Through Drying Characteristic of Oil Palm Empty Fruit Bunches (EFB) Fiber Using Superheated Steam

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Abstract
This study successfully shows good performance in drying characteristic of through drying system using empty fruit bunches (EFB) as the material to be dried and superheated steam as drying medium. The optimum drying rate was obtained under temperature range of 200 – 220°C and velocity of 0.89 – 0.99 m/s. Under higher temperature than 220°C and at fixed velocity of 0.89 m/s this investigation found two drying rate periods, i.e. the increasing drying rate period and the falling drying rate period. Similar condition was also observed under velocity range of 0.89-1.09 at fixed 220°C. However, at lower 220°C using fixed velocity of 0.99 m /s and at lower velocity than 0.89 m /s (fixed 220°C), this experiment shows a constant drying rate period besides the increasing and falling rate period. By equation simulation using experimental data, the exponential increasing rate (ni) and exponential coefficient were found to be 2.909 and 1.065 respectively, while the power in falling rate period (nf) was found to be 1.506. These two parameters (ni and nf) improves the drying characteristic performance by producing shorter drying time.

Keywords: through drying, Empty Fruit Bunches fiber, superheated steam.

Introduction
Through drying is technique well established in the chemical industry for efficient drying of porous beds of granular material but is of more recent application in the paper industry (Polat et al. 1987). Through air drying involves drying porous materials by the passage of heated air or gas through the material. Commercial application of this process in the pulp and paper industry began with patents issued in the late 1960’s (Ryan et al. 2003). Through drying provides higher drying rates and, for products such as bulky tissue, paper and toweling, improved quality (Polat et al. 1987). In addition to higher drying rates, through drying offers the ability to produce a relatively unconsolidated structure with superior product attributes namely softness, bulk, hand feel, and absorbency (Ryan et al. 2003). The water removal by air flow through the wet material was used both for the high heat and mass transfer rate in the dried material. This experiment has attempted to dry the biomass (solid waste) from palm oil mill applying through drying system. During this time empty fruit bunches have been mainly incinerated to produce ash for fertilizer, however, the conventional method for burning these residues often caused environmental problems. In fact, the EFB fibers are strong and stable and can be processed easily into various dimensional grades to suit specific applications in mattress and cushion manufacture, soil stabilization/compaction for erosion control, landscaping and horticulture, ceramic and brick manufacture, and flat fiber board manufacture. Earlier works, dry loose EFB fiber was obtained by applying hot flue gases in a conventional diesel-fired rotary drum dryer suffered from over-drying, browning, entangled fiber and dust explosions.
In recent years, a novel drying system has been developed by employing superheated steam as drying medium which has some advantages over hot air drying medium to enhance the drying rate (Mujumdar 1987, Faber et al. 1986), while other investigator (Schwartz et al. 1998) has successfully dried fiber mats using through drying system with superheated steam as drying medium at atmospheric pressure.

Previous study (Rosdanelli and Wan Ramli 2004) reported that through drying system using superheated steam as drying medium for drying loose EFB fibers could improve the product quality i.e. browning avoidance, brighter color product, unchanged modulus elasticity, and preventing dust explosion due to air absence in the drying medium.

The term ‘drying’ commonly describes as moisture removal from materials. Earlier theory has defined the typical drying rate which has three periods, i.e. initial heating rate period, constant drying rate period and falling drying rate period. Generally, drying theory (Keech et al. 1995) described that the initial heating rate period is usually short and thereby ordinarily neglected. On the contrary, previous investigation (Polat et al. 1987, Chen and Douglas 1998) reported that in the heating rate period a moisture removal was occurred nearly 50% from the whole moisture content in the materials.

Chen’s report (1998) stated that Polat (1989) was the first investigator who claimed that the increasing drying rate period (which previously termed as initial heating rate period) displayed an important role in the drying rate curve. This statement has then been developed by Chen and Douglas (1998). Based on this thought, this experiment will investigate the drying characteristic with respect to both investigation (Chen & Douglas 1997, Chen & Douglas 1998, Polat et al. 1987) by applying 5 parameters, i.e. the exponent of R-X over increasing rate period (ni), the moisture content at end of increasing rate period (Xi), the critical moisture content (Xc), the constant drying rate period (Rc), and the power of R-X over falling rate period (nf).

Material and Method

Material

The empty fruit bunches (EFB) was obtained from palm oil mill, was crushed by a crushing machine to yield the fiber. A 20 mm thick fiber “mat” was then placed on 150 mm diameter aluminium perforated plate and secured by aluminium net. The plate diameter and the mat thickness are used as the material size. The sample was weighed before drying to obtain the initial mass. The mass of dried sample was determined by drying in a convection oven at 130°C for 24 hours.

![FIGURE 1: The schematic diagram of the through steam drying system test equipment](image-url)
Equipment

The experimental through dryer using superheated steam is shown schematically in fig. 1. The whole part consists of three main instruments, i.e. the steam generator, superheater, and drying chamber. The steam generator with its capacity of 60 lbs/h has been used to generate steam. The superheater has been employed to reheat steam to dry steam which is often called superheated steam. The drying chamber has been applied to dry the EFB fibers. The drying chamber is made of stainless steel with its size of 50 cm x 50 cm x 70 cm which is insulated by a ceramic fibre with 10 cm thickness. The weighing system consists of an electronic balance (AND R200) with maximum capacity of 210 g and precision of ± 0.01 g, placed outside the drying chamber. A by pass circuit consisting of 142 series type DCX Electric Actuators and a 3-way Ball valve has been utilized to redirect steam during weighing. The temperature profile in the sample has been measured by a K-type thermocouple. The LabView TM 6.0 provided by National Instrument® is installed to support the 3-way Ball valve and has the function for temperature data collecting.

Procedure

Initially, the steam is generated by a steam generator and then passed to a superheater for advance heating. This superheated steam is used as the drying medium for drying EFB fibers. The steam is flowed to a chamber drying via a nozzle of 0.67 mm diameter and sprayed directly to the material. To obtain the sample weight directly the sample is placed on the perforated tray which is hanging to the electronic balance in the middle of the drying chamber. The electronic balance (AND R200) with its maximum capacity of 210 g and precision of ± 0.01 g is applied to monitor weight loss continuously and accurately without removing the sample from the drying chamber. The reading from the electronic balance can be displayed and stored directly using a PC by an RS 232 wire as connector. For accuracy in continuous weighing, during sample weight loss the steam has been redirected outside the drying chamber in every one minute.

The temperature and velocity of the steam in the drying chamber are firstly settled and the system has been allowed to reach a steady state. After achieving the steady state condition, the EFB fibers are placed in the drying chamber with its moisture content in the range of 0.88-1.1 g/g. The drying process has been conducted until obtaining the constant weight.

Results and discussion

Drying curve

Figure 2a shows the temperature effect on moisture content removal, where higher temperature caused faster moisture content removal, and shorter time required to attain the equilibrium of moisture content. From Figure 2a, the most significant slope to determine the optimum condition is observed in the range of 200 – 220°C. At 220°C the moisture content equilibrium is attained at the 16th minute, where this moisture content value in materials is suitable for commercial purpose with 10% moisture content. To examine the other slope the velocity effect has been conducted under 220°C as shown by Figure 2b.

The change in moisture content due to velocity effect to obtain optimum drying has been observed in the velocity range of 0.89 – 0.99 m/s (Figure 3). Under that velocity range the moisture content attains its equilibrium at the 15th minute. If those both effects are combined in one graph and fitted, the velocity effect is appeared more pronounced than the temperature effect. The slope in moisture content vs. drying time under 220°C and velocity of 0.89 m/s is found much smaller than the slope of moisture content under 220°C and velocity of 0.99 m/s. Under velocity of 0.99 m/s the final moisture content was found to be 0.009 g/g while under 220°C and velocity of 0.89 m/s its moisture content was found to be 0.061 g/g. From the above evaluation, the optimum drying was obtained under 220°C and velocity of 0.99 m/s.
The effect of temperature and steam velocity

Fig. 4a and 4b show the effect of drying rate vs. moisture content by varying the drying intensity, i.e. the temperature and velocity of steam. There are two conditions in drying characteristic of the EFB fiber. The first condition, i.e. the increasing drying rate period followed by the falling drying rate period was observed at higher than 220°C and steam velocity of 0.89 m/s.

The second condition is occurred under lower temperature than 220°C and velocity of 0.89 m/s where it has three drying rate periods, i.e. the increasing drying rate period, the constant drying rate period and the falling drying rate period. These phenomena are in agreement with Polat’s report (Polat et al. 1987).

Under the first condition of drying characteristic (Fig. 4a) from 220 °C to 280 °C the existence of the constant drying rate period is appeared insignificantly compared to those reports by Chen (1997) and Polat (1989) due to superheated steam using as drying medium in this experiment.

Moreover, this experiment used longer time for data collecting that caused its constant drying rate period not distinctly appeared. The increasing drying rate period from 220 °C to 280 °C appears longer and followed by faster falling drying rate period. Under the highest temperature, the constant drying rate is coincided with its curve peak, or in another words, the constant drying rate disappeared. The second condition of drying characteristic is occurred under temperature lower 220°C in this condition, the constant drying rate is distinctly appeared, i.e. under 0.72 g/g cm2.min drying rate and moisture content range of 0.5 – 0.9 g/g as shown in Fig.4a. For next discussion, the characteristic to be evaluated is only underlined on the first condition of drying characteristic, i.e. under operational condition higher than 220°C at 0.89 m/s.

Quantified variable

The drying rate curve is quantified in 5 variables, i.e. $X_i$, $m_i$, $R_c$, $X_c$, and $n_f$, where $X_i$ is the moisture content at the end of
increasing rate period, \( ni \) is the exponent of \( R-X \) for through drying over increasing rate period, \( Rc \) is the constant drying rate, \( Xc \) as critical moisture content, and \( nf \) as power of \( R-X \) for through drying over falling rate. From the experimental data it is found that the critical moisture content \( (Xc) \) appears as a point. For respective temperatures and velocities, the values of \( Xi, Xc \) and \( Rc \) are presented in table 1. The values of \( Xc \) are as the same as \( Xi \).

### Increasing rate curvature \( (ni) \)

Figure 5 shows the normalized drying rate vs normalized moisture content. If the increasing drying rate curve is approached by eq.1 (Chen & Douglas 1997), and based on simulation on eq. 1, and thus eq. 1 converted to eq.2 with its exponential increasing rate \( (ni) \) as large as 2.9091 and its exponential coefficient is found to be 1.065. Graphically, eq. 2 is presented in Figure 5b.

\[
\frac{R}{Rc} = \left[ 1 - e^{-ni\frac{(x_i-x)}{(X_o-X_i)}} \right] 
\]

(1)

\[
\frac{R}{Rc} = \left[ 1 - 1.065e^{-2.9091\frac{(x_i-x)}{(X_o-X_i)}} \right] 
\]

(2)

The change of drying rate vs moisture content at increasing drying rate period is performed in eq.3. From eq. 3 the slope of drying rate at any \( x \) value can be determined as follows:

\[
\frac{d}{dx}\left(\frac{R}{Rc}\right) = \left[ -3.098 \frac{1}{x_i-x} e^{-2.9091\frac{(x_i-x)}{(X_o-X_i)}} \right] 
\]

(3)

![Figure 4: The drying characteristic curve](image)

(a) different temperature (b) different velocity
TABEL 1: Experimental Parameter

<table>
<thead>
<tr>
<th>Run No.</th>
<th>Xo (g/g)</th>
<th>Xc = Xi (g/g)</th>
<th>Rc</th>
<th>T (°C)</th>
<th>V (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2</td>
<td>1.036</td>
<td>0.84</td>
<td>0.073</td>
<td>200</td>
<td>0.89</td>
</tr>
<tr>
<td>T3</td>
<td>0.899</td>
<td>0.62</td>
<td>-</td>
<td>220</td>
<td>0.89</td>
</tr>
<tr>
<td>T4</td>
<td>0.961</td>
<td>0.68</td>
<td>-</td>
<td>240</td>
<td>0.89</td>
</tr>
<tr>
<td>T5</td>
<td>1.020</td>
<td>0.7</td>
<td>-</td>
<td>260</td>
<td>0.89</td>
</tr>
<tr>
<td>T6</td>
<td>0.954</td>
<td>0.63</td>
<td>-</td>
<td>280</td>
<td>0.89</td>
</tr>
<tr>
<td>v1</td>
<td>1.083</td>
<td>0.7</td>
<td>0.08</td>
<td>200</td>
<td>0.79</td>
</tr>
<tr>
<td>v2</td>
<td>1.044</td>
<td>0.77</td>
<td>-</td>
<td>200</td>
<td>0.89</td>
</tr>
<tr>
<td>v3</td>
<td>1.073</td>
<td>0.82</td>
<td>-</td>
<td>200</td>
<td>0.99</td>
</tr>
<tr>
<td>v4</td>
<td>1.119</td>
<td>0.95</td>
<td>-</td>
<td>200</td>
<td>1.09</td>
</tr>
</tbody>
</table>

Falling rate curvature (nf)

If the falling drying rate period is approached by eq. 4 (Chen & Douglas 1997) and based on simulation on eq.4, the nf (power equation) is found to be 1.506 expressed by eq. 5. Graphically, eq. 5 is presented in Figure 5a.

\[
\frac{R}{R_c} = \left[ 1 - \left( 1 - \frac{X}{X_c} \right)^{nf} \right] \quad \ldots
\]

(4)

\[
\frac{R}{R_c} = \left[ 1 - \left( 1 - \frac{X}{X_c} \right)^{1.506} \right] \quad \ldots
\]

(5)

Graph evaluation

Figure 6 can be used to represent the evaluation of increasing and falling drying rate period. Fig.6 represents the drying characteristic for both paper and EFB fiber. For graph evaluation, let us compare two drying processes, i.e. the drying process for paper using hot air as drying medium (Chen & Douglas 1997) and for EFB fiber using superheated steam as drying medium (this study), where both of them use the same drying system, i.e. the through drying system. Based on eq.1, the difference between both studies is observed in the values of \( n_i \) and its exponential coefficient. The \( n_i \) value for hot air drying is found to be
3.6 (Chen & Douglas 1997), while this experiment using the superheated steam as drying medium found the $n_i$ value of 2.9.

Using lower $n_i$ value obtained by the equation simulation, this present study (Fig.6b) shows shorter increasing drying rate period or the constraint of time consuming in drying process can be overcome. Moreover, this investigation found an exponential coefficient of 1.065, while earlier work on hot air obtained the exponential coefficient value as unity (Chen & Douglas 1997). This exponential coefficient is the key factor in describing the specific drying characteristic. Figure 6a represents the falling drying rate period for hot air (Chen & Douglas 1997) and superheated steam (this present study). Based on eq.4, the difference between both studies is found in the $n_f$ (power equation). The hot air drying found the $n_f$ value of 1.7 (Chen & Douglas 1997), while this present study found the $n_f$ value of 1.5. With lower $n_f$ value obtaining by equation simulation, the duration of falling drying rate period in this present study getting shorter, or in another words, this present study yields an improvement in drying rate performance.

**Conclusion**

Regarding the above evaluations, the optimum drying is found at 220°C and velocity of 0.99 m/s. Under the drying condition from 220°C to 280°C, the constant drying rate period is not found. This present study obtained $n_i$ value of 2.9 and exponential coefficient of 1.065 for the increasing drying rate of EFB fibers. This exponential coefficient is the key factor for representing the specific characteristic drying rate. This study also obtained the $n_f$ value of 1.5 (power equation) in falling drying rate period. From these characteristic values obtained by this investigation, this study successfully shows a good performance of its drying characteristic and can be used as the basic idea underlying the steam through drying system.

![Figure 6](image.png)

**FIGURE 6:** Graph evaluation of increasing and falling drying rate period
References


