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APPLICATION OF HOT AIR TRAY DRYING IN SMALL SCALE TRADITIONAL HOME ROOF TILES MANUFACTURE CLUSTER IN NGUNUT SUB-DISTRICT EAST JAVA INDONESIA

Puguh Setyopratomo
Chemical Engineering Department, University of Surabaya Jl. Raya Kalirungkut, Surabaya, Indonesia
E-Mail: puguh_sptm@yahoo.com

ABSTRACT

Home roof tiles cluster located in Ngunut Sub-district, East Java Indonesia has been developed since 1970. In such traditional tiles manufacturing business sun drying is still used and the main problem is the long drying time and its dependency on the season. This work intends to solve the main problem by implementing hot air tray drying instead of the sun drying. Hot air drying at air temperature range 50 - 90 ^{o}C and air velocity ranging from 0.4 m/s to -0.6 m/s resulted in moisture diffusivity within wet tile range 2.46x10-4 - 4.20x10-4 m^2/s and drying rate range 25 - 35 gr $H_2O/(m^2.mnt)$. Application of hot air tray drying instead of sun drying result in reduction of total drying time from 5 days to one day, then production capacity significantly increases. Furthermore, another major advantage of the application of hot air tray drying is its independency on the seasons, since hot air drying will running well in both dry and rainy season.

Keywords: hot air drying, moisture diffusivity, roof tiles, small cluster.

INTRODUCTION

Sumberingin Kulon village which is part of the Ngunut Sub-district, Tulungagung, East Java, is one of the main roof tiles producing areas in East Java Province, Indonesia. In this village about 200 households work as a tile craftsmen and produce approximately 2 million pieces of roof tiles monthly. The roof tiles products are not only to meet the need of tiles around Tulungagung Regency but also to supply the need of other areas such as Surabaya, Malang, and Bali.

The raw material for the production of the tiles is a mixture of 70 % by weight white clay and 30 % by weight black soil. Tile-making process begins with mixing of raw materials and followed by wet milling. Milling is done to obtain finer, more homogeneous and more dense raw materials mixture in order to produce tile with good quality. The finer the particles will result in the smaller porosity of the tiles products, then increase the strength against a bending force and decrease the water infiltration. The next process is tile printing. The tiles printing are done manually by inserting the milled raw material into a moulded pressing machine. The output of this printing stage is a wet tile with moisture content around 20 - 25 % by weight on wet basis. The next step is drying of wet tiles which are divided into 2 stages.

The first stage of drying is performed by putting the wet tiles on a set of trays which was placed in a room that facilitate the occurrence of a natural air flow. The first drying stage is slow rate drying to avoid cracking occurs in the tiles. Tiles cracking can occur if the initial drying rate is too fast which led to the emergence of a strong strain due to the big difference between the water content at the surface and inside of the tile.

The second stage drying is drying under the sunlight. The second stage drying is performed by putting the tiles on a inclined tray and place it on yard to facilitate direct drying under the sunlight. The second stage drying lasted for approximately one day.

The final stage of the tiles manufacturing process is tiles burning. The burning was performed in a refractory brick insulated furnace. The burning processes using wood as the main fuel and coconut husks as a complemented fuel. Burning was taken place at temperatures of about 1000 °C for approximately 22 hours. After experiencing the natural cooling in the furnace, the tile is removed from the furnace and was stored in warehouse for sale.

The main problem faced by the roof tiles industry cluster is the too long drying process. Furthermore, since the drying process only utilizing the sunlight, in the rainy season the production is almost stopped altogether.

This research work is aimed to design and apply a simple hot air roof tiles drying and examine its performance. The significance of this research is to solve the main problem faced by the roof tiles industry cluster by reducing the drying time to increase the production capacity and the productivity.

MATERIAL AND METHODE

In order to produce a proper design of hot air tiles drying, it is considered very important to investigate the most controlling stage during the drying. Stages which may control the overall drying rate are the internal mass transfer as molecular diffusion within the tiles material or the external mass transfer in the form of convective mass transfer. To draw a conclusion about that and even to get an idea of the optimum operating conditions, its necessary to observe the dependency of the moisture diffusivity within the tiles on the temperature and the linier flow rate of the hot air stream. To obtain such information, a thin layer tile drying is carried out in small-scale electrical heated hot air dryer by varying the air temperature at 30 ^{o}C, 70 ^{o}C and 90 ^{o}C, and the air flow rate at 0.4 m/s and

0.6 m/s for each of the applied air temperature. The sample was a cut of wet roof tile, 5.5 cm long and 4.5 cm wide, obtained from the production line resulted from the tiles printing stage. The moisture diffusivity then calculated using Crank formulation for thin layer drying.

The applied commercial scale roof tiles dryer was designed and operated base on the conclusive result of the previous observation on the small scale dryer. To ensure that there is no leakage of air stream to the environment, concrete was used as construction material of the wall and the roof of the dryer. Air stream was supplied by centrifugal blower, while Liquefied Petroleum Gas (LPG) burner was used as a heat source in heating process of the air stream.

THEORY

Kinetic of drying

In any drying process, there are some transport processes which are involved in control the drying kinetic, they are [1]: a). External heat transfer which supply energy to the material surface, the driving force is the temperature difference between the heating media and the material surface, b). Conduction heat transfer which transmit energy from surface to inside part of the material, c). Moisture diffusion from inside to the material surface, the driving force is the different of moisture content within particle and on its surface, d). Moisture transport from the surface toward external moisture carrier media, the driving force is the difference of moisture partial pressure. Material with high moisture content result in constant rate of drying, which will happen only in very short time, afterward the drying rate decreases. The later was called fallling rate periode. For dense solid particles, such as most of agriculture products, the moisture transport mainly take place within the product, then falling rate drying will happen in almost the whole of the drying process.

As the air flow velocity was considered adequate then the external heat and mass transfer were assumed didn't control the overall drying rate and the process was basically controlled by internal transfers. Moreover, since mass transfer is much slower than conduction heat transfer within material, then the overall drying process was assumed to be controlled by moisture transfer within the material [2]. A first stage of superficial interaction followed by a diffusion Fick-types's law within material was used to describe the diffusion process where Allaf's formulation is commonly used: [3]

$$\frac{\rho_w}{\rho_m}(\vec{v}_w - \vec{v}_m) = -D_{eff}\ \vec{grad}\,\frac{\rho_w}{\rho_m} \qquad (1)$$

where:
ρ_w: apparent density of water in the material (kg.m^{-3})
ρ_m: apparent density of dry material (kg.m^{-3})
v_w : absolute velocity of water flow within the porous medium (m.s^{-1})
v_m absolute velocity of solid medium (m.s^{-1})
D_{eff}: effective diffusivity of water within the solid medium (m².s^{-1})

Assuming that the effects of possible shrinkage is negligible, and the effective diffusivity was considered to be constant during drying, for one dimension diffusion in spherical particle the Fick's second law could be formulated as:[3]

$$\frac{\partial \rho_w}{\partial t} = \left[D_{eff}\frac{\partial^2 \rho_w}{\partial r^2}\right] \qquad (2)$$

Where:
t: drying time
r: position within particle in radial direction

As the temperature during drying was assumed to be constant, then the effective diffusivity D_{eff} is considered as constant. This application of constant D_{eff} was performed only within moisture content range implemented in this study. Some different mathematical solutions have been proposed for this equation, which depend on the initial and boundary conditions [4]; in this study, the solution given by Crank was adopted, according to the geometry of the solid matrix [5]; by expressing the amount of water in the solid as moisture ratio, as expressed in equation (3), where X is the water content dry basis at any time, X_e is the amount of X at equilibrium and X_0 is the value of X at time = 0.

$$\text{Moisture Ratio} = \frac{X - X_e}{X_0 - X_e} \qquad (3)$$

For a slab geometry form, Eqn. (2) can be presented as:

$$\frac{X - X_e}{X_0 - X_e} =$$

$$\frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left(-\frac{(2n+1)^2\pi^2 D_{eff}\,t}{4L_0^2}\right) \qquad (4)$$

Where L_o is the thickness of slab (m), and t is time (s). Furthermore, for long drying period, Eq. (4) can be further simplified to only the first term of series [4], [6]. Then in logarithmic form Eq. (4) could be expressed as:

$$\ln\left(\frac{X - X_e}{X_0 - X_e}\right) = \ln\frac{8}{\pi^2} - \frac{\pi^2 D_{eff}\,t}{4L_0^2} \qquad (5)$$

Diffusivities are then determined by expressing the experimental drying data in term of the logarithmic Solid Moisture Ratio versus drying time t as shown in

Eqn. (5), it can be seen that the plot gives a straight line with a slope expression:

$$\text{Slope} = \frac{\pi^2 D_{eff}}{4L_0^2} \tag{6}$$

Activation energy

The influence of temperature on the effective diffusivity was generally expressed by the Arrhenius-type equation, which was expressed in Eqn. (7), and compare to the initial moisture content of the product, temperature has more significant effect over the drying process [7].

$$D_{eff} = D_o \exp\left(-\frac{E_a}{RT}\right) \tag{7}$$

Where E_a represented the activation energy of the moisture diffusion (kJ/mol); D_0 is the Arrhenius factor which is equivalent to the diffusivity at infinitely high temperature (m^2/s); D_{eff} is the moisture effective diffusivity (m^2/s); R is the universal gas constant (=8.314 J/mol/K) and T is the absolute temperature (K).

RESULTS AND DISCUSSION

The moisture diffusivity

Drying of a wet tile slab, which was considered as a 5.5 cm length and 4.5 cm wide thin layer, resulted in profile of the decreasing sample moisture content started from the initial moisture content X_0 and terminated on its equilibrium moisture content X_e?

Plot of the logarithmic solid moisture ratio versus drying time, refer to the formulation expressed in Eqn. (5), and its linier regression was shown in Figure-1 and Figure-2. In the display which expresses the regression result y represent the logarithmic of moisture ratio while x represent the drying time.

The value of R^2 which close to unity indicate that Crank solution model was suitable applied to this case. The moisture diffusivity was derived from the value of the corresponding slope follows the formula expressed in Eqn. (6) and the result at the applied air velocity was expressed in Figure-3.

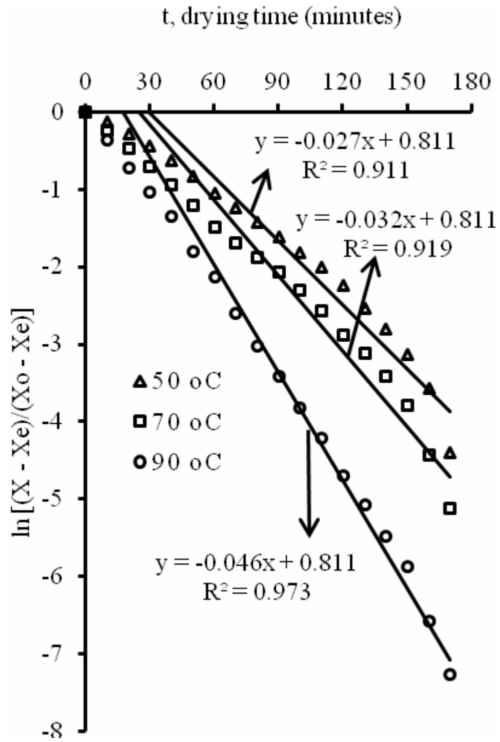

Figure-1. Plot of the solid moisture ratio versus the drying time and its linier regression, air velocity 0.4 m/s.

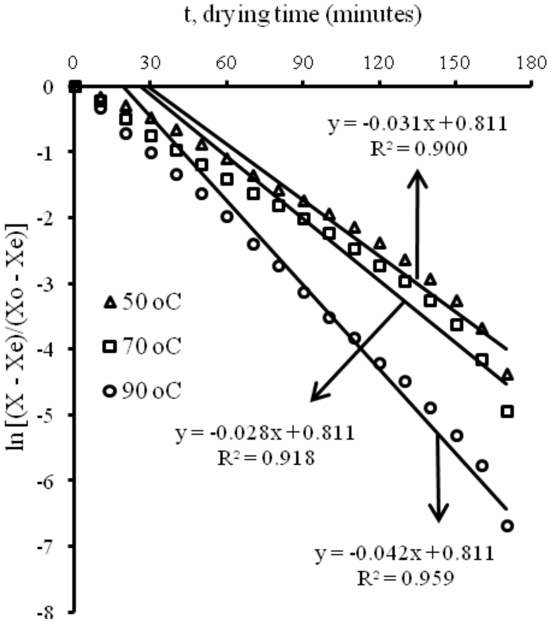

Figure-2. Plot of the solid moisture ratio versus the drying time and its linier regression, air velocity 0.6 m/s.

The lowest moisture diffusivity is 2.46.10-4 m^2/s resulted from drying at air temperature 50 ^{o}C and air velocity 0.6 m/s, while the highest value is 4.20.10-4 m^2/s resulted from drying at air temperature 90 °C and air velocity 0.4 m/s.

It was clearly shown in Figure-3 that at the range of operating conditions, the dependency of the moisture diffusivity on the air temperature is significantly higher than its dependency on the air velocity. It indicates that the overall drying rate was controlled by the moisture diffusion within material rather than by the external convective moisture transfer.

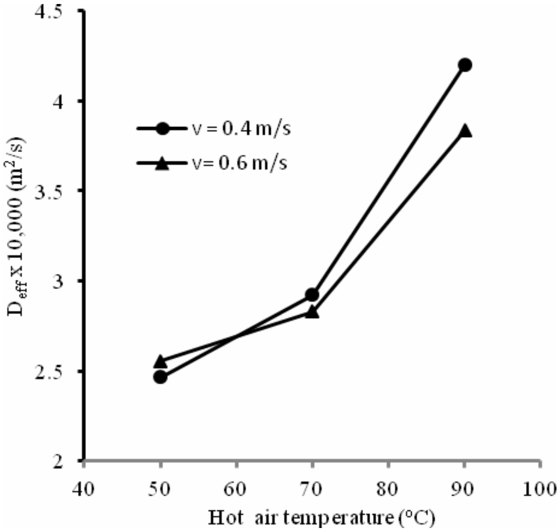

Figure-3. Plot of the moisture diffusivity versus the temperature of hot air stream.

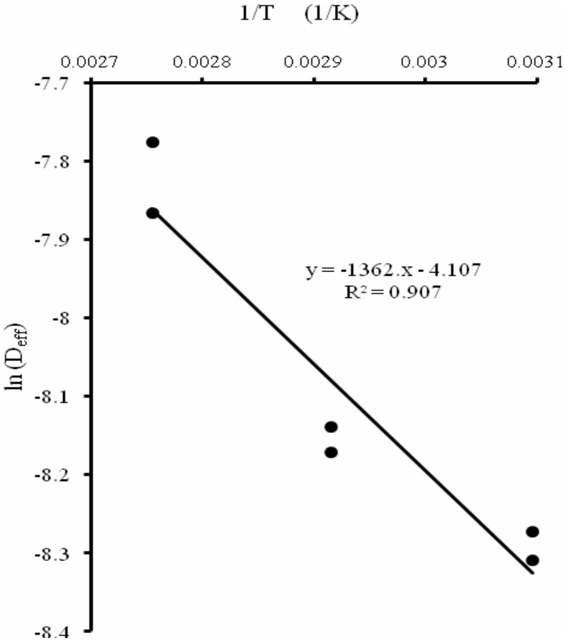

Figure-4. Plot of moisture diffusivity versus the reciprocal of the absolute temperature.

The activation energy

Figure-4 shows plot of logarithmic moisture diffusivity within the roof tiles versus the reciprocal of the absolute air temperature and its regression result which was expressed by the correlation of y and x on the display. This plot was used to construct the correlation between the activation energy and the absolute temperature which refer to Eqn. (7) from which the calculation resulted in the Arrhenius factor $D_0 = 1.65 \times 10^{-2}$ m^2/s and the activation energy E_a = 11.32 kJ/mol. The obtained the linear regression coefficient is R^2=0.907, it was confirmed that an Arrhenius-equation was applicable for the relationship between the effective moisture diffusivity D_{eff} and the absolute temperature T for moisture diffusion within roof tiles. Activation energy is the energy needed to initiate mass diffusion [8]. At any dehydration process, the activation energy barrier must be overcome to activate moisture diffusion. It is the reason why dehydration at higher temperature would be beneficial to increase the dehydration rates by increasing moisture diffusion [9].

The influence of air temperature on drying time calculated from crank solution model

After the value of the activation energy E_a and Arrhenius factor D_0 was obtained then the moisture diffusivity can be calculated at various temperature and further the value of the moisture ratio at any drying time can be obtained from Crank solution by using Eqn. (5). Result of the application of that approach was plotted in Figure-5. From the plot it can be concluded that by considering energy cost for heated the air stream the optimum temperature of drying may be in the range 50-70 °C.

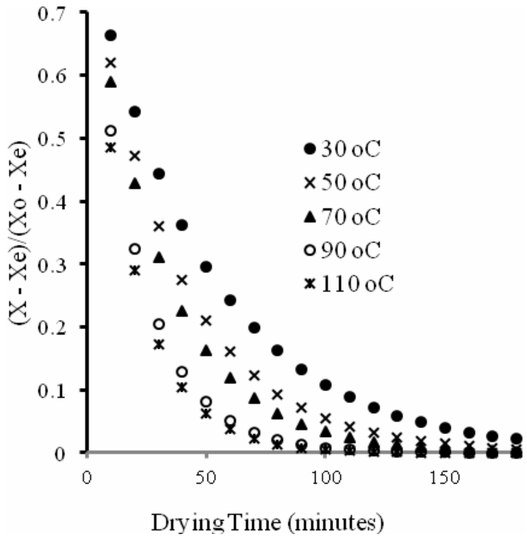

Figure-5. Plot of the solid moisture ratio versus drying time calculated using Crank solution model

The arrangement of hot air tray dryer

The arrangement of applied hot air tray dryer was shown in Figure-6. To facilitate air flow, two 250 Watt air blowers were installed. The required space for this arrangement is 10 m long 3 m wide and able to accommodate 1000 pieces of tiles. The drying was designed to use LPG as fuel.

The advantages of the application of hot air tray drying

In general the comparison between the application of hot air tray drying and the existing sun drying was shown in Table-1 which was expressed on the basis production of 1000 pieces of tiles. It was shown that by apply hot air tray drying; the number of drying stage was reduced from 2 stages to only one stage.

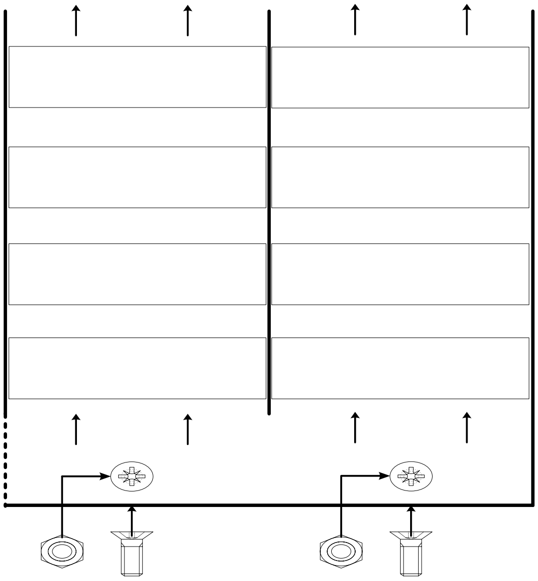

Figure-6. The layout and arrangement of the hot air tray dryer.

Moreover, in the existing sun drying process we have to move and rearrange the tiles from the tray of the first drying stage to the tray of the second drying stage, while in the hot air tray drying such movement and rearrangement is not needed.

In hot air drying, the tiles will be directly exposed to hot air stream to reduce its initial water content (the water content just after printing) up to the final water content level in which the tiles are physically strong enough to be arranged in furnace for burning process. To avoid tile cracking due to very fast rate of drying during the early drying process, the hot air stream temperature could be reduced by adjust the supply of gas fuel to the burner.

Table-1. Comparison between the two drying processes.

The advantages of Applying the Hot Air Drying Instead of the Existing Sun Drying		
Parameter	**Existing Sun Drying**	**Hot Air Tray Drying**
Drying Stage	2 stages	1 stage
Drying Time	5 days	1 day
Required space	60 m^2	20 m^2
Man power Cost	5 US$	-
Electricity Cost	-	2 US$
Fuel Cost	-	3 US$
Applicability	Only in the dry season	The whole year

In the hot air drying process it will need only one day instead of 5 days to proceed the overall drying process which includes tiles loading on the tray, drying process and tiles unloading. It means that very significant reduction of drying time will be achieved. This significant reduction of the drying time will consequently increase the production capacity and the productivity.

The required space was also reduced significantly from 60 m^2 to 20 m^2 to produce 1000 pieces of tiles. From production cost view of point, both type of drying will spend the same cost. Another major advantage of the application of hot air tray drying is its independency on the seasons, it will running well in both dry and rainy season. There are many ways to proceed drying of any material, and understanding the drying processes is very important in regard with the objective of optimizing the processes [10], [11]. It was very important to apply the optimum drying temperature, since the drying temperature and initial moisture content of clay strongly influence the drying kinetics and transport properties [12], [13]. The hot air tray drying has been successfully applied in many field such as paddy drying, tobacco drying, cocoa drying, starch drying, fish drying etc.

Considering the above advantages of the application of hot air drying, it was clear that a good economical impact will happen which was mainly due to the significant increase of the production capacity and the productivity. Moreover, the lifetime of the device could be reached 20 - 25 years then the increase of production capacity as well as the productivity surely can be achieved.

CONCLUSIONS

In roof tiles drying using hot air tray dryer applied in this work, the overall drying rate was controlled by the moisture diffusion within material rather than by the external convective moisture transfer. Moisture diffusivity values on a wet tiles is in the range 2.46x10-4 - 4.20x10-4 m^2/s for air temperature range 50 - 90 ^oC and air velocity range 0.4 - 0.6 m/s. The drying resulted in drying rate range 25 - 35 gr $H_2O/(m^2.mnt)$.

The advantages of applied hot air tray drying instead of sun drying include the reduction of drying stage from two stages into one stage, the reduction of drying time from 5 days to only one day, the reduction of required space from 60 m^2 to 20 m^2 on the basis of production of 1000 pieces of tiles and its independency on the seasons.

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