destruction in the woods. Moisture can leave the surface at initial condition depending on many parameters. For the purpose of achieving good drying of lumber, it requires a method that eliminate the moisture from the inside of the dried wood to the outside surface at the same rate as the evaporation of moisture surface. In this work, the heat transfer and the drying kinetics of rubberwood were studied to increase thermal efficiency of dryer for minimizing drying period. In preliminary study, the heat transfer between hot air and rubberwood was investigated experimentally and numerically. The time variations of internal temperature inside rubberwood between experiment and simulation were compared. The simulation results were taken to justify a heat transfer mechanism.

Governing Equations

The heat transfer and fluid flow phenomena in conjugated heat transfer model are governed by momentum, continuity and energy equations in order to determine temperature distribution. These equations, for the model, are solved in COMSOL Multiphysics [4]. The equations describing three- dimensional heat transfer in wood during heat treatment are given as followed.

$$\rho\,(u.\nabla)u \;=\; \nabla.[-pl + \mu(\nabla u + (\nabla u)^T) - \frac{2}{3}\mu(\nabla.u)l] + F \quad (1)$$

$$\nabla.(\rho u) = 0 \quad (2)$$

$$\rho C_p u.\nabla T = \nabla.(k\nabla T) + Q \quad (3)$$

MATERIAL AND METHOD

In this work, drying of rubberwood was investigated experimentally and numerically. In the experiment, the rubberwood sample which has 3 inches in width, 1 inch in thickness and 46 inches in length was dried for 4 hours in hot air dryer [5]. The temperature and velocity of hot air were 80, 90 and 100°C and 1.75 m/s. The variations of internal and external temperature of rubberwood were recorded using K-type thermocouples with data logger in figure 1 [6]. A simulation, the complete mesh consist 5962 elements and test under the same condition as hot air, as reported in figure 2, the conjugated heat transfer which solves problems of convective heat transfer from hot air to rubberwood and conductive heat transfer inside rubberwood was considered at the same rate as the experiment [7,8]. The numerical model was created with the same experimental conditions using COMSOL [9]. In addition, simulation results for velocity distribution was obtained as shown in figure 6.

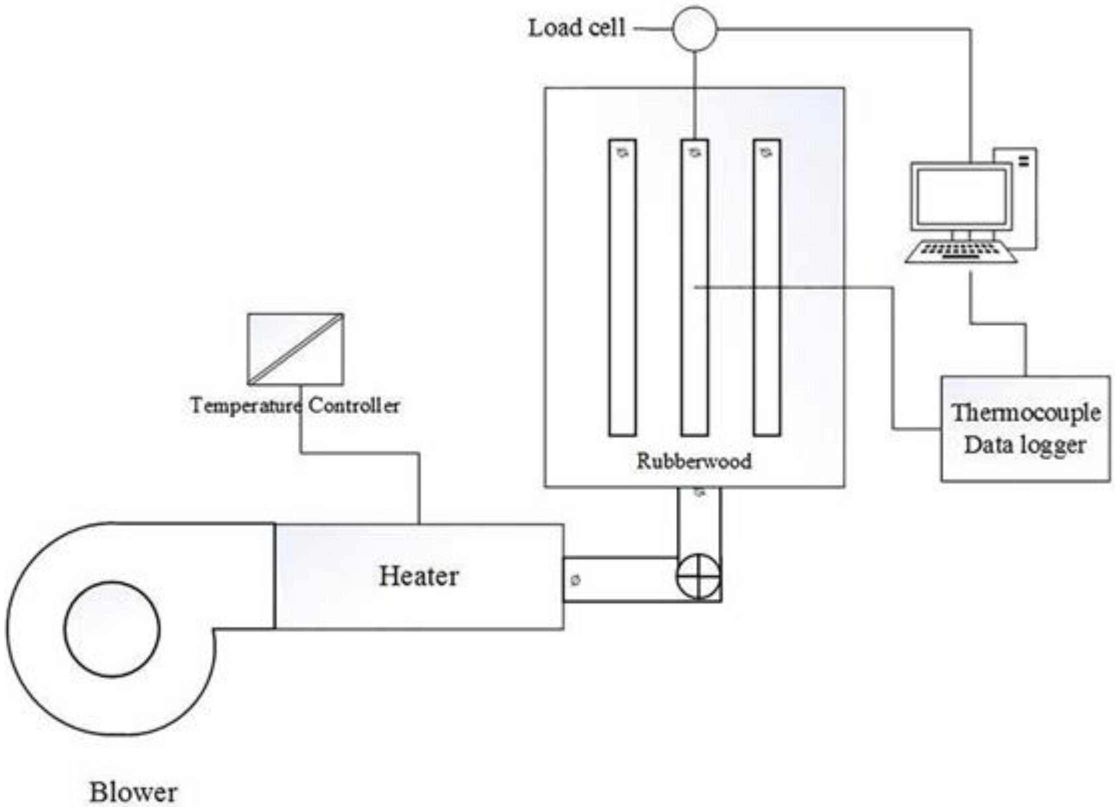

Figure 1: The experimental setup and measurement technique

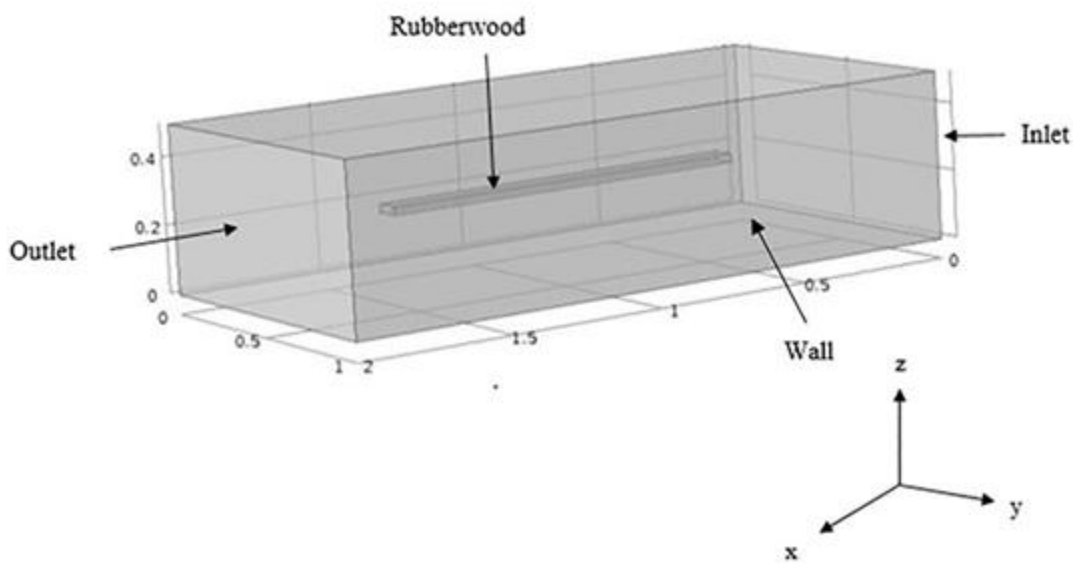

Figure 2: The geometry in numerical analysis showing fluid flow system

RESULTS AND DISCUSSION

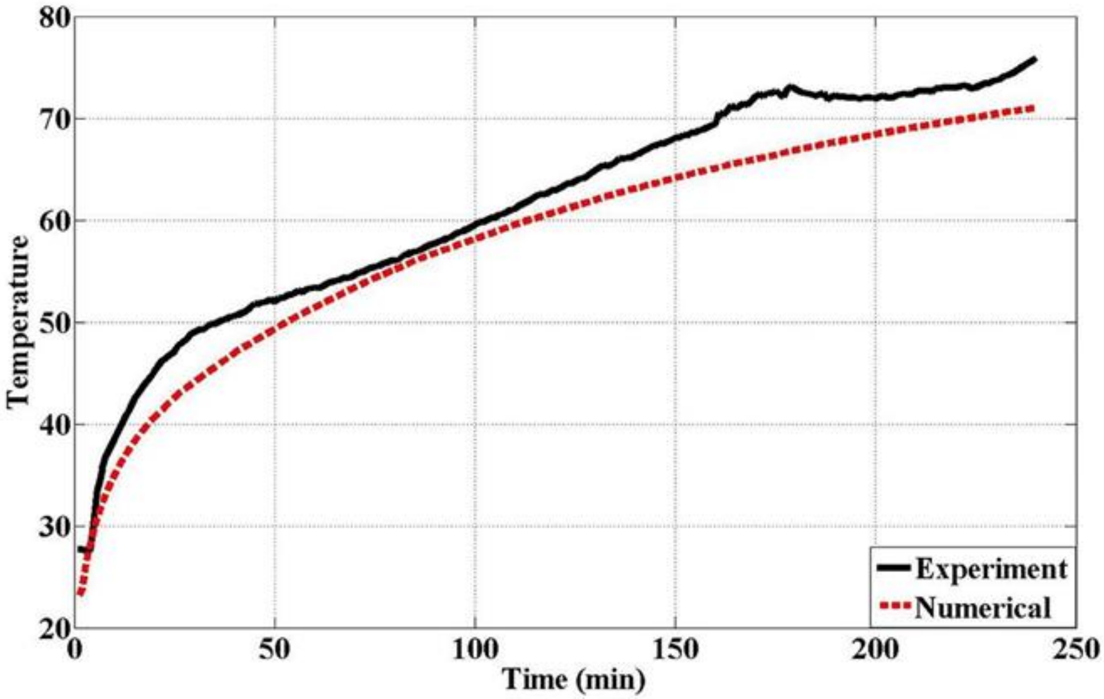

Figure 3: Temperature profiles, simulation and experimental at 80 °C

The result of hot air experiment within 80, 90 and 100°C temperature range reveals that drying times in impinging hot-air is significantly shorter when compared to the numerical method results[10]. The figure shows the comparison between the experimental data and numerical data for the prediction of distribution of rubberwood temperature profile at different time[11]. During the drying process the influence of gas temperature has an effect on the wood by increasing temperature profile linearly with time. The goal of the study was to determine the temperature distributions in the wood as well as on the surface and the internal temperature gradients are shown in figure during convective and conductive drying of rubberwood. The temperature profile for distribution is shown in figure 3, 4 and figure 5 respectively.

As a result, the final temperature profile from experiment illustrated in figure 3 is lower than numerical analysis due to need to repeat an experiment in hot air machine during the experimental process. However, from 230 min onward it has been observed that the temperature increases gradually. Figure 4 shows the maximum temperature of 96°C in the experiment was reached.

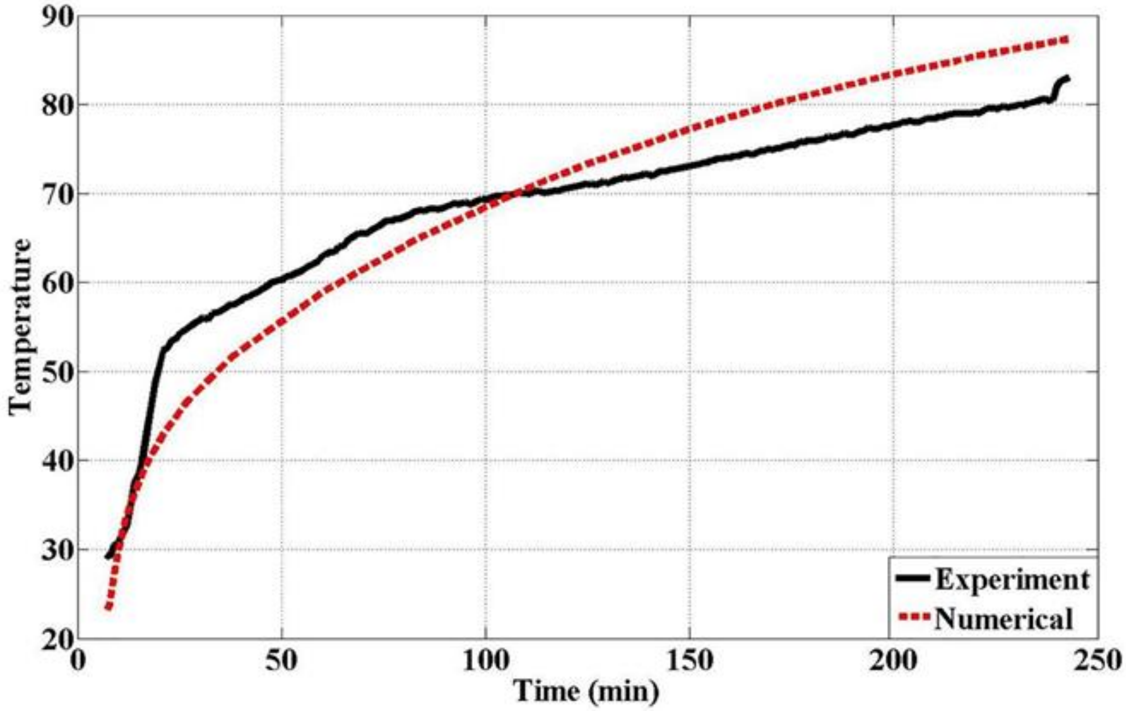

Figure 4: Temperature profiles, simulation and experimental at 90 °C

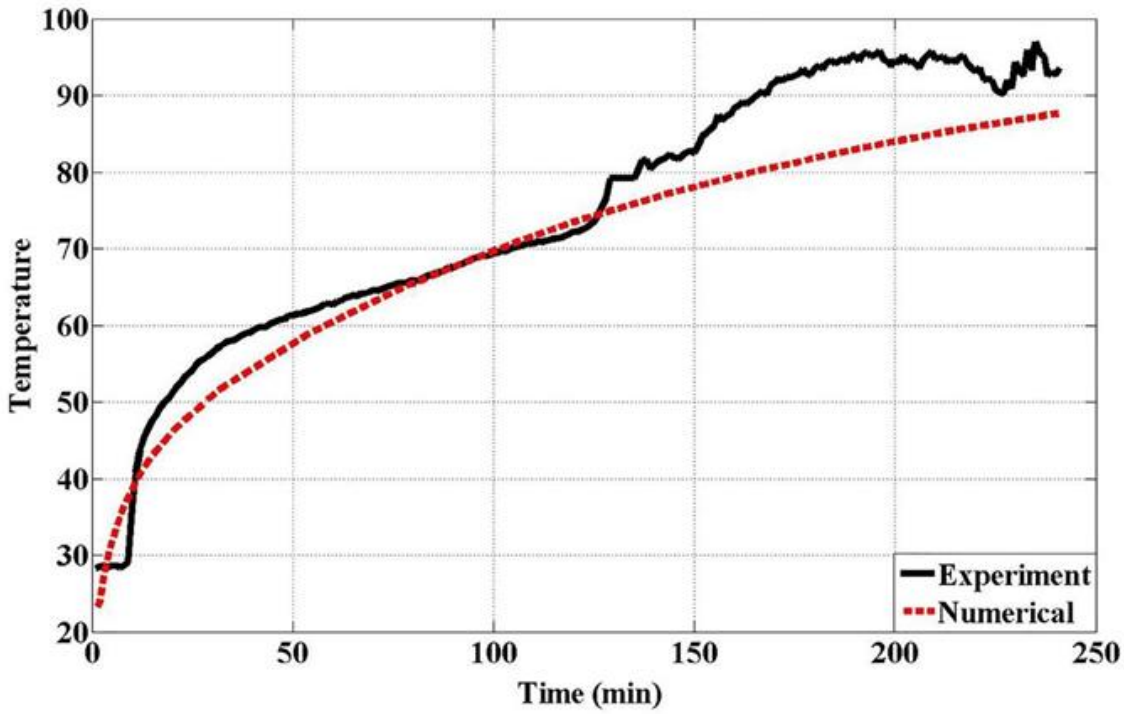

Figure 5: Temperature profiles, simulation and experimental at 100°C

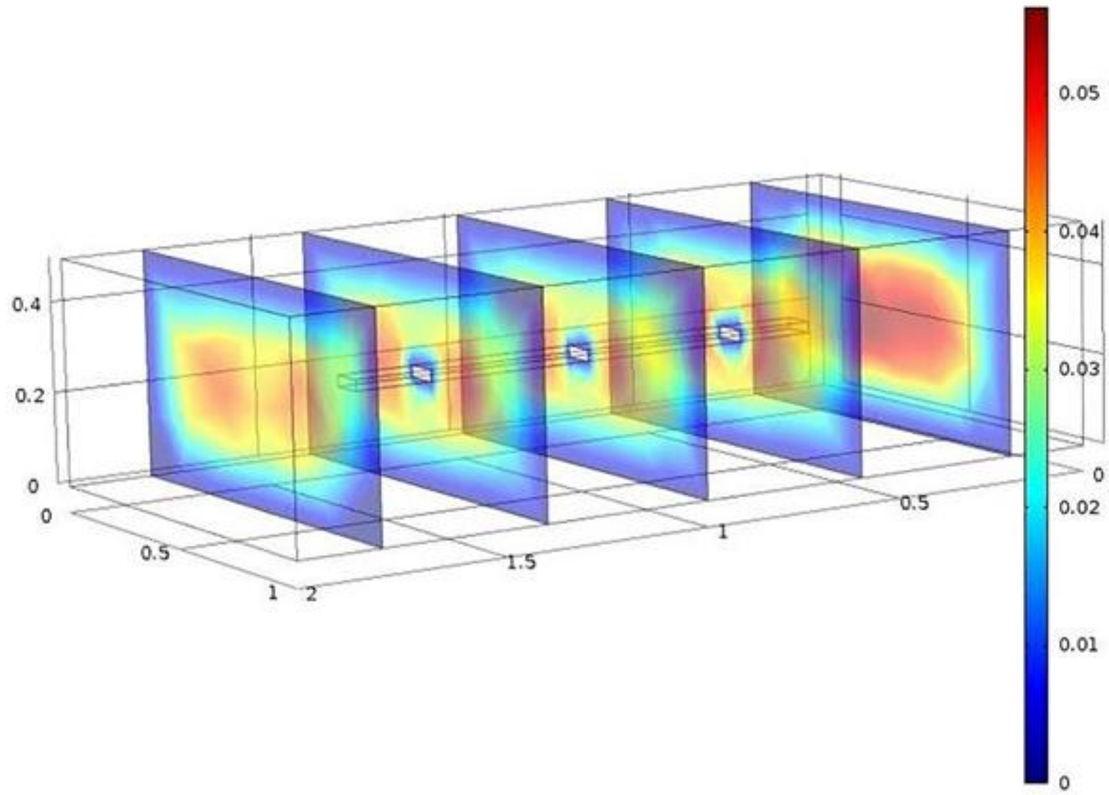

Figure 6: Velocity distribution at 4 hour

CONCLUSION

When comparing an experimental temperature founded at 90°C and 100 °C (figure 3, figure 4), there is variant temperature profile of more than 80°C (figure 2) due to high temperature that was difficult to control. Thus the recommended operating temperature is 80°C for the next time.

The differences between the numerical and experimental results were compared and validated. Moreover, results of both numerical and experimental from the temperature distributions in the wood revealed the temperature gradients are satisfy. The results of the two methods showed an acceptable level of agreement; thus, the numerical simulation results was valid and can be used to improve model future experiments.

Nomenclature

C_p	Specific heat	J/kg.K
F	Body force	N/m^2
k	Thermal conductivity	W/m.K
p	Pressure	Pa
u	Velocity	m/s
t	Tangential to a surface	
T	Temperature	K
l	Length	m
Q	Heat source	W/m^3
x, y, z	Cartesian coordinates	m
Greek symbols		
ρ	Density	kg/m^3
μ	Dynamic viscosity	
Subscripts		
f	Fluid	
s	Solid	

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