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# Drying of Durian Peel Fiber Particleboards using Embedded Hot Air Oven

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***Abstract***

Drying durian particleboards was developed using embedded system and image processing techniques. The surface color change of particleboards during drying process was measured by digital image correlation analysis in real time. The moisture profiles during drying were measured. The tested properties are the relations between temperature and moisture profile with respect to elapsed time and drying rate. The physical (density, moisture content, thickness swelling) and mechanical (Internal Bond, Modulus of Rupture, Modulus of elasticity) properties of particleboard after drying were investigated. The results suggest that hot air drying combined with embedded system (microcontroller (Arduino Uno r3) and Rasberry Pi-Model B) and image processing techniques is an effective tool for assessment of color characteristic and moisture distribution during drying.

***Keywords:*** hot air drying, embedded system, image processing, durian peel fiber particleboard

## 1. Introduction

Agricultural waste utilization in building materials with energy conservation properties is one promising alternative to meeting the challenges of disposing agricultural waste and to adding economic value to such new building materials [1-7]. 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. In Thailand, there is a lot of agricultural waste from durian (*Durio zibethinus*) peel each year as shown in Fig. 1. The goal is thus to use agricultural waste to manufacture energy-saving building materials with low thermal conductivity so as to reduce heat transfer into the building [1-7].

Fig.1 Durian peel waste at Talaad Thai (Thai Market)

Durian peel particleboards [9] can be produced using synthetic binders (i.e., Urea-Formaldehyde, Phenol-Formaldehyde, and Isocyanate). Formaldehye-based adhesives, such as Urea-Formaldehyde and Phenol-Formaldehyde resins, presently dominate the wood adhesive market. However, formaldehyde is a human carcinogen that causes nasopharyngeal cancer. In addition, carcinogenic hazard, exposure to formaldehyde causes non-cancerous health problems, such as eye, nose, and throat irritation. Moreover, formaldehyde emission and its non-renewable nature have become a matter of increasing concern. Environmentally-friendly adhesives from renewable resources and free of formaldehyde therefore are being developed to replace the Urea-Formaldehyde and Phenol-Formaldehyde binders at present. However, there is a problem of naturally-occurring microbiological growth in the binderless particleboard. For this reason, there has been a method to preserve the binderless particleboard like drying. Drying the product is to reduce biochemical and microbiological degradation. It is the complicated process involving heat and mass transfer between the material surface and its environment. Thermal drying in solids might be considered 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 also depends on external pressure and temperature distribution on the total area of solid surface and the moisture content of drying air. That thermal drying occurs in slow rate at ambient conditions, thus drying plants should be designed and developed to accelerate appropriate drying rates supplying more heat for the product in those ambient conditions [2].

The process of drying in the particleboards industry could be the most energy intensive and costly process. Referring conventional particleboard dryers, they 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 particleboard

[2]. 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. In conventional heating the temperature and drying time are preset. When the preset time is over, the drying process stop without knowing the exact remaining moisture content. It can be higher or lower than the standard. Thus, this research aims to propose the new hot air drying process for the real-time measurement of color characteristic, appearance and moisture content in durian particleboards by applying embedded system and image processing techniques. With this new technique, the drying process can properly terminate when the desired moisture content is achieved.

## 2. Related works

### 2.1 Hot air oven technology

Drying Technology [2] is one of the widely used wood technologies which overcome problems related to production and short shelf life. Drying is applied to lower the moisture content of product to a level that can prevent the growth of mould and fungi and thus minimize microbial degradation. Different drying technology can be applied to reduce water activity and thus achieving the objective of product preservation [2]. It can also help in the development of new product. Sun drying, hot air drying, spray-drying microwave drying, osmotic dehydration and freeze drying are widely used for drying of wood. Various modes of heat input and drying conditions can be used, which are dependent on the target moisture namely surface moisture and internal moisture. Surface moisture can be easily removed by convective drying especially when it is conducted at high temperature and in rapid mode. Internal moisture is normally removed at the later of drying and the removal rate is generally slow.

Modern tools derived from the fields of applied mathematics and physics are encouraged to be used in the drying community [2]. Among the computational methods, multiscale and multiphysics approches are proposed as operational tools to address the practical problems of optimization, design, and innovation encountered by the industry. On the experimental side, many amazing tools have emerged recently from the field of physics. Several time-resolved imaging possibilities were presented.

### 2.2 Image processing in agricultural industry

External quality is the most important and direct sensory quality attributes of agricultural products. In general terms, the external quality of agricultural products is evaluated by considering their colors and visual defects. The outer appearance of agricultural affects their point-of-sale value and consumer's buying behavior.

Automatic external quality inspection of products is a challenging work. It is necessary to develop an automatic external quality inspection system to replace manual inspection. Due to the fact that most part of the external quality attributes is currently inspected visually, computer vision provides a means to perform this task automatically. Computer vision is an engineering technology that combines digital video and image processing, optical instrumentation, electromagnetic sensing and mechanics technology. In addition, it is the technology responsible for the study and application of method which enables a computer to understand the content of an image, and this interpretation involves the extraction of certain characteristics which are important for a given aim.

Image processing and image analysis are considered to be the core of the computer vision with the algorithms and methods available to complete the specific classification and measurement.

Color is one of the most important sensorial quality attributes of fruit and vegetables, and it is the first factor that influences the consumer to choose or reject the fruits and vegetables. Color of fruit and vegetables is governed by the internal biochemical, microbial, physical and chemical changes which occur in growth, ripeness and postharvest handling and processing stages. Therefore, color inspection has been used as the indirect measurement of some internal quality attributes, such as maturity, freshness, variety and desirability and safety. Color is the most elementary information that is stored in pixels, and it contains the basic visual information in the images corresponding to human vision.

The images are acquired and stored in RGB color space in most computer vision systems, and each pixel in the images is composed of three integers which represent the intensity value of red, green and blue wavelengths. RGB color space is one of the most widely used color spaces in the color inspection tasks. Apples can be graded into four categories according to European standards based on external quality by using a traditional computer vision system [8]. Kurita investigated the use of an index based on red and green component ratio (R/G) to grade the tomatoes according to their color [9]. They found that an index based on a red and green color component ratio could offer more reliable results than only using a single color component. This was probably due to the fact that a ratio between the two components could reduce the influence of the uneven distribution of the lightness in the different areas of the tomatoes.

However, the RGB color space is hardware-orientated space, or device-dependent space (different devices may produce different RGB values for the sample pixel in the image). For this reason, several transformations have been made to standardized values, such as transform the RGB color space to standard RGB (sRGB) color space, or human-orientated spaces which are closer to the human perception of color, like HIS color space, or instrumental spaces, like Hunter Lab space, CIE L*a*b* space and CIE XYZ space [9]

## 3. Methodology

### 3.1 Durian peel powder and Durian peel fiber Preparation

As shown in Fig. 2, durian peel powder was made as follows; the first step was to reduce the fresh durian peel to approximately chip size. The chip size pieces were oven-dried at 80 ºC for 8 h. Dried durian peel chips were hammermilled. Durian peel powder for being natural adhesives were screened by being sieved over 80-100 mesh screen. Then, fibers were screen to remove excess fines by sieve machine over a 60 mesh screen. Durian fruit, fresh durian peel, dried durian peel and dried durian fibres are shown in Fig. 3.

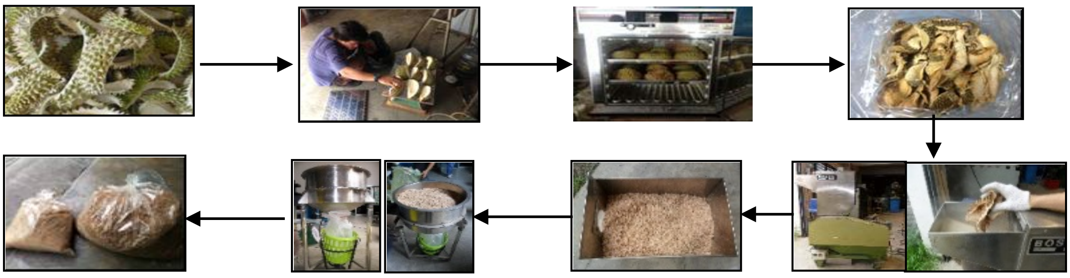

Fig. 2 Durian peel powder and Durian peel fiber preparation [1]

Fig. 3 Durian fruit (Top-Left), fresh durian peel (Top-Right), dried durian peel (Bottom-Left) and dried durian fibre (Bottom-Right) [1]

### *3.2 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. Pressure of 1000 - 1500 psi was applied to the boards. After the hot pressing, the boards were dried by embedded hot air oven to completely cure before being trimmed and cut into test specimens.

Table 1 Mixing Ratio (Fiber: Powder: Water) and Drying temperature

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

### 3.3 Embedded system hot air oven design

A standard hot air oven normally cannot automatic changes its preset drying temperature or stop the drying process when the desired moisture content is achieved. To have an oven that can automatic adjust the drying temperature and time, many subsystems must be integrated. Fig. 4 shows the system diagram of the proposed embedded hot air oven. There are four main parts connected each other: a standard hot air oven, a set of sensors, a set of embedded boards control system, and display unit. The sensors are attached with the standard hot air oven for real time measuring the particle board and the drying process condition. The sense data is sent to the low level embedded board, Arduino Uno R3, to calculate current moisture content and temperature. The camera, attached at the front cover of the oven, continually takes image of the drying particle board and sends the image to high level embedded board, Raspberry Pi. The image is processed to extract the appearance and color of the particle board for further use in the control system.

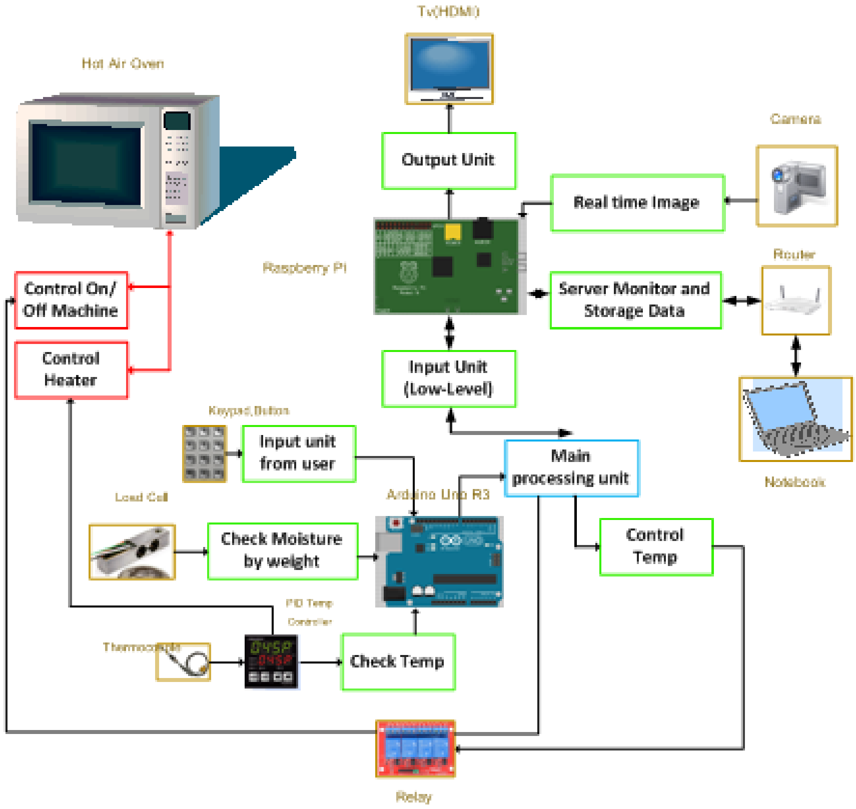

Fig. 4 Hardware architecture of the embedded control hot air oven [2]

The chamber of the designed hot air oven has 40 cm deep, 60 cm long, and 35 cm high. High definition display is attached on top of the oven along with push button and keypad. The power usage monitoring is installed at the left side of the table and the main power box is attached at the right side. The embedded boards and necessary circuit boards are installed at the back of the display. The real time moisture content value is estimated based on the current weight divided by the calculated dry weight of the particle board. The dry weight is calculated from the initial moisture content and initial weight measured before was brought the particle board inside the oven. User of the system has to input the initial weight, initial moisture content and the desired moisture content. The controller will automatically calculate the proper drying temperature based on the moisture content and color of the particle board. The control system will terminate the drying process when the desired moisture content is achieved.

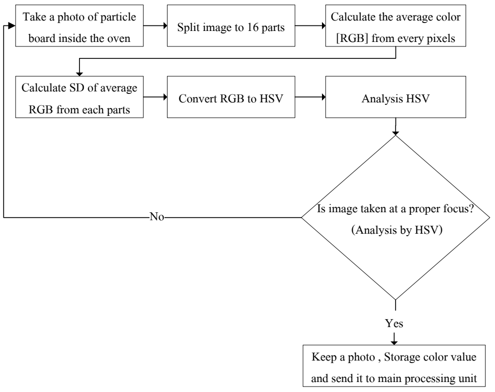

Fig. 5 Flow chart of the image acquisition and analysis. [2]

### 3.4 Image analysis for durian particle board

The image of the drying durian particleboard is sent to Rasberry Pi, high level embedded board, for analyzing its characteristic and moisture distribution. The control strategy for the image analyzing is shown in Fig. 5.

## 4. Result

### 4.1 Accuracy of the temperature control

The drying temperature can be controlled from the embedded board. Fig. 6 shows the experimental result of the actual temperature when the desired temperature is changed in a series of 60, 40, 80, 40, 90, and 40 °C accordingly. The temperature in the oven can be quickly heated up to the desired temperature in 1 – 2 minutes but it takes a longer time to decrease the temperature especially when the desired temperature is much lower than current temperature.

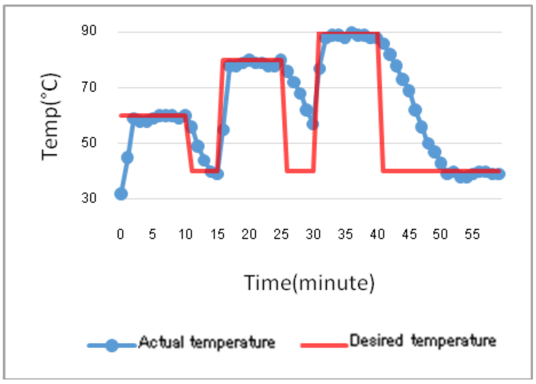

Fig. 6 The actual temperature according to the desired target [2].

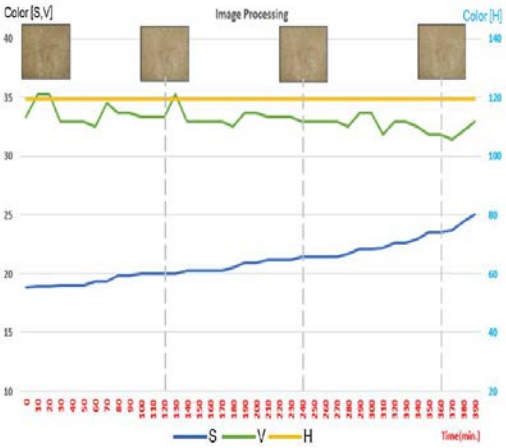

Fig. 7 Color profile of the particleboard during the drying process.

### 4.2 Moisture level from an image analysis

The example of color profile in HSV color space of the drying particleboard is shown in Fig. 7. In the beginning of the drying process, the particleboard has a dark color due to the moisture content inside the board. The color of the board is continually brightened when the time is passed as the moisture inside the board is evaporated.

### 4.3 Physical property of the particle board

After the drying process in the oven is finished, the dried particleboard is trimmed and cut into test specimens. Testing of the specimens was afterward carried out to determine their physical properties. The desired moisture content is 12% in this case. Table 2 and 3 show the properties of the specimens.

As shown in Table, 2 the drying time of the new system is 2 hours shorter and less energy is used compared to the standard hot air oven. The MOR and MOE are much better for the embedded hot air oven where the rest of the properties are similar.

Table 2 The properties of the durian peel powder-based adhesive particleboard using embedded hot air oven

| Properties | Mixing Ratio 1:1:1 | Mixing Ratio 1:1:1.5 | Mixing Ratio 2:1:1.5 | Mixing Ratio 2:1:2 |
|---|---|---|---|---|
| Density (g/cm$^3$) | 0.824 | 0.828 | 0.865 | 0.895 |
| Moisture Content (%) | 12.5 | 12.3 | 12.1 | 12.3 |
| Thickness Swelling(%) | 40.25 | 49.64 | 52.2 | 44.64 |
| Internal Bond (MPa) | 0.0209 | 0.0183 | 0.0234 | 0.0170 |
| MOR (MPa) | 1.0355 | 1.2095 | 1.3435 | 0.7130 |
| MOE (MPa) | 105.70 | 154.80 | 172.250 | 72.13 |
| Drying time (hour) | 7 | 7 | 7 | 7 |
| Consumed energy (kW-hr) | 3.61 | 3.55 | 3.52 | 3.51 |

Table 3 The properties of the durian peel powder-based adhesive particleboard using standard hot air oven at 80 °C

| Properties | Mixing Ratio 1:1:1 | Mixing Ratio 1:1:1.5 | Mixing Ratio 2:1:1.5 | Mixing Ratio 2:1:2 |
|---|---|---|---|---|
| Density (g/cm$^3$) | 0.843 | 0.864 | 0.887 | 0.835 |
| Moisture Content (%) | 13.6 | 14.2 | 13.6 | 13.4 |
| Thickness Swelling(%) | 40.7 | 43.6 | 46.8 | 43.8 |
| Internal Bond (MPa) | 0.0234 | 0.0126 | 0.0124 | 0.0130 |
| MOR (MPa) | 0.798 | 0.876 | 0.897 | 0.548 |
| MOE (MPa) | 70.54 | 71.89 | 71.93 | 70.83 |
| Drying time (hour) | 9 | 9 | 9 | 9 |
| Consumed energy (kW-hr) | 3.76 | 3.72 | 3.68 | 3.65 |

Note: Mixing Ratio (Durian Fiber: Durian Powder: Water)

## 5. Summary

The new hot air oven with embedded system and image processing for real time monitoring and control provides a more effective drying process in terms of time and energy usage. The dried particle board from this new system has slightly better physical properties compared to a dried board from a standard one but uses a lower drying time and energy consumption. This automatic control design can be applied in other drying processes.

## 6. Acknowledgement

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## 7. References

[1] Charoenvai, S., "New Insulating Material: Binderless Particleboard from Durian Peel", The 2nd International Conference on Civil Engineering and Building Materials (CEBM 2012), November 17~18, 2012, Hong Kong.

[2] Keeratipranon, N., Charoenvai, S., "A Novel Drying Process of Drying Durian Peel Fiber Particleboards", The 5th TSME International Conference on Mechanical Engineering, 17-19th December 2014, The Empress, Chaiang Mai.

[3] Charoenvai, S, J. Khedari, J. Hirunlabh, C. Asasutjarit, B. Zeghmati, D. Quenard and N. Pratintong, 2005, "Heat and moisture transport in durian fiber based lightweight construction materials", Journal of Solar Energy, Volume 78, Issue 4, April 2005, Pages 543-553.

[4] Khedari, J., Watsanasathaporn, P., Hirunlabh, J., 2005, "Development of fibre-based soil-cement block with low thermal conductivity," Cement & Concrete Composites, volume 27, Pages 111-116.

[5] Khedari, J., Nangkongnab, N., Hirunlabh, J. and Sombat Teekasap, 2004, "New Low-Cost insulation particleboards from mixture of durian peel and coconut coir" , Building and Environment, Vol. 39, pp. 59-65.

[6] Khedari J, Suttisonk B, Pratintong N, Hirunlabh J. New Lightweight Composite Construction Materials with Low Thermal Conductivity, Cement and Composites 2002; 23: 65-70.

[7]Khedari, J.,Charoenvai, S. and Hirunlabh, J., 2003, "New insulating particleboards from durian peel and coconut coir" Journal of Building and Environment, Vol. 38, Issue 3, pp. 435-441.

[8] Sachin V Jangam, Chung Lim Law, Arun S Mujumdar, 2011, Drying of foods, vegetables and Fruits, Vol. 2, ISBN: 978-981-08-7985-3, 220 p.

[9] Patrick Perre, 2011, A Review of modern computational and experimental tools relevant to field of drying, Drying Technology, Vol. 29, pp. 1529-1541.