WATER ADSORPTION CAPACITY OF PALM KERNEL CAKE

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ABSTRACT. *The role of water in solid state fermentation of Palm Kernel Cake is a critical factor Water adsorption properties of Palm Kernel Cake were determined using a packed bed adsorption column. Effect of air flow rate, particle size and relative humidity ware studied. Adsorption isotherms that best fits the experimental data were determined for PKC with particle sizes of 455μm and 855μm.*

KEYWORDS. Adsorption isotherms, Palm kernel cake, relative humidity, Water content

INTRODUCTION

In the solid state fermentation (SSF) of Palm Kernel Cake (PKC) to produce animal feed, a common problem often faced is in the optimization of the yield. SSF is a process where an insoluble substrate is fermented with sufficient moisture but in the absence of free – flowing water. The fermentation in this manner takes place in absence or near absence of free water.

Among the most critical and relevant issues in solid state fermentation could be the selection of process parameters and their optimization. These include physicochemical and biochemical parameters such as particle size, initial moisture, pH and pre-treatment of the substrate, relative humidity, temperature of incubation, agitation and aeration (Pandey, 2002).

Palm kernel cake is the leftover of an oil palm fruit which has been squeezed to extract its crude palm oil content. There are two types of PKC depending on the process to get it, either through mechanical or solvent process (Osman and Hisamuddin, 1999). There has been no thorough studies done on the water adsorption capacity of PKC. The moisture content is a critical factor on SSF processes because this variable has influence on growth and biosynthesis and emission of different metabolites (Perez-Guerra et al., 2003). The optimal value of water content depends both on the microorganism and the solid substrate used. Pandey (2002) has reported that high moistures results in decreased substrate porosity, which in turn prevents oxygen penetration. This may help bacterial contamination. On the other hand, low moisture content may lead to poor accessibility of nutrients resulting in poor microbial growth. During fermentation the water level of the substrate can change due to evaporation and microbial activity. The water required by microorganism is better defined in terms of water activity rather than water content on the solid substrate. Water activity indicates the available or accessible water for the growth of the microorganism. Water activity of PKC has determinant influence on microbial growth during SSF. The water activity affects the biomass development, metabolic reaction and the mass transfer processes (Gervais and Molin, 2002). Therefore it is essential to supply the microorganism and the solid substrate in this case, PKC, with adequate moisture for optimal fermentation condition.

From this literature survey, it was concluded that the water content or the water retaining capacity of the solid substrate plays a major role in obtaining the desired properties of the end product in solid state fermentation. The scope of work in this research covers the study on the water adsorption phenomena of PKC. The water activity can be obtained by evaluating the Relative Humidity of the air that is being supplied for the aeration of the PKC.

This study is will take into consideration a few parameters that affects the water retaining or adsorption capacity of PKC namely the substrate sizes, Relative Humidity of the air, and air flow rate. At the end of this research, it is believed that the optimal conditions of these parameter will be identified which can in turn provide the best environment to facilitate solid state fermentation of PKC.

MATERIALS AND METHODS

Materials
Since this research work in mainly concerned only on the water content of Palm Kernel Cake, the foremost materials used in this research are Palm Kernel Cake obtained from IOI Edible Oils Sdn Bhd, Sandakan and tap water.

Design and Fabrication of Experimental Set-up
It was required to design and fabricate an air humidifying unit which can provide humidified air into a column where PKC will be placed. This humidifier is of continuous water flow concept. The experimental set up was fabricated using PVC piping materials.

Calibration and Optimization of:
Experimental Set-up
The whole unit is run while maintaining the air flow rate at a constant value of 1cm/s. Air flow rate is predetermined on the flow meter and maintained constant. The relative humidity is monitored by using a Thermo Hygrometer which was placed inside the column. The value of relative humidity is recorded for every 5 minutes until the value becomes constant. The same procedure is repeated for different sets of water level. This trial and error step is repeated until each different water level gives a RH with deviation more than 5%. This will determine the level height that can be fixed for a specific desired relative humidity.

Water adsorption studies
The water content studies on PKC were carried out in the following steps.
1. **Preparation of Palm kernel Cake**
   For the purpose of this study, the water retaining capacity of PKC at various sizes namely at 855μm, 655μm and 455μm was studied. 500g of PKC was sieved for each size range. All the sieved PKC was dried in oven at 118°C ± 2 for 48 hours.
2. **Water Adsorption on Palm Kernel Cake**
   In this study, the effect of air flow rate, particle size and relative humidity were investigated that affects the water adsorption characteristics of PKC. For each parameter studied, the other parameters were kept constant. 100g of dried PKC was used for each test. By forcing the humidified air through the PKC bed, the water content was measured gravimetrically. Measurements were taken at 10 min, 30min, 1 hr, 2 hr, 4 hr, 6 hr, 12 hr, 24 hr, 36 hr and 48 hr. Analysis were performed at least in duplicate measurement and results averaged.

RESULTS AND DISCUSSION

Humidifier Calibration
The calibration was done to relate water level inside the humidifier tower as the manipulated parameter to the relative humadity as the desired output. It enables us to identify the exact parameters that have to be manipulated in order to obtain designed relative humidity.

Effect of Water Level
By manipulating the height of water level inside the tower, we were able to control the exit air humidity. The water level was maintained at 0.2 m, 0.4 m, 0.7 m and 1.0 m. The outlet air humidity was obtained to reach a constant value of 72%, 78%, 85% and 95% respectively. Figure 4.5 provides a graphical view of the outcome.

The height of water level inside the humidifier is a vital factor in influencing the relative humidity. A higher level produces a higher relative humidity as the volume of liquid phase that comes in contact with the gas phase is larger. The room humidity was affected by the weather, temperature and also the time of the day. On a rainy day, the room humidity can reach up to 80% compared to normal condition of about 68%.
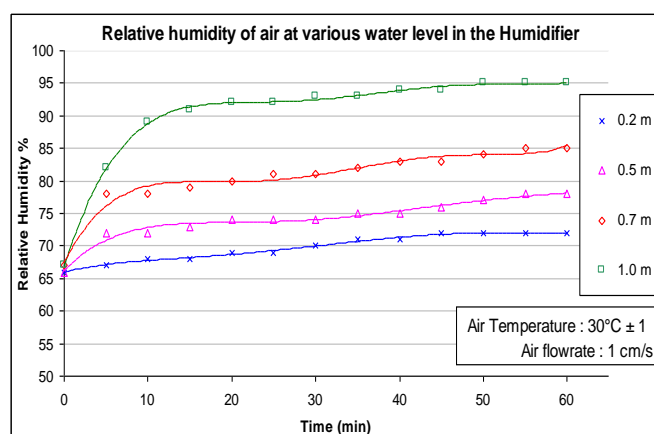

Figure 2.1. Relative humidity of outlet air at various water levels in the Humidifier.

Water Adsorption Studies
The changes in sample mass as a function of time were measured for different varying parameter that is believed to influence the water adsorption kinetics of PKC. The effect of air flow rate, particle size and relative humidity on water adsorption of PKC is shown in the following sections. The initial moisture content of each samples of PKC used in these studies is considered zero as each sample has been bone dried at $118°C \pm 2$ for 48 hours prior to conducting the experiments. The apparent equilibrium conditions were considered to be reached when the dynamic changes in sample mass as a function of time were lower than 0.02%/min (2.0g water/ 100g dry PKC/ day) (Roman-Gutierrez et al., 2002). However in this study, an assumption made is that the equilibrium water content was achieved in 48 hours of running the entire operation. Due to equipment, each experiment could not be conducted for more than 48 hours without stop.

Effect of Air Flowrate

The first parameter studied was the effect of air flowrate on the water adsorption capacity of PKC. As shown in Figure 3.1. the columns were operated with air flow rates of 0.5cm/s, 1cm/s and 1.5cm/s and bed depth and column diameter were 1cm and 18.5cm respectively. The equilibrium moisture content was found to be 15.33gH_2O/gPKC, 30.76 gH_2O/gPKC and 32.65 gH_2O/gPKC for air velocity of 0.5cm/s, 1cm/s and 1.5 cm/s respectively. Changes in water content as a function of flow rate during adsorption showed similar trends. However from Figure 3.1, it can be seen that the rates of adsorption is higher at 1.5 cm/s after 12 hours and more particularly after 24 hours. It is apparent that at higher air flowrate, larger numbers of air bubbles were formed inside the humidifier. This provides larger volume of humidified air to pass through the PKC bed in the column, thus increasing the adsorption rate. Similar experiments were also conducted for PKC of particle size of 455µm and 655µm. The results demonstrate similar trends as for 855µm.
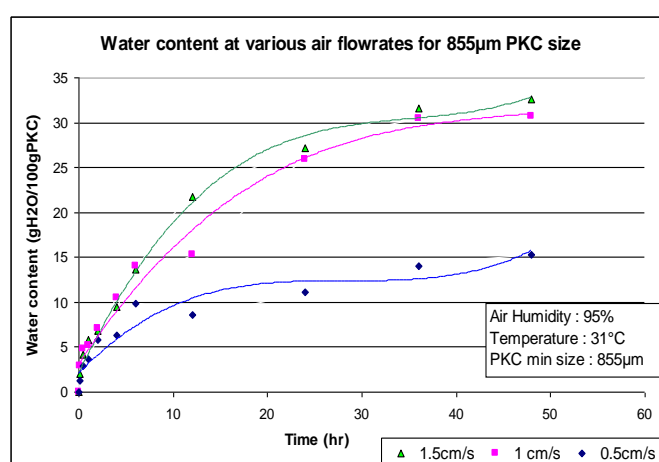

Figure 3.1. Effect of air flowrate on the water adsorption of PKC.

Effect of Particle Size

The water adsorption capacity of PKC was determined at three average particle sizes: 855µm, 655µm and 455µm. The air flow rate and air humidity was maintained constant at 1cm/s and 95% ± 2 respectively. The equilibrium moisture content was found to be 30.76 gH_2O/gPKC, 32.35 gH_2O/gPKC and 40.76 gH_2O/gPKC for PKC sizes of 855µm, 655µm and 455µm respectively as shown in Figure 3.2. Water adsorption capacity may be related to the physical properties of the solid. Fine particles have a larger surface area per unit volume (or mass) than coarse particles. Consequently, they have a greater surface area available for water molecules to adsorb to the pores on PKC surface. However, the time necessary for the water molecules to diffuse from the surface to the centre of particles is less for smaller particles than for larger particles. These physical differences between small and large particles may be responsible for the observed variation in equilibrium moisture content of PKC. It may also be that the values of water diffusion coefficient are affected by the particle size, but our results do not permit evaluation of the effect of particle size on diffusion coefficient (Hebrard et al., 2003). Similar experiments were also conducted for PKC at air flow rate of 0.5cm/s and 1.5cm/s. The results demonstrate similar trends as for 1cm/s.
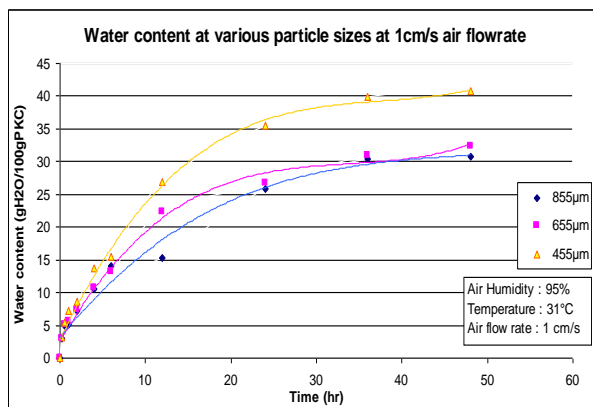
Figure 3.2. Effect of particle size on the water adsorption of PKC.

Effect of Relative Humidity

The relative humidity of the air fed into the column can be varied by adjusting the height of water level inside the humidifier. However this method exhibit limited reproducibility in terms of the desired RH. It is difficult to retain the RH at a constant value as the RH is affected also by the room humidity, weather and temperature. The data obtained during calibration of the humidifier was used to set an appropriate water level and to gain the corresponding RH. The water level was set at 0.2m, 0.5m, 0.7m and 1.0m and RH was obtained at 71%, 77%, 83% and 95% respectively. Air flow rate (1cm/s) and particle size (855µm) was made as constant. The higher the RH of inlet air, the higher was the equilibrium moisture content achieved as shown in Figure 3.3.

At higher RH, the air was able to supply large amount of excess moisture in the form of water vapor to PKC bed in the column. Water adsorption is characterized by a rapid increase in sample mass immediately after changing the RH conditions that tend to reach a near constant value after a long period. As stated earlier, the equilibrium conditions were considered to be reached when the change in sample mass as function of time were lower than 0.02% / min. Similar equilibrium conditions have already been considered for the construction of water vapor sorption isotherms for other systems (Saccheti, 1998). The same experiment was also repeated using similar process conditions except for change in the particle size where PKC of 455µm was used. The outcome of this experiment is shown in Figure 3.4. Equilibrium moisture content attained at varying RH was used to determine the suitable adsorption isotherm that fits the data.
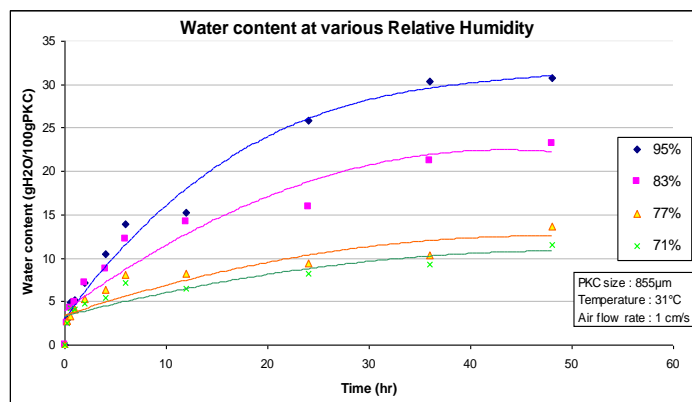

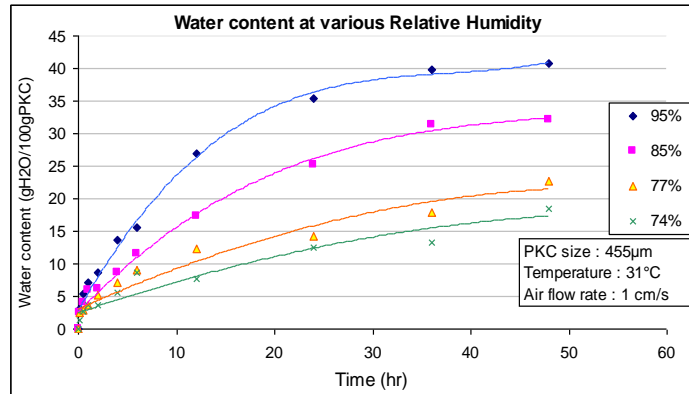**Figure 3.3. Effect of Relative Humidity on water adsorption of PKC of 855µm.**

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Figure 3.4. Effect of Relative Humidity on water adsorption of PKC of 455μm.

Exponential model

The changes in sample mass as a function of time at constant RH were also described using an exponential model (Equation 3.1)

$$q(t) = Q\left[1 - \exp\left(\frac{-t}{B}\right)\right] \quad \text{.......................... (3.1)}$$

where q(t) is the change in sample mass (g water/100g dry PKC) as a function of time, t is the time (hr), Q is the equilibrium water adsorption capacity (t=48hr) and B is the time (hour) necessary for the samples to adsorb half of the equilibrium water adsorption capacity (i.e., B = t when q(t) = Q/2) (Roman-Gutierrez . et al., 2002). By rearranging Equation 3.1, we obtain a linear equation as Equation 3.2.

$$-Ln\left[1 - \left(\frac{q(t)}{Q}\right)\right] = \frac{1}{B}t \quad \text{..................... (3.2)}$$

The value of B was obtained by plotting this linear equation as shown in Figure 3.5. The slope of the curve can be used to calculate the value of B.

The slope for this straight line for 855μm was found to be 0.0978. Therefore 1/B equals to 0.0978. Solving for B gives 10.225. Similarly for the straight of 455μm, the slope is 0.1059 which gives B as 9.443. The half equilibration time (B) can be used to compare the water adsorption rates of a compound. Higher rates of water adsorption (lower B value) were observed for PKC of particles size of 455μm. On the other hand, lower water adsorption rate were observed for PKC with particle size of 855μm.
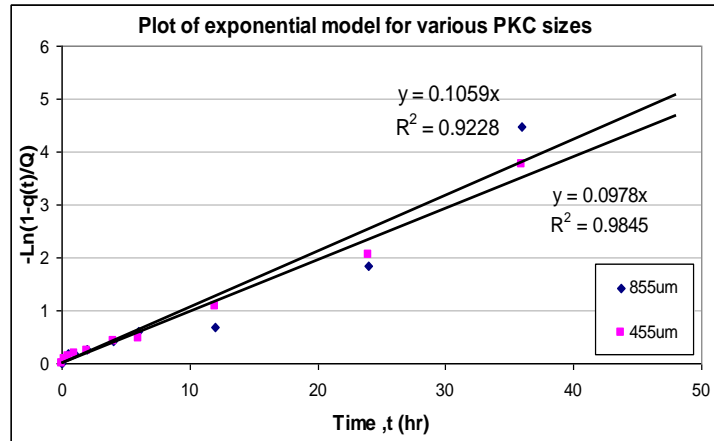
Figure 3.5. Plot of exponential model for various PKC sizes.

By using the calculated model parameters (B and Q), a plot of the exponential model (Equation 3.1) was obtained and compared with the actual experimental points. In the present study, the use of the exponential model (Equation 3.1) was sufficient to calculate the water adsorption capacity at a given time or equilibrium. The experimental points and fitted curves are presented for PKC of 455µm in Figure 3.6 and 855µm in Figure 3.7. It should be noted that the exponential model fits the experimental data quite well for both sizes of PKC particles with R^2 of more than 0.9. The slight deviation can be ignored as experimental errors.
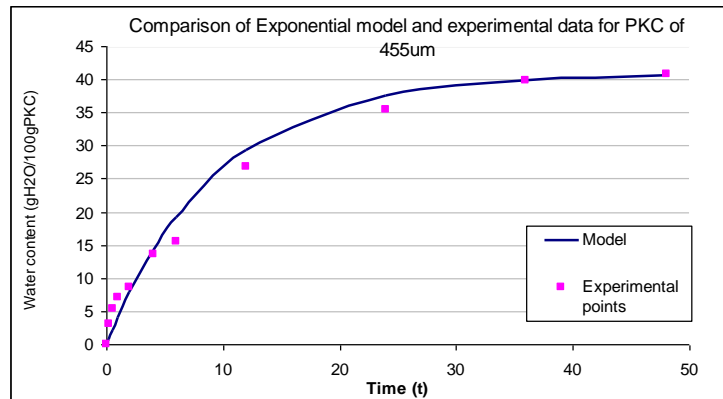

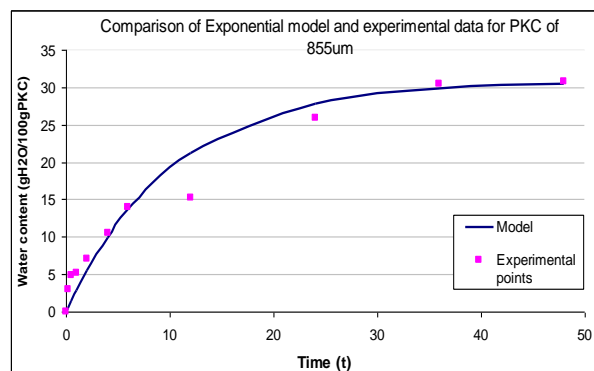**Figure 3.6. Comparison of Exponential model and experimental data for PKC of 455um.**

Figure 3.7. Comparison of Exponential model and experimental data for PKC of 855um.

Adsorption Isotherm

Water adsorption isotherms of PKC are presented by plotting the changes in moisture content versus RH. An equilibrium moisture content Q against RH for 855µm and 455µm is presented in Figure 3.8 respectively. The plots show an exponential shape that can be described in terms of a two step moisture adsorption process (Roman-Gutierrez et al., 2002). During the first stage, water molecules are bound onto the monolayer and water clusters begin to form. In the second stage, accumulation of water in intermolecular free spaces occurs and results in partial swelling that in turn may expose additional binding sites for the water molecules. This argument is based on the evident increase of particle sizes of PKC after it was run with humidified air for 48 hours. The size of PKC particles was observed to increase double their original dried size.

The water adsorption constructed for PKC size of 455µm is significantly higher than those constructed for 855µm. The size of PKC particles clearly plays a role in their water adsorption capacity. As discussed earlier, smaller particle size provides larger surface area for water adsorption. This is probably because for larger particles, water molecules adsorption occurs only on the external area of the pores. Accumulation of water molecules here blocks the pore passage and thus preventing further adsorption to take place even though the pores passage maybe longer and extending to the center of the particle. For smaller particles, the pores are relatively shorter, however water molecules makes full use of this pores for adsorption.

The water adsorption isotherms were plotted and shown with the resulting equation in the Fig. 3.8. The equation can be also represented in terms of q and c where q is the concentration of moisture in the PKC (g water/ 100gPKC) and c (RH) is the concentration of moisture in the air.
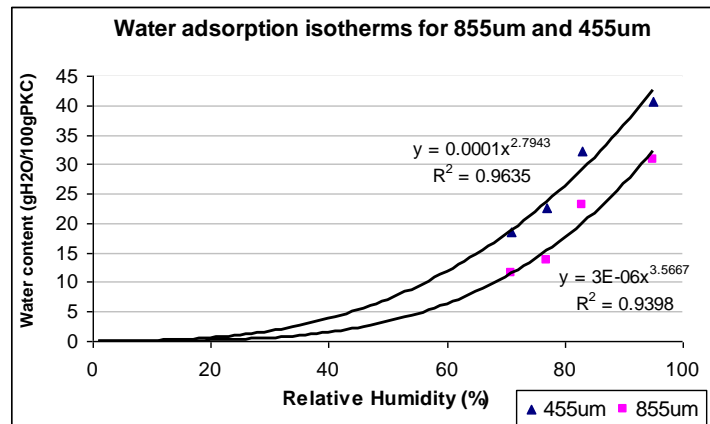

Figure 3.8. Adsorption isotherm for PKC of 455µm and 855µm.

Therefore, for PKC of 855µm size, the adsorption isotherm can be expressed as

$$q = 3 \times 10^{-6} \, c^{3.5667} \quad .... \ (3.3)$$

whereas for the size of 455µm, the adsorption isotherm is expressed as

$$q = 1 \times 10^{-4} \, c^{2.7943} \quad .... \ (3.4)$$

By using these equations, at a given process conditions we are able to estimate the water content of PKC. This adsorbent is comparable to silica gel adsorbent (McCabe, *et. al,* 2005).

CONCLUSION

The present work permitted the collection of experimental data describing the water adsorption properties of PKC of different sizes at various air flow rate and relative humidity. The oven drying method determines the total water content of PKC. The water content of PKC was recorded highest when smaller particles are used with higher air velocity containing higher relative humidity. Adsorption isotherm obtained for PKC of particle size 455µm and 855µm show the water retaining capacity of PKC at specific temperature and air flow rate. PKC can adsorb sufficient water and compares well with other adsorbents.

The humidifier built for this research was proved to be reliable by producing high relative humidity and maintaining constant air flow rate. However, it does not posses high reproducibility probably to the interference of external factors such as weather and climate which can affect the relative humidity. Water content at RH lower than 70% could not be determined because it is almost impossible to achieve RH below 70% using the laboratory built humidifier.

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