THE EFFECT OF DRYING TECHNIQUES ON THE ELASTOPLASTIC PROPERTIES OF LOCALLY PROCESSED MICROCRYSTALLINE CELLULOSE.

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ABSTRACT

The study investigated the effect of three different drying techniques i.e. microwave, sun and oven drying on the physicochemical and compressional characteristics of microcrystalline cellulose obtained from sawdust, an agricultural waste product. The physicochemical properties were investigated by assessing the tapped and bulk densities, flow properties i.e. angle of repose, flow rate, compressibility index and Hausner's ratio, while the compressional properties were evaluated using both the Heckel and Kawakita equations. The results obtained showed that the values obtained for angle of repose was in the order of micro< sun< oven while the order for flow rate was the reverse of the angle of repose ratio and it was in the order; sun<oven<micro. The compressional characteristics showed that the order of P_y values i.e plastic deformation at onset of compression of the microcrystalline cellulose powder was in the order of micro<oven<sun, while the order of P_k value i.e. plastic deformation during compression was micro<sun<oven. The study concluded that microwave drying method would lead to production of microcrystalline cellulose with enhanced physicochemical and compressional properties.

Keywords: Microcrystalline Cellulose, Drying Techniques, Flow Properties, Compressional Properties.

INTRODUCTION

Researchers in the pharmaceutical sciences working on development of excipients from local sources have made efforts in the production of starches (Esezobo *et al.,* 1982; Alebiowu and Itiola, 2002; Odeku *et al.,* 2005; Muazu *et al.,* 2009), gums (Odeku and Itiola 1998; Adetogun and Alebiowu, 2007) and celluloses (Okhamafe *et al.,* 1991; Musa, 2000; Oyeniyi *et al.,* 2011). It is known that process variables like source of raw material (Odeku *et al.,* 2005) and drying techniques (Dyer *et al.,* 1994) can affect the quality of the excipient produced. Process variables have also been found to affect the activity of the excipient developed when used in a formulation (Esezobo *et al.,* 1989). It has been reported, that the choice of drying method used in processing of pharmaceutical raw materials is critical to its physicochemical properties and the release properties of its tablet formulations (Esezobo *et al.,* 1989). It is therefore important to investigate the effects of drying techniques on the quality of microcrystalline cellulose obtained from sawdust, an agricultural waste which is commonly available in Nigeria. In the development of an excipient, various methods such as densities, flow properties and compressibility are used to evaluate the characteristics of the new excipient before it is finally introduced to the market. Hence, this study aims to assess the physicochemical, flow, and compressional properties of the extracted microcrystalline cellulose. The flow properties were evaluated with the use of angle of repose, flow rate, Carr's index and Hausner's ratio, while Heckel and Kawakita equations were used to assess the compressional properties.

The Heckel (1964) equation is widely used for relating the relative density, *D,* of a powder bed during compression to the applied pressure, *P.* It is written as:

$$\ln\frac{1}{1-D} = kP + A \qquad (1)$$

The slope of the straight line portion, *K,* is the reciprocal of the mean yield pressure, P_y, of the material. From the value of the intercept, *A,* the relative density, D_a, can be calculated using the following equation (Itiola, 1991; Dyer *et al.*, 1994; Alebiowu and Itiola, 2002)

$$D_A = 1 - e^{-A} \qquad (2)$$

The relative density of the powder bed at the point when the applied pressure equals zero, D_0, is used to describe the initial rearrangement phase of

densification as a result of die filling.
The relative density, D_b, describes the phase of rearrangement at low pressures and is the difference between D_a and D_o:

$$D_B = D_A - D_o \quad (3)$$

The material constant (K) and the mean yield pressure (P_y) depends on the processing conditions such as drying methods and temperature, therefore different values of mean yield pressure had been reported for the same material (Ilic *et al* 2009).

The Kawakita equation is used to study powder compression using the degree of volume reduction, *C,* and is written as

$$C = (V_o - V_p)/V_o = abP/(1 + bP) \quad (4)$$

The equation, in practice, can be rearranged to give

$$P/C = P/a + 1/ab \quad (5)$$

where V_o is the initial bulk volume for granular materials and V_p is the bulk volume after compression. The constant a is equal to the minimum porosity of the material before compression; the constant *b,* which is termed the coefficient of compression is related to the plasticity of the material. The reciprocal of *b* is related to the pressure term P_k, which is the pressure required to reduce the powder bed by 50 %, (Kawakita and Ludde, 1970/71; Shivanand and Sprockel, 1992).

Both the Heckel and the Kawakita plots have their limitations and are generally believed to exhibit linearity for many materials at high and low pressures, respectively (Çelik, 1992). Therefore, the combined use of the two plots should provide more accurate information about the effects of three drying methods on the compressional characteristic of microcrystalline cellulose obtained from a local waste material.

MATERIALS AND METHODS.

Materials.

The sawdust was obtained from a local sawmill located in Samaru, Zaria, Kaduna State Nigeria; sodium hydroxide pellets and concentrated hydrochloric acid were obtained from BDH Chemicals Limited, England.

Methods.

A. Collection, Drying and Size Reduction of Sawdust.

The sawdust was sun-dried to a constant weight and milled with an Alizco milling machine (Type AZIO, Alizco Ltd, Shangai, China.) This was however separated into different sizes using a sieve shaker (Erweka apparatus type AZ 24 (Erweka apparatebau Germany) fitted with the following sieve sizes: 150, 300, 450, 600 and 900 micrometer. The fraction retained on sieve mesh size 300 micrometer was collected, weighed and used for the extraction process.

B. Extraction and Purification of Cellulose.

The method of Oyeniyi *et al,* 2011 was used. One litre of 17.5 % $^{w}/_{v}$ sodium hydroxide was prepared in a stainless steel bowl. This was then heated in the water bath to 80 ^{o}C, after which 600 g of sawdust was transferred into the solution. The extraction process was conducted at 80 ^{o}C for a period of about 12 h after which the alpha cellulose obtained as the residue was filtered and thoroughly washed five times with de-ionized water. The alpha cellulose obtained was then bleached with a 50 % dilution of 6 % $^{v}/_{v}$ sodium hypochlorite until a complete white powder was obtained. Microcrystalline cellulose was obtained by depolymerizing the alpha cellulose with 200 mL of concentrated hydrochloric acid at 105 ^{o}C. The final product was removed and repeatedly washed five times with de-ionized water until all the acid was completely removed (Reilly *et al.,* 2000). The extracted microcrystalline cellulose was then divided into three batches. Each batch was then dried with one of the three methods of drying, i.e. microwave (irradiation), sun and oven.

C. Pharmacopeial Tests

British Pharmacopeia (BP) (2004) test was carried out on the extracted sawdust microcrystalline cellulose (SDMCC) to confirm its true identity. Also, B.P tests were carried out on sawdust microcrystalline cellulose for the presence of the following substances: starch, lignin and reducing sugars.

D. Flow and Compressibility Tests.

(i) Angle of Repose

This was done using a slight modification of Train's (1958) method I. A fixed load of sawdust microcrystalline cellulose powder was placed in a standing open-ended dry cylindrical tube. The cylinder was gently raised to leave a heap of the powdered gum. The circumference of the base of the heap was outlined and its radius, *r*, measured. The height, *h*, of the heap was also measured. The repose angle θ was calculated using the following equation:

$$\theta = \tan^{-1}(h/r) \quad (6)$$

The procedure was carried out for the remaining two batches of microcrystalline cellulose (SDMCC) and all determinations were in triplicate.

(ii) Flow Rate.

The flow rate in g/s was determined using a flow tube with an orifice of 10 cm (Alebiowu and Femi - Oyewo, 1998), while keeping the powdered material (SDMCC) load, degree of packing and height of funnel constant throughout the determination Determinations were in triplicate and the same procedure was carried out for the remaining two batches of SDMCC

(iii) Determination of Hausner's Ratio and Compressibility Index

The Hausner's (1967) ratio (HR) was determined from the bulk and tapped volumes according to the relationships: Vt and Vb

$$HR = \frac{Vt}{Vb} \quad (7)$$

while the Compressibility index (CI) was obtained from the following i.e.

$$CI = 1 \quad \frac{Vb}{Vt} \quad (8)$$

where Vt is the tapped volume (cm^3) and Vb is the bulk volume (cm^3)

(iii) Determination of Density Parameters.

The particle density (ϱ_{PD}) of SDMCC was determined for each batch of the extracted microcrystalline cellulose by pycnometer method using xylene as the displacement fluid. The particle density (ϱ_{PD}) was calculated using equation (7);

$$\varrho_{PD} = W_2 \times W_3)/50\ W_3 - W_4 + W_2 + W) \quad (9)$$

where W = the weight of empty pycnometer
W_1 = weight of pycnometer filled with xylene.
$W_2 = W_1 - W$
W_3 = weight of sample
W_4 = weight of sample + weight of pycnometer + xylene.

The bulk and tapped densities of SDMCC were calculated from the ratio of the sample weight to its bulk volume and tapped volume respectively. The bulk volume was however determined by pouring known weight of powder at an angle of 45 ^{o} through a funnel into a glass measuring cylinder with a diameter of 21 mm and a volume of 50 mL. This was repeated three times and the mean value noted (Paronen and Juslin, 1983). This same procedure was carried out for the remaining two batches.

(iv) Determination of Swelling Capacity.

A two-gram sample of the SDMCC was placed in a 100 mL measuring cylinder. Deionized water was added to 100 mL level. This was agitated for 30 min and left to stand and settle for about 24 h. The weight of sediment was obtained after the supernatant was decanted. This procedure was however repeated thrice and the mean value used. The swelling capacity of the material is the ratio of the sample weight to the average weight of the sediment, (Kornblum *et al.,* 1973).

(v) Determination of Moisture Content.

A 5 g sample of the SMDCC was placed in a porcelain dish and dried in an oven at 105 ^{o}C until a constant weight was obtained. The moisture content was obtained using the equation below;

$$\text{Moisture content (MC)} = \frac{initial\ weight - final\ weight}{final\ weight} \quad (10)$$

(vi) Determination of Total Ash Content.

A one - gram sample of the SDMCC was placed in

a porcelain dish and heated in a furnace at 450 °C for 3 h. The charred residue obtained after 3 h was taken as the total ash content of the sample (The International Pharmacopoeia, 1979). This procedure was repeated three times and the mean value used.

(vii) Preparation and Evaluation of Compacts.

This was carried out with the use of a Carver hydraulic hand press (Model C, Carver Incorporation, Menomonee Falls, Wisconsin, USA). The press was fitted with a 10.5 mm diameter punches and die set which was lubricated with a 1 %w/v dispersion of magnesium stearate in chloroform. Compacts weighing 500 mg each were prepared by compressing them for 30 s with the following predetermined pressures: 28.31, 56.62, 84.93, 113.23 141.54 and 169.85 MNm^{-2}. The tablets were thereafter stored over silica gel in a desiccator for 24 h to allow for elastic recovery and hardening in order to prevent falsely low yield values (Ogunjimi and Alebiowu, 2013). The tablet weights and dimensions were determined and the average values calculated. The relative density (D) of the tablets was calculated using the equation below:

$$D = \frac{w}{Vt \times \varrho_{PD}} \quad (11)$$

where V_t is the volume of the whole tablet (cm^{-3}) and ϱ_{PD} is the particle density of SDMCC obtained above.

RESULTS AND DISCUSSION

Table 1: Identification and Chemical Tests

Test	Sun mcc	Oven mcc	Microwave mcc
Presence of mcc	Positive	Positive	Positive
Presence of lignin	Negative	Negative	Negative
Presence of reducing sugar	Negative	Negative	Negative
Determination of pH	7.0	7.0	7.0
Melting point	260°C	260°C	260°C
Solubility in water	Insoluble	Insoluble	Insoluble

Table 2. Physicochemical Properties of Microcrystalline Cellulose Extracted from Sawdust.

Flow Parameters	Sun mcc	Oven mcc	Micro mcc
Angle of repose	25.08 ± 0.02	26.00 ± 0.02*	24.40 ± 0.03*
Flow rate	1.37 ± 0.01	1.40± 0.01	1.71 ± 0.01
Bulk density	0.33 ± 0.01	0.31 ± 0.01	0.34 ± 0.01
Tapped density	0.34 ± 0.06	0.32 ± 0.06	0.35 ± 0.06
Carr`s index	2.95 ± 0.04	3.13 ± 0.06	2.86 ± 0.02
Hausner`s ratio	1.03 ± 0.07	1.03 ± 0.04	1.03 ± 0.03
Particle density	1.79 ± 0.09	1.79 ± 0.09	1.81 ± 0.09
Moisture content	2.10 ± 0.05	2.21 ± 0.05	2.02 ± 0.05
Swelling Index	3.31 ± 0.04	3.30 ± 0.04	3.28 ± 0.04
Total Ash Content	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.00

*Standard deviation, n = 3

Table 3. Parameters Derived from Density Measurements, Heckel and Kawakita Plots

Microcrystalline cellulose	D_O	P_y	D_A	D_B	D_1	P_k
Sun dried	0.184	649.35	0.777	0.590	0.467	1.43
Oven dried	0.190	467.29	0.727	0.537	0.347	2.01
Microwave dried	0.166	373.13	0.765	0.599	0.577	1.25

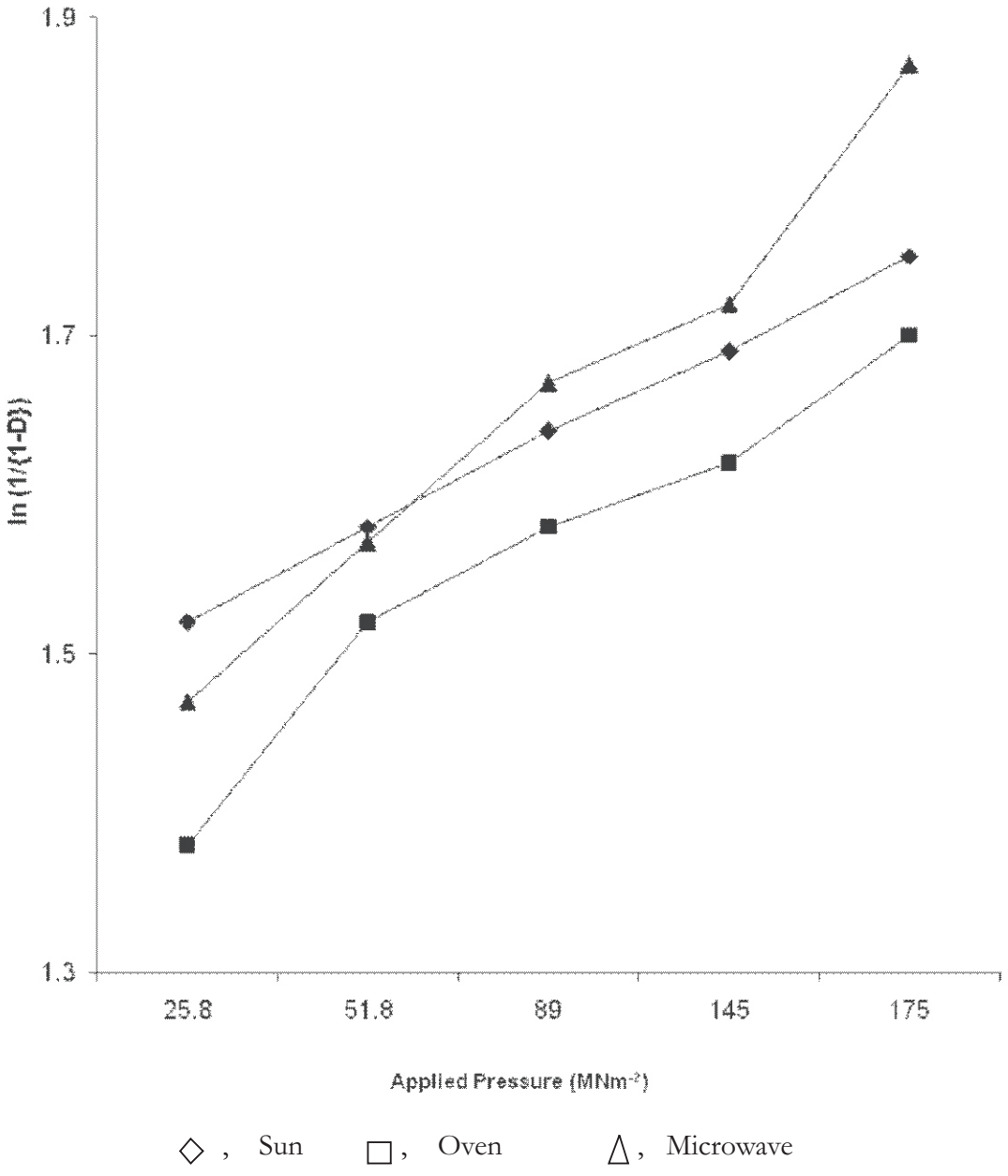

Figure 1. Heckel Plots of SDMCC Dried with Different Methods

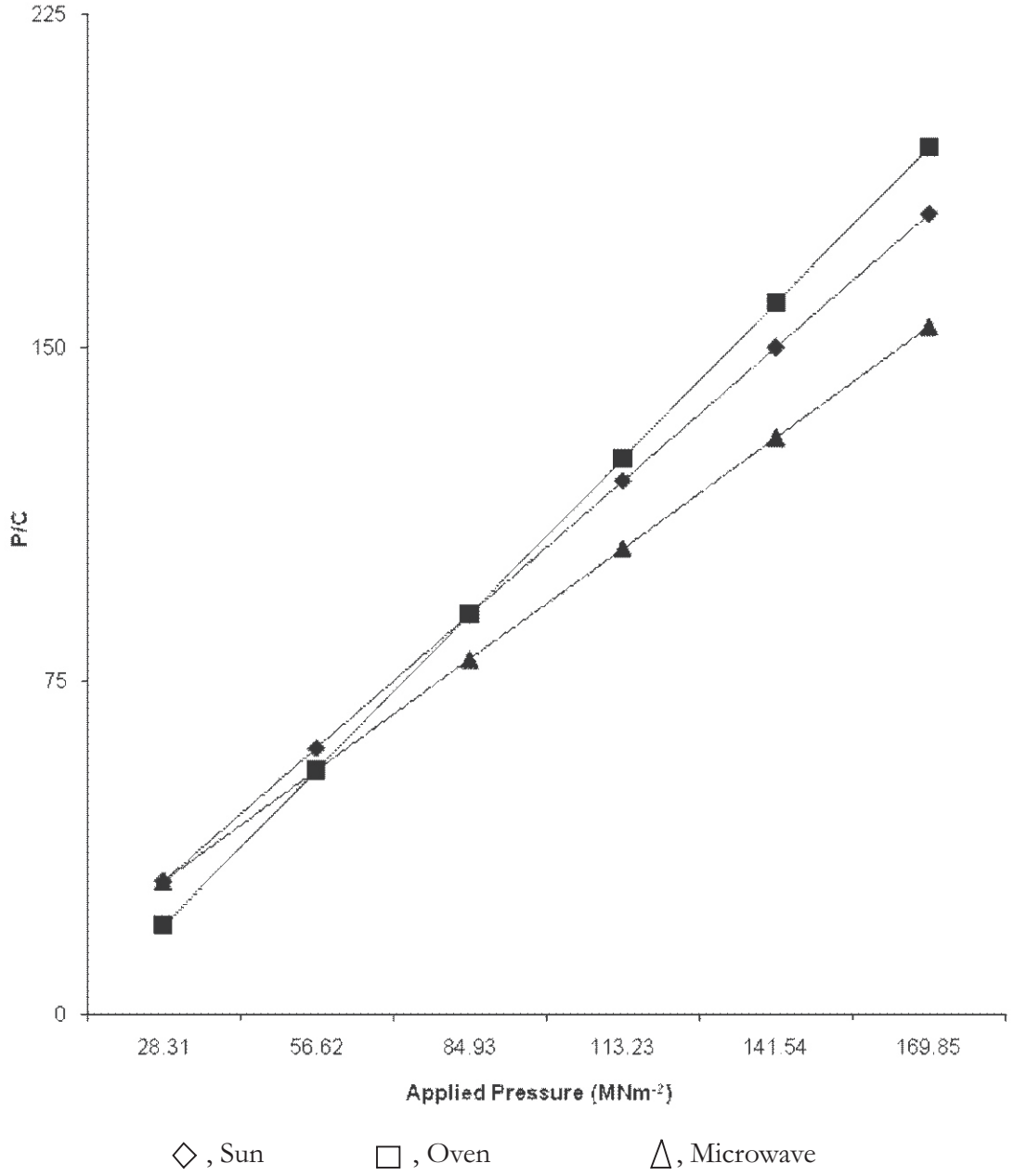

Figure II. Kawakita Plots of SDMCC Dried with Different Methods.

The results presented in Table I showed that the SDMCC extracted is totally free from impurities like sugar and lignin which most times are in close association with cellulose. The melting point obtained for all the batches i.e. 260 °C is in conformity with the BP 2004 specified range i.e. 260-270 °C. This sharp melting point obtained suggests the absence of impurities. The absence of impurities could be responsible for the pH value of 7.0 obtained and its insolubility in water, which are two important characteristics of pure microcrystalline cellulose (BP, 2004). The flow and compressibility properties shown in Table II indicate that the SDMCC extracted will be free flowing with no compressibility problem. This suggests that SDMCC may be used as a directly compressible excipient with good low properties particularly for active drug substances with flow and compressibility problem (e.g. paracetamol). Also, because of the good flow properties of SDMCC, it is suspected that when used in formulation the SDMCC it will assist in ensuring accurate and uniform tablet weight. It is observed that the SDMCC obtained from microwave drying method presented an enhanced flow property as shown in its angle of repose, Carr`s index and

Hausner's ratio.

The Heckel plots for the three celluloses are shown in Figure I. Values of mean yield pressure P_y were calculated from the region of the plots showing the highest correlation coefficient for linearity i.e. 0.922, 0.932 and 0.955 for sun dried, oven-dried, and microwave dried SDMCC respectively, (i.e. between 79 and 191 MNm^{-2}). The intercept, A, was determined from the extrapolation of the region used for the calculation of P_y. The values of D_a and D_b were calculated from equations 2 and 3, respectively. The values of P_y, D_a, D_o and D_b for all the celluloses are presented in Table 3.

The ranking of the value of D_o for SDMCC is microwave-dried < sun dried < oven dried, which implies that microwave dried SMDCC exhibited a higher degree of packing in the die as a result of die filling. The densification of the celluloses at low pressure was represented by D_b. The ranking of the values of D_b for SDMCC is microwave dried > sun-dried > oven dried. The mean yield pressure P_y is inversely related to the ability of the material to deform plastically. The ranking of P_y for SDMCC is microwave dried < oven dried < sun dried. The values suggest that the onset of plastic deformation in both microwave dried and oven dried occurred at lower pressures while that of sun dried occurred at higher pressure.

Figure II shows Kawakita plots for all the three batches of sawdust microcrystalline cellulose. A linear relationship was obtained at all compression pressures employed with correlation coefficient of 0.999 for the three batches of SDMCC. Values of a and ab were obtained from the slope and intercept of the plots, respectively. Values of (1-a) gave the initial relative density of the material, D_i while P_k values were obtained from the reciprocal values of b. The values of D_o, (the loose initial relative density) for all the three batches of SDMCC was lower for corresponding values of D_i. This may be due to wide range of particle size and hence more packing in the die due to rearrangement of the particle. Low values of P_k indicate materials that are soft and readily deform plastically under pressure. The ranking of the P_k for SDMCC was microwave-dried < sun-dried < oven-dried (Table III).

It has been shown that many official and proprietary powdered materials deform mainly by plastic flow (Rees and Rue, 1978; Paronen and Juslin, 1983). The difference in P_k and P_y values for each of the SMDCC could be due to the fact that P_y is the deformation at onset of compression while P_k is the deformation during compression.

CONCLUSION

This study had provided information on the effect that three drying methods could have on the flow and compressional properties of microcrystalline cellulose extracted from sawdust. The study also concluded that microwave drying technique would assist in producing microcrystalline cellulose with enhanced flow and compressional properties than those of sun and oven drying.

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