Analysis of Energy Consumption in a Drying Process of Particleboard Using a Combined Multi-Feed Microwave-Convective Air and Continuous Belt System (CMCB)

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Abstract
This research presents the energy consumption analysis in a drying process of particleboards using a Combined Multi-Feed Microwave-Convective Air and Continuous Belt System (CMCB). The construction of this system consists of twelve magnetrons. The of materials are: particleboards, made from contained durian fiber, durian peel powder and water. Four different mixture proportions, formulated for 20 cm × 20 cm × 1 cm particleboards were: 1:1:1, 1:1:1.5, 2:1:1.5 and 2:1:2. All the tested parameters are moisture content, temperature, dielectric properties, time, specific energy consumption, and efficiency in the drying process. By using a constant microwave power of 2400 W, the study analyzed for 3 cases: different temperatures of hot-air 40, 50, and 60 °C. Particleboards quality was verified with a scanning electron microscope. The physical properties, mechanical properties, and thermal properties were examined. The results show that with a higher hot-air temperature, the drying time was shortened, and the specific energy consumption and efficiency in the drying process was decreased. By considering all cases with the microwave power fixed at 2400 W, using hot-air temperatures of 40, 50, and 60 °C, the specific energy consumption was equal to 0.1129, 0.0968, and 0.0926 MJ/kg, respectively. Conclusively, using a hot-air temperature of 60 °C yields the lowest specific energy consumption.

Keywords: Durian Peel; Dielectric Properties; Drying; Scanning Electron Microscope; Specific Energy Consumption

1. Introduction

Over the past few years, ever since the energy crunch began, there has been a tremendous interest in energy saving both on new and existing structures. Contractors and builders have found that, over time, using certain materials and techniques can result in big savings.

Today, due to increased awareness on the environment, the use of natural products [1-7] is receiving increased attention. By far, fiber-based construction materials are the most promising for building due to various parameters such as their wide distribution.

Thailand is located in the tropical zone. Thailand can grow many kinds of fruits and therefore produces a huge amount of fruit peels annually. Furthermore, agricultural waste is anticipated to increase in the future, and if we are unable to efficiently dispose of the agriculture waste, it will lead to social and environmental problems. Reference[8] found that coconut coir and durian peel have low thermal conductivities of 0.0779 W/m.K and 0.0921 W/m.K. Reference [9] produced durian peel particleboards using synthetic binders, i.e., Urea-Formaldehyde (UF), Phenol-Formaldehyde (PF), and Isocyanate. Formaldehye-based adhesives, such as UF and PF resins, currently dominate the wood adhesive market. However, formaldehyde, regarded by many as a toxic air contaminant, is a human carcinogen that causes nasopharyngeal cancer. Besides being a cancer-causing hazard, exposure to formaldehyde causes non-cancerous health problems, such as eye, nose, and/or throat irritation (Hashim et al, 2011). Furthermore, formaldehyde emission and its non-renewable nature have become a matter of increasing concern. Environmentally-friendly adhesives from renewable resources that are free of formaldehyde, therefore, are now being developed to replace the UF and PF binders. However, binderless particleboard has a general problem related to microbiological growth. Hence, drying is used to preserve binderless particleboard. Drying the product reduces biochemical and microbiological degradation. It is a complicated process involving heat and mass transfer between the material surface and its environment. Thermal drying in solids might be regarded as a result from two simultaneous actions: a heat transfer process by which the moisture content of the solid is reduced, and a mass transfer process that implies fluid displacement within the structure of the solid towards its surface. Motion depends on medium structure, moisture content and characteristics of the material. Moreover, the separation of vapor from solid depends also on external pressure and temperature distribution on the total area of solid surface and the moisture content of drying air. Thermal drying occurs at a slow rate at ambient conditions, thus, drying plants are designed and developed in order to accelerate appropriate drying rates to supply product is more heat than those in ambient conditions [10].

The drying of particleboard is the most energy intensive and costly process in the particleboards industry. Conventional particleboard dryers function under the basis of convective heat transfer from circulating hot air to the surface of particleboard, followed by subsequent conductive heat transfer from the surface to the center of the particleboard. These dryers require a considerable amount of energy and long drying times in order to obtain high-quality particleboards. Therefore, innovative particleboard drying methods have been researched and studied. Unlike conventional heating, where heat is applied externally to the surface of particleboard, microwave irradiation penetrates and simultaneously heats the bulk of the particleboard. When properly designed, microwave drying systems offer several advantages over several mechanical methods, including reduction of drying time, high energy efficiency, and improvements in product quality for various applications. Microwave drying is one of the most interesting methods for drying particleboards. The application of volumetric heating can decrease the gradients of temperature and moisture during drying, resulting in an increase in the rate of heat transfer in particleboard.

The objective of this research was to evaluate on the energy consumption in the drying process of particleboards using a Combined Multi-Feed Microwave-Convective Air and Continuous Belt System (CMCB) at hot air temperatures of 40, 50, and 60 °C, and investigate finished particleboard properties.

2. The related theory

2.1 Drying with Microwave Energy [10-12]

In convective drying, dry air is used to take away surface water saturation from the dried sample, therefore, creating a pressure gradient between the surface and inner part, which causes moisture migration from inside the sample to the surface. In this process, the temperature gradient enhances the ability of dry air to remove water from the surface and increases the moisture migration rate within the sample. However, there are many disadvantages with this method. Among these are low energy efficiency and lengthy drying time during the falling rate period. This is mainly caused by rapid reduction of surface moisture and consequent shrinkage, which often results in reduced heat transfer. Unlike conventional heating, where heat is applied externally to the surface of the material, microwave irradiation penetrates and simultaneously heats the bulk of the material. During applied microwave energy, a resonance effect can occur inside the material, which results in the field distribution not having an exponential decay from the surface. In some cases the highest field strength and therefore power density, can actually occur in the center of the sample. This is caused by the interfere of waves reflected from the back side of the sample. This mechanism pushes moisture out of the product with great efficiency as the moisture content of the product decreases. When properly designed, microwave drying systems have several advantages over conventional mechanical methods, including reducing the drying times, high energy efficiency, and offer improvements in product quality.

2.2 Fundamental Equation of Heat Generation with Microwaves [10-12]

Dielectric materials absorb and transform microwave energy to heat energy, which is called the density of microwave power absorbed (Q) and is relates to the electric field and magnetic field. In analysis of dielectrics, intensity E is normally used to evaluate the microwave energy absorbed. Therefore, the microwave energy absorbed or local volumetric heat generation term can be defined as Eq. (1):

$$Q = \omega \varepsilon_0 \varepsilon_r' E^2 = 2\pi \cdot f \cdot \varepsilon_0 \cdot \varepsilon_r' (\tan\delta) E^2 \tag{1}$$

Where E is the electric field intensity, dependent upon position; f is the microwave frequency; ω is the angular velocity of microwave; $\varepsilon' r$ is the relative dielectric constant which describe energy absorption, transmission, and reflection at the microwave electric field; $\varepsilon_0$is the permittivity of air; and tan δ is the loss tangent coefficient that indicates the ability of the product to absorb microwave energy.

Corresponding to Eq. (1), because of the impact of tan δ, a lack of specimen penetration by the microwave without heat generation lowered the loss tangent coefficient, thus decreasing its impact on the absorbed microwave energy and volumetric heating. However, this can change at higher temperatures depending on relevant variables such as specific heat capacity and the characteristics and size of the material.

When the materials is heated unilaterally, it is found that as the dielectric constant and loss tangent coefficient can vary, the penetration depth will be changed and the electric field within the dielectric material is altered. The penetration depth is used to denote the depth at which the power density has decreased to 37% of its initial value at the surface.

$$D_p = \frac{1}{\frac{2\pi f}{\upsilon}\sqrt{\frac{\varepsilon_r'\left(\sqrt{1+\left(\frac{\varepsilon_r''}{\varepsilon_r'}\right)^2}-1\right)}{2}}} = \frac{1}{\frac{2\pi f}{\upsilon}\sqrt{\frac{\varepsilon_r'\left(\sqrt{1+(\tan\delta)^2}-1\right)}{2}}} \tag{2}$$

Where *Dp* is the penetration depth, $\varepsilon''r$ is the relative dielectric loss factor, and υ is the microwave speed. The penetration depth of the microwave power is calculated according to Eq. (2), which shows how it depends on the dielectric properties of the material. It is noted that products with huge dimensions and high loss factors may occasionally overheat a considerably thick layer on the outer layer. To prevent such a phenomenon, the power density must be chosen wisely; thus, enough time is provided for the essential heat exchange between the boundary and core. If the thickness of the material is less than the penetration depth, only a fraction of the supplied energy will be absorbed. Furthermore, the dielectric properties of particleboard specimens typically showed moderate loss depending on the actual composition of the material. A greater amount of moisture content revealed a greater potential for absorbing microwaves. For all particleboard specimens, a decrease in the moisture content typically decreased $\varepsilon''r$, accompanied by a slight increment in *Dp*.

2.3 Specific Energy Consumption (SEC)

Specific energy consumption (SEC) equation is represented by:

$$SEC = \frac{\text{Total electrical power supplied in drying}}{\text{Amoumt of water removed during drying}}, \left[\frac{kW-hr}{kg}\right] \tag{3}$$

Where P total is a total electrical power supplied in the drying process; this term can be calculated from:

$$P_{total} = P_{mg} + P_{heater} + P_{exfan} + P_{cofan} + P_{con} \quad ,[kW \times 3600s] \tag{4}$$

Where Pmg is the electrical power supplied to the magnetron, P heater is the electrical power supplied to the heater, P exfan is the electrical power supplied to the exhaust fan, P blfan is the electrical power supplied to the blower fan, P cofan is the electrical power supplied to the cooing fan, and Pcon is the electrical power supplied to the conveyor.

2.4 The Energy Efficiency (η_e) for the drying process

The energy efficiency for the drying process is defined as:

$$\eta_e = \frac{W_d[h_{fg}(M_{p1} - M_{p2}) + c_m(T_{m2} - T_{m1})]}{\dot{m}_{da}(h_1 - h_0)\Delta t + \Delta t\,\dot{Q}_{MW}} \tag{5}$$

Where W_d is the weight of dry material (kg), h_{fg} is latent heat of vaporization (kJ/kg water), M_p is the particle moisture content dry basis (kg water/ kg solid) , c_m is the specific heat of material (kJ/kg K), T is tempertature, m_{da} is mass flow rate of dry air, h is the enthalpy of dry air, Δt is heating time difference, and Q_{MW} is microwave energy (kW)

3. Experimental Setup

3.1 Particleboard preparation

The specimens were prepared by first weighing durian peel fiber, durian peel powder, and water according to the ratios in Table 1 and mixing well. The blended particles were gradually, manually placed layer-by-layer into a 250 mm x 250 mm mould to form the final mats, which were then pressed at a platen temperature of 150 ºC. A pressure of 1000 - 1500 psi was applied to the boards. After the hot pressing, the boards were dried to completely cure before being trimmed and cut into test specimens.

Table 1. Mixing Ratio (Fiber: Powder: Water).

Board	Mixing Ratio (Fiber:Powder:Water)
1	1:1:1
2	1:1:1.5
3	2:1:1.5
4	2:1:2

Fig.1. Binderless particleboard from durian peel [1].

3.2 Microwave-convective air drying at RCME [12]

Microwave-convective air drying was carried out using a combined multi-feed microwaved-convective air and continuous belt system (CMCB). The shape of the microwave cavity is rectangular with a cross-sectional area of 90 cm x 45 cm x 270 cm. The dryer was operated at a frequency of 2.45 GHz with a maximum working temperature of 180 °C. The microwave power was generated by means of 12 compressed air-cooled magnetrons. The maximum microwave capacity was 9.6 kW with a frequency of 2.45 GHz. The power setting can be adjusted individually in 800 W steps. In the continuous processing equipment, two open ends are essential .The material is to be heated up on the belt conveyer where it was put in and taken out. In this equipment, leakage of microwaves was prevented by a countermeasure in duplicate with a combination of mechanical blocking filters (corrugate chokes) and a microwave absorber zone , was provided at each of the open ends. The microwave leakage was controlled under the DHHS standard of 5 mW/cm^2. The multiple magnetrons (12 units) were installed in an asymmetrical position on the rectangular cavity. The microwave power was then directly supplied into the drier by using a waveguide. An infrared thermometer (located at the opening ends) was used to measure the temperature of the specimens (accurate to ± 0.5 °C). The magnetrons and transformers used in this system were cooled down by a fan. In continuous heating/drying equipment, two open ends were essential to feed in and feed out the product. The material to heated up on the belt conveyer and arranged in certain positions. The belt conveyor system consisted of a drive motor, a tension roller, and a belt conveyor. During the drying process, the conveyor speed was adjusted to 0.54 m/min (at the frequency 40 Hz) and the motor speed was controlled by the VSD control unit. Hot air was generated using 24 units of electric heaters with a maximum capacity of 10.8 kW and the maximum working temperature of 240 °C. The hot air was provided by a blower fan with 0.4 kW power through the air duct into the cavity. The hot air temperature was measured using a thermocouple. For combination of microwave and hot air dryer drier, hot air was varied from 40, 50, and 60 °C.

4. Specimen preparation for testing

Before drying and after drying, dielectric properties of particleboard were measured using Network Analyzer (PUSCHNER). After drying, testing of specimens was carried out according to JIS A 5908-2003 (Japanese Industrial Standards, 2003) for physical properties, i.e., density, moisture content, and thickness swelling. Internal Bond of the particleboard was measure using Universal Testing (Testometric MICO 500). Thermal conductivity of the particleboards was measured using a thermal conductivity analyzer NETZSCH Model HFM 436 Lamda, according to ASTM C 518 (American Society for Testing and Materials). The structure of particleboard was examined using Scanning Electron Microscopy (JEOL, SM-6510). Results show the comparative evaluation on product properties and specific energy consumption of a single microwave dryer and combination of microwave and hot air dryer for durian peel particleboards.

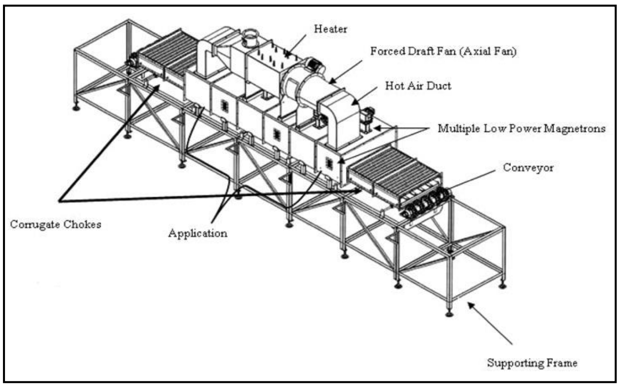


Fig .2. Schematic diagram [10-12].

5. Results and Discussions

5.1 Dielectric Properties

Dielectric constant, relative dielectric constant, and dielectric loss tangent coefficient of the durian peel particleboard are carried out by combination of microwave and hot air dryer with different temperatures of 40, 50, and 60 °C, as shown in Table 2. No marked difference is found between the methods with hot air supplied in the cavity.

5.2 Effect of Hot Air Temperature

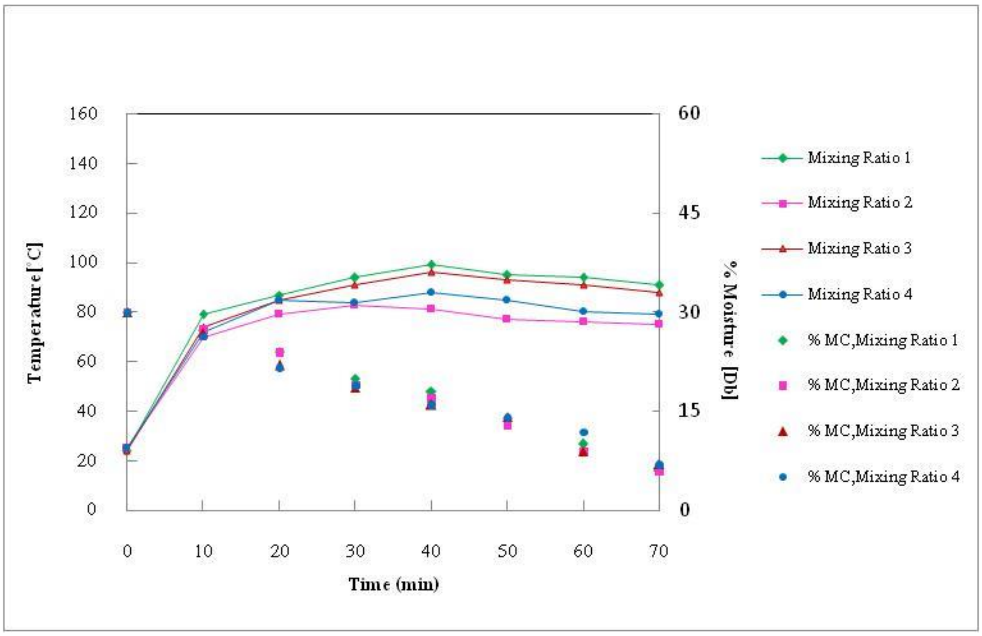
Figure 3 shows the temperature and moisture profiles with respect to elapsed times as parameters of hot air temperature (T_∞ = 40, 50, and 60 °C) with fixed microwave power level (P = 2400 W). It is found that at high hot air temperature, the temperature profile of the particleboard sample continuously rises faster than that in the case of low hot air temperature. The reason is that in the case of high hot air temperature, convective drying is strong while the microwave energy is still supplied. For the moisture profile, in the early stages of drying, the large moisture content corresponds to a higher dielectric loss factor. A majority of the microwave can be absorbed within the particleboard sample as shown in Fig. When the drying time increases, the microwave power absorption is lowered because the moisture content decreases. This result is due to the influence of capillary pressure and vapour diffusion, which drives the moisture to the sample surface of a particleboard sample. Figures 3 (a), (b), and(c) display the profiles of temperature and moisture within the particleboard sample.

Figure 3 shows the effect of hot air temperature on temperature and moisture profiles. As seen in Fig.3, convection carries the water from the inside to the leading edge of the particleboard sample and microwaves simultaneously are used to heat inside the particleboard sample. At this stage the microwave power absorption is high and the transmitted wave is zero as shown in Fig.3. This is because the moisture content is high, corresponding to the higher dielectric loss factor. Furthermore, near the end stage of the drying process as the moisture content inside the particleboard is reduced, the microwave power absorption decreases accordingly.

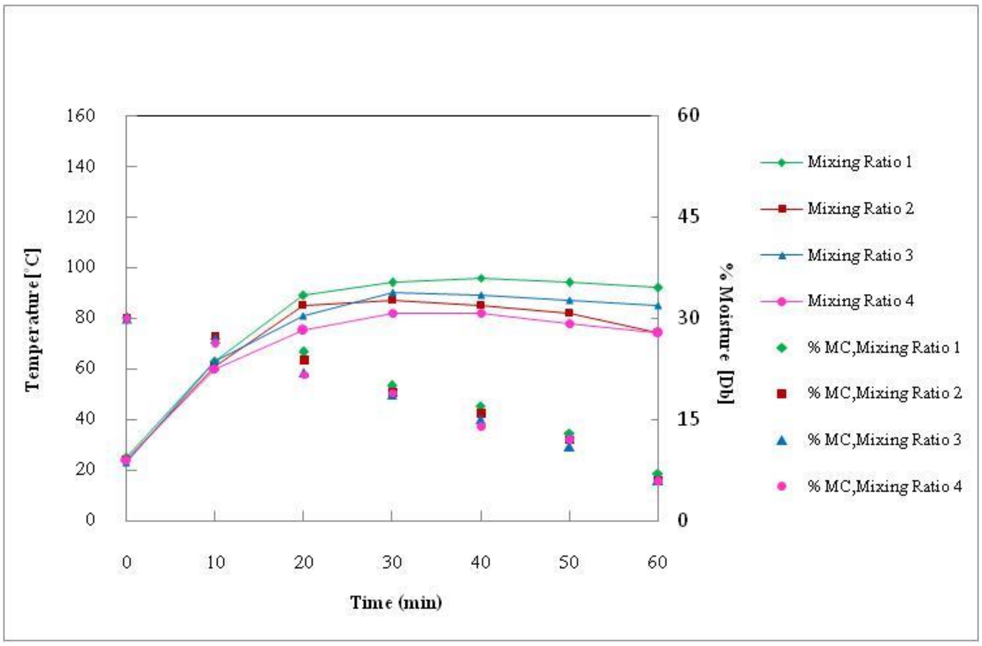
Capillary action plays an important role in the moisture migration mechanism and maintains a good supply of liquid to the surface. Continued drying causes the average moisture content inside the particleboard sample to decrease and leads to decreased microwave power absorption. During long stages of drying, the vapor diffusion effect plays an important role in the moisture migration mechanism because of the sustained vaporization that is generated within the particleboard sample.

Table 2. Dielectric Properties of Particleboard.

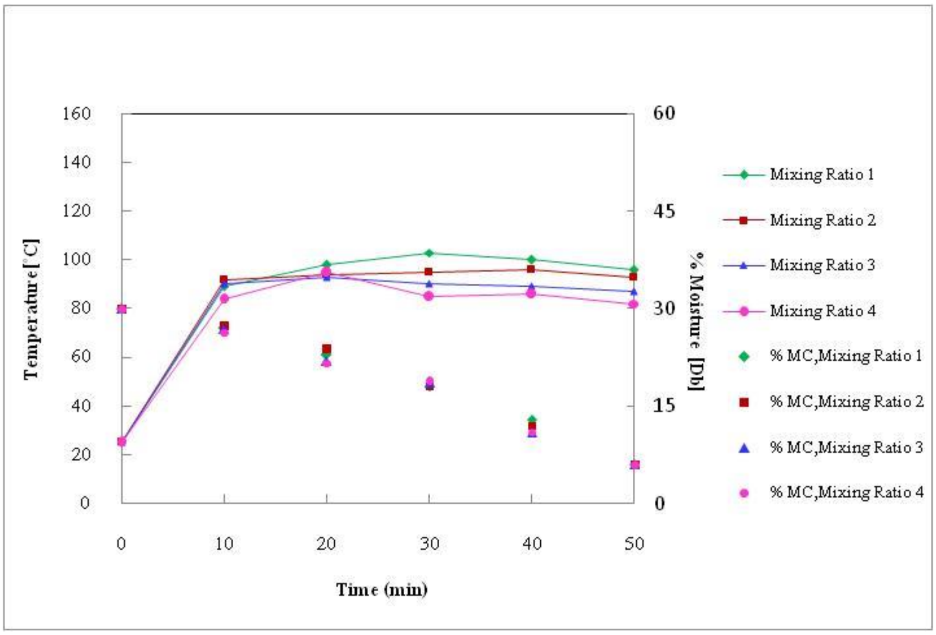
Hot Air Temp. (°C)	Mixing Ratio	Dielectric constant (ε_r')	Before Drying Dielectric loss factor (ε_r'')	Loss tangent coefficient, tanδ	Dp (m)
40	1:1:1	2.18862	0.345547	0.157533942	0.167757
	1:1:1.5	2.14632	0.379913	0.176934528	0.150947
	2:1:1.5	2.25451	0.446069	0.197688973	0.131943
	2:1:2	2.31650	0.443787	0.191471577	0.13435
50	1:1:1	2.37493	0.525012	0.220931119	0.11517
	1:1:1.5	2.39608	0.539043	0.224797550	0.11271
	2:1:1.5	2.23818	0.455578	0.203464611	0.12870
	2:1:2	2.48531	0.306049	0.162227395	0.15290
60	1:1:1	2.59829	0.610489	0.234860799	0.10365
	1:1:1.5	2.18999	0.419730	0.191616784	0.13807
	2:1:1.5	2.72758	0.677368	0.255083833	0.09326
	2:1:2	2.53574	0.422795	0.189115917	0.12999


160
140
120
100
80
60
40
20
0
Temperature [°C]
60
45
30
15
0
% Moisture [Db]
0
10
20
30
40
50
60
70
Time (min)
Mixing Ratio 1
Mixing Ratio 2
Mixing Ratio 3
Mixing Ratio 4
% MC,Mixing Ratio 1
% MC,Mixing Ratio 2
% MC,Mixing Ratio 3
% MC,Mixing Ratio 4

(a)


160
140
120
100
80
60
40
20
0
Temperature [°C]
60
45
30
15
0
% Moisture [Db]
0
10
20
30
40
50
60
Time (min)
Mixing Ratio 1
Mixing Ratio 2
Mixing Ratio 3
Mixing Ratio 4
% MC,Mixing Ratio 1
% MC,Mixing Ratio 2
% MC,Mixing Ratio 3
% MC,Mixing Ratio 4

(b)



(c)

Fig. 3. Temperature and moisture profile with respect to elapsed time at hot air temperature

a) 40 °C b) 50 °C c) 60 °C.

5.3 Electrical Energy Consumption and Drying Time

The electrical energy consumption during microwave convective air drying and convective drying of a combined multi-feed microwave-convective air and continuous belt system is given in Fig.4. When the three cases are compared in terms of electrical energy consumption, it is noted that the lowest electrical energy consumption is observed from the microwave-convective air drying at the highest hot air temperature of 60 °C. The best result with regard to electrical energy consumption is obtained from a microwave at the highest hot air temperature of 60 °C. Electrical energy consumptions at hot air temperatures of 40, 50, and 60 °C are 7.5, 6, and 5.3 kW-hr, respectively.

The drying time of convective drying along the drying process is given in Fig.4. The lowest value in all drying conditions regarding the drying time is noted in the convective drying process operating at a hot air temperature of 60 °C for 50 minutes.

5.4 Analysis of Specific Energy Consumption (SEC)

Fig 5 shows the specific energy consumption with the variation of the particleboard sample particles.To obtain the experimental results, the microwave power level is set at 2400W. Figure 5 show the specific energy consumption with three cases at hot air temperatures of 40, 50, and 60 °C. In the case of convective drying, the surface is dried while the interior is still wet; the dry layer offers resistance to the heat transport, resulting in a reduction of the evaporation rate and drying rate, and also causing high specific energy consumption at low hot air temperature. Specific energy consumption depends on the power absorbed by the cavity and the drying time. For convective drying at low hot air temperature, the drying time is long because the convective heat transfer coefficient of the particleboard is low. The reduction of specific energy consumption is achieved by increasing the hot air temperature level supplied to the cavity. Conclusively, using a hot-air temperature of 60 °C yields the lowest specific energy consumption of 0.0926 MJ/kg , observed from the microwave-convective air drying method at an air temperature of 60 °C. This causes the moisture content to decrease quickly. Therefore, microwave-convective air drying at a hot air temperature of 60 °C can be used to efficiently dry durian peel particleboard.

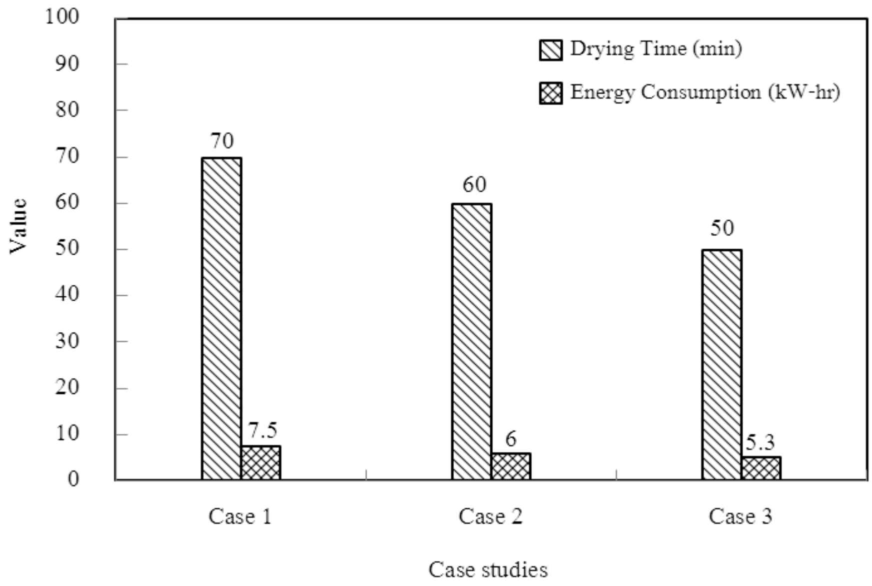


Fig .4. Variation in drying time and electrical energy consumption in difference cases.

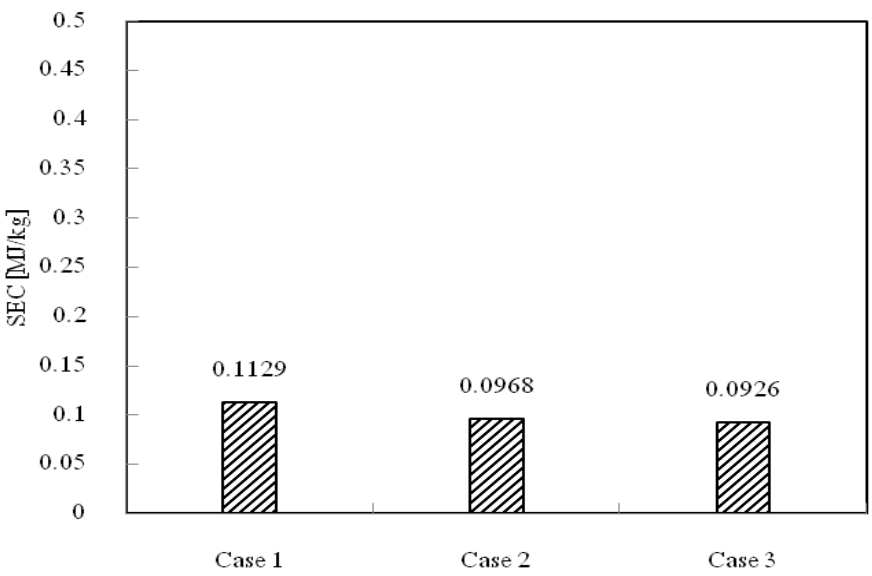


Fig. 5. Variations in specific energy consumption at different hot air temperatures.

5.5 Energy Efficiency

Figure 6 shows the energy efficiency with respect to the drying time in different cases. It is found that the energy efficiency at the starting period is high due to the high quantity of moisture in the particleboard, which leads to a high value of dielectric loss factor; thus, the wave absorption is more converted by the particleboard. The results are high energy efficiency after the vapour moves from the surface of the particleboard. This causes the moisture content to decrease quickly. The low quantity of absorbed waves results in a decreased energy consumption and decreased efficiency of absorbed microwave power. Therefore, the energy efficiency depends on the level of absorbed microwave power. In Fig. 6, the energy efficiency profile for the sample in all the cases rises up quickly in the early stages of drying (between 30-40 min.). However, the efficiency rises slowly after this stage (between 50-70 min.). It is evident from the figure that the moisture content inside the sample decreases at the final stages of drying, causing the decrease in the absorbed microwave power. Consequently, the energy efficiency profiles decrease in this stage of drying.

5.6 Physical, Mechanical, and Thermal Properties

Physical, mechanical, and thermal properties of the durian peel particleboard are examined with three cases at hot air temperatures of 40, 50, and 60 °C, as shown in Tables 3 and 4. No marked difference of internal bond and thermal conductivity is found between the methods with hot air temperatures of 40, 50, and 60 °C supplied in the cavity.

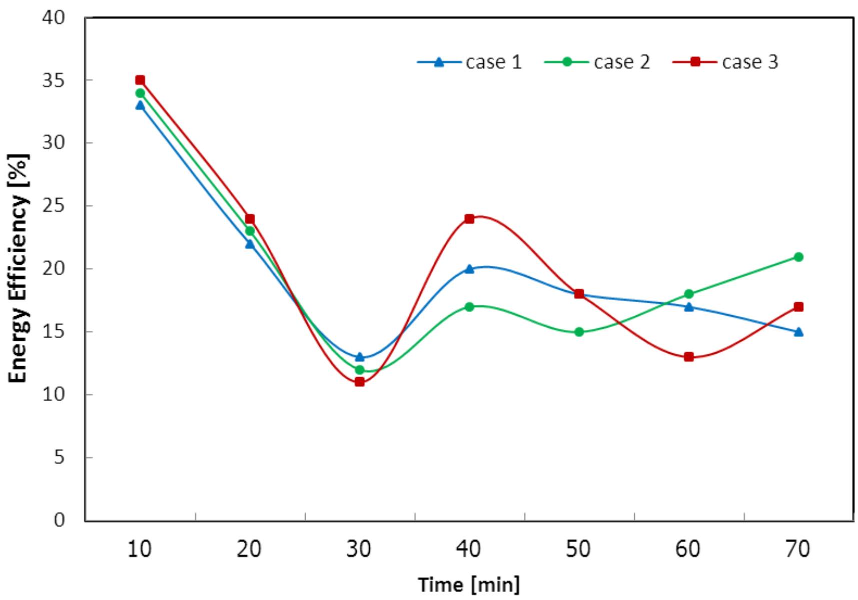


Fig. 6. Energy efficiency profiles with respect to elapsed time in a different hot air temperatures of 40, 50, and 60 °C.

Table 3. Internal Bond of Particleboard.

Case	Mixing Ratio	Hot Air Temp. 40 °C	Hot Air Temp. 50 °C	Hot Air Temp. 60 °C
1	1:1:1	0.065	0.013	0.061
2	1:1:1.5	0.086	0.022	0.031
3	2:1:1.5	0.061	0.028	0.047
4	2:1:2	0.013	0.020	0.029

Table 4. Thermal Conductivity of Particleboard.

Case	Mixing Ratio	Density, (g/cm^3)	Thermal Conductivity (k, W/m·K)
Microwave + Hot air (T=40 °C)	1:1:1	0.9372	0.095
	1:1:1.5	0.7803	0.094
	2:1:1.5	0.7451	0.089
	2:1:2	0.7461	0.095
Microwave + Hot air (T=50 °C)	1:1:1	0.7088	0.087
	1:1:1.5	0.7001	0.098
	2:1:1.5	0.7246	0.093
	2:1:2	0.6811	0.092
Microwave + Hot air (T=60 °C)	1:1:1	0.7065	0.094
	1:1:1.5	0.7126	0.094
	2:1:1.5	0.7154	0.091
	2:1:2	0.73662	0.092

5.7 Microstructure of durian peel particleboard

Tables 5 and 6 present the texture (cross section and surface) overview of the durian particleboard specimens under various dried processes by using scanning electron microscopy (SEM). It is found that the dried specimens in all cases seem to have a similar micro structure arrangement. However, microwaving at high hot air temperature of 60 °C, a dried specimen has a better micro structure arrangement because of uniform energy absorption and less shrinkage. This leads to better mechanical properties of the dried product.

5.8 Mixing Ratio

The optimum mixing ratio (durian fiber: durian powder: water) was 2:1:1.5.

Table 5. The Structure (Cross Section) of particleboard.

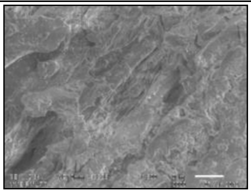
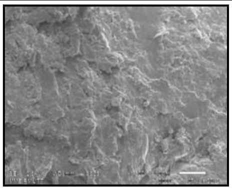
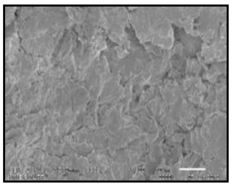
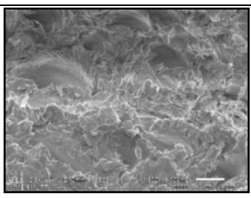
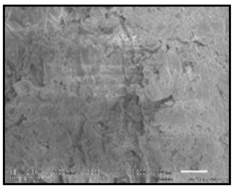
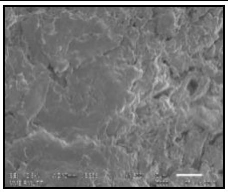
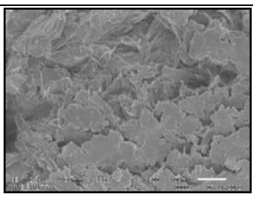
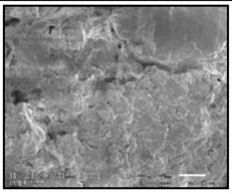
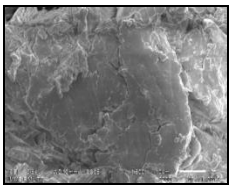
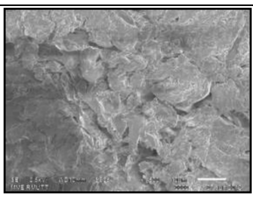
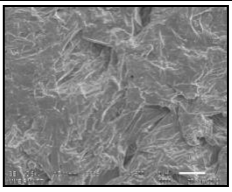
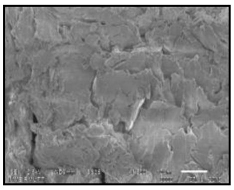
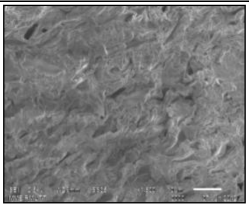
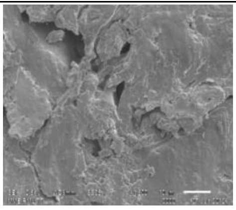
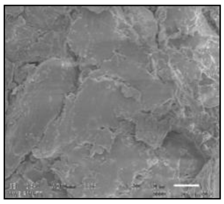
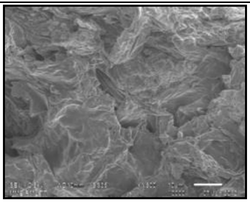
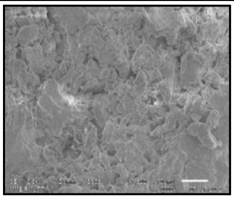
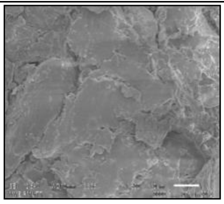
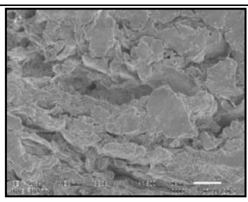
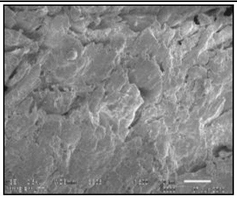
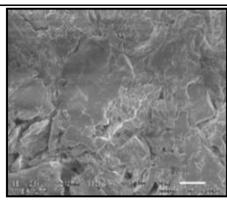
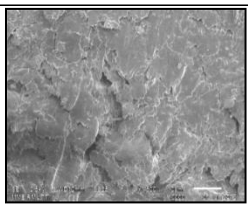
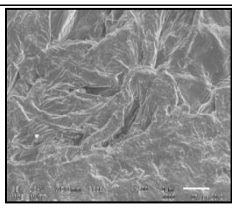
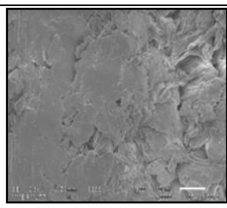
Candition	**Microwave and Hot Air 40 °C**	**Microwave and Hot Air 50 °C**	**Microwave and Hot Air 60 °C**
1:1:1			
1:1:1.5			
2:1:1.5			
2:1:2			

Table 6. The structure (Surface) of particleboard.

Candition	**Microwave and Hot Air 40 °C**	**Microwave and Hot Air 50 °C**	**Microwave and Hot Air 60 °C**
1:1:1			
1:1:1.5			
2:1:1.5			
2:1:2			

6. Conclusion

A combined multi-feed microwave-convective air and continuous belt dryer is one of the best heating methods (requires lower energy consumption, SEC of 0.0926 MJ/kg) for better product qualities. It shows the potential to reduce electrical energy consumption. Moreover, a combined system permits quicker drying at a high hot air temperature of 60 °C. If this technology is implemented in industry, it will decrease the production costs due to the lower electrical energy consumption.

7. Acknowledgements

The authors would like to express sincere appreciation to the National Research Council of Thailand (NRCT) and the Rajamangala University of Technology Thanyaburi (RMUTT) for the financial support of this research, and deep gratitude to Dr. Sorapong Pavasupree of Faculty of Engineering, the Rajamangala University of Technology Thanyaburi, and Dr. Chanakan Asasutjarit of the Thailand Institute of Scientific and Technological Research, for their invaluable and useful suggestions.

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