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Pretreatment of Rubber Tapping (*Heava brasiliensis*) and *Achi Mkpuru* (*Gossweilerodendron balsamiferum*) Hardwood Sawdust for Bio-Oil Production: Drying and Particle Size Characteristics at Different Temperatures

By

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Abstract

Drying and particle size characteristics of Rubber Tapping (Heava brasiliensis) and Achi Mkpuru (Gossweilerodendron balsamiferum) hardwood sawdust for bio-oil production were investigated. The samples were dried at temperatures of 80, 90 and 105^{O}*C. The drying curves were then modelled using nineteen different equations, eighteen of which were obtained from the literature. The Modified Henderson and Pabis model gave the best fit for the drying characteristics of the rubber tapping and Achi Mkpuru sawdust. The coefficient of determination, used to measure the goodness of fit, were in the range of 0.97039 to 0.99997 for the Rubber Tapping sawdust and 0.9764 to 0.99973 for the Achi Mkpuru data. The particle size analysis indicated that about 73% and 61% of dried Rubber Tapping and Achi Mkpuru sawdust respectively were less than or equal to 1mm. Hence further grinding of these samples may not be necessary when they are used for bio-oil production.*

Keywords: Sawdust, Drying, Particle Size, Bio-oil.

1. Introduction

The current over-dependence of the global population on fossil fuel as its primary source of energy as well as sustainability and emerging climatic challenges such as global warming, environmental degradation of fossil fuel has raised many questions concerning energy security. Consequently, eco-friendly, renewable and sustainable sources of energy are being aggressively explored in order to meet the global energy demand at minimum cost to the environment. Some of these alternative sources of energy include hydrogen, biofuel and synthesis gas with biofuel being the most eco-friendly. It should be noted that fossil fuels are carbon based energy sources such as coal and natural gas while bio fuels are made from plants such as wood sawdust and sugar cane. Biofuels can be obtained from bio oil. Bio oil is a dark-brownish organic liquid whose appearance is close to the conventional fossil crude oil. Bio oil can be produced from the fast pyrolysis of lignocellulosic biomass, such as wood sawdust[1]

Wood sawdust is readily available in Nigeria. Ohunakin[2] estimates that Nigeria's annual value of about 4.39 x 10^6 m^3 of log split and plywood processed, roughly translates to about 42 tonnes of sawdust generated from every 100 tonnes of timber, further resulting in an annual generation potential of about 1.8million tonnes. At the moment, such an enormous amount of the wood sawdust are often discarded, used for landfill, used as a bulking agent for compost manufacture,

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burnt as wastes or used for cooking[3,4,5,6]. Also, the indiscriminate disposal and incineration of sawdust constitute an environmental nuisance. The incineration of sawdust produces hazardous pollutant such as polychlorinated dibenzo-dioxins and dibenzo-furans which are injurious of the health of plants and animals[7,8].

We are not aware of any systematic study on the use of Nigerian sawdust for the production of bio oil. However from literature, before the wood sawdust can be processed into bio oil, it has to be subjected to a combination of drying and size reduction steps. The drying process is primarily aimed at expelling the inherent free moisture from the raw sawdust. Bridgwater and Peacock[9] posited that sawdust could contain an initial moisture content of about 30-60wt. %. The initial moisture content of the sawdust determines its behavior during the pyrolysis process and can have deleterious effects on the stability, corrosiveness, pH, fuel value of the bio oil produced[10,11].

The experimental data obtained from the drying process can equally be used in formulating an empirical model for predicting the drying behaviour of samples. Such models are often called “thin layer drying models”. These models provide an estimate of the drying times of the sawdust samples and their drying curves - which provide for an improved performance of drying system[12]. They can be formulated on theoretical, semi-empirical or empirical basis[13,14].

As stated earlier, another very important parameter to be considered in the utilization of the wood sawdust in the production of bio oil by fast pyrolysis is the particle size. Understanding the particle size distribution of wood sawdust prior to bio oil production will help to minimize the

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residence time of the pyrolytic reaction and problems arising from heat transfer[15]. The particles should be very small to allow for rapid heating and high yields of bio-oil[16]. Jahirul et al[17] puts this size at <1mm. The size of the wood sawdust depends mostly on the type of wood and the size of the saw teeth[18]. According to Himmel et al.[19] and Houghton et al[20], wood sawdust is directly associated with the size of the saw teeth/knife. Thus, increase in the size of knife/saw teeth will produce sawdust that has larger particle size. The utilization of such sawdust with larger particle size in bio oil production will require size reduction. Particle size has been shown to affect the yield of bio oil[21,22,23,24,25,26,27,28].

The aim of this work was to experimentally study and model the drying characteristics as well as determine the particle size distribution of Rubber Tapping (*Heava brasiliensis*) and *Achi Mkpuru* (*Gossweilerodendron balsamiferum*) sawdust obtained from Port Harcourt area in Nigeria at temperatures of 80°C, 90°C and 105°C.

2 Materials and Methods

2.1 Raw Materials:

Rubber Tapping and *Achi Mkpuru* sawdust samples were collected directly during the normal logging work at Aluu timber sawmill and Dagogo timber sawmill, Iloabuchi both within Port Harcourt, Rivers State, Nigeria. A Stanner and CD 6 band sawmill machines were used in the case of Rubber tapping and *Achi Mkpuru* logs respectively. The samples were bagged and

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immediately analysed at the PTDF Bio-oil Research Laboratory located at the Department of Chemical Engineering, University of Port Harcourt, Rivers State, Nigeria.

2.2 Drying Experiments

The equipment used in conducting the drying experiments consisted of a muffle furnace and an analytical balance (Radwag WLC 6/A2). The muffle furnace was switched on for 45minutes for the air and a cleaned stainless steel pan within the furnace to attain the chosen drying temperature (80, 90 or 105°C). The stainless pan was later withdrawn from the furnace and allowed to cool down to the ambient temperature, after which it was weighed with the analytical balance to the nearest 0.1g. 120g wet sawdust samples were evenly distributed on the pan and weighed to the nearest 0.1g. The sample was withdrawn from the furnace periodically (every 20min) and reweighed. At each interval, the change in the weight of the sample resulting from a gradual loss of moisture was recorded until there was no further change in the sample weight. The procedure was repeated three times; the average values were computed and used for analyses. The moisture content (on dry basis) was obtained using the equation:

$$M_t = \frac{W - W_d}{W_d} \qquad (1)$$

where M_t(g water/g dry solids) is moisture content at a time t, $W(g)$ is the total product weight at each time and $W_d(g)$ is weight of the dry solids.

The moisture content can be converted to a non dimensionless quantity referred to as moisture ratio (MR) by dividing M_t by the initial moisture content M_0(g water/g dry solids), that is:

$$MR = \frac{M_t}{M_0} \qquad (2)$$

An empirical drying model was formulated to fit the experimental data as follows:

$$MR = a_0 t^3 + at^2 + bt + c \qquad (3)$$

Eighteen other empirical and semi empirical drying models were also considered in the study. These models are:

Lewis[29]	$MR = \exp(-kt)$	(4)
Page[30]	$MR = \exp(-kt^n)$	(5)
Modified Page[31]	$MR = \exp[-(kt)^n]$	(6)
Henderson and Pabis[32]	$MR = a\exp(-kt)$	(7)

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Logarithmic[33]	$MR = a\exp(-kt) + c$	(8)
Two-term[34]	$MR = a\exp(-k_0 t) + b\exp(-k_1 t)$	(9)
Two-term exponential[35] (Approximation of diffusion)	$MR = a\exp(-kt) + (1-a)\exp(-kat)$	(10)
Wang & Singh[36]	$MR = 1 + at + bt^2$	(11)
Diffusion approach[37]	$MR = a\exp(-kt) + (1-a)\exp(-kbt)$	(12)
Verma et al.[38]	$MR = a\exp(-kt) + (1-a)\exp(-gt)$	(13)
Modified Henderson & Pabis[39]	$MR = a\exp(-kt) + b\exp(-gt) + c\exp(-ht)$	(14)
Midilli et al.[40]	$MR = a\exp(-kt^n) + bt$	(15)
Weibull distribution[41]	$MR = a - bexp[-(kt^n)]$	(16)
Aghbashlo et al[42]	$MR = exp(-k_1 t/1 + k_2 t)$	(17)
Logistic[43]	$MR = a_0/(1 + aexp(kt))$	(18)
Jena & Das[44]	$MR = a\ exp\left(-kt + b\sqrt{t}\right) + c$	(19)
Demir et al.[45]	$MR = a\exp(-kt)^n + c$	(20)
Alibas[46]	$MR = a\exp\left((-kt^n) + bt\right) + g$	(21)

In Eqns. 3 to 21, MR = moisture ratio; $a, a_0, b, c, n =$ coefficients; $k, k_0, k_1, k_2, g, h =$ drying constants; $t =$ drying time. Non-Linear regression analyses of these models [Eq (3)-Eq (21)] were made using Microsoft Office Excel 2007 Solver. The purpose of the non-linear regression analysis was to calculate the parameters; $k, k_0, k_1, k_2, a, a_0, b, c, g, h$ and n of the models.

The coefficient of determination (R^2) was used to select the best equation from Eqs (3) to (21) that provides the best fit to the experimental sawdust drying data at each temperature. (R^2) is given by:

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$$R^2 = 1 - \frac{\sum_{y=1}^{N}(MR_{pre,y} - MR_{exp,y})^2}{\sum_{y=1}^{N}(MR_{exp,y} - MR_{ave})^2} \qquad (22)$$

where; $MR_{exp,y}$ is the y^{th} experimental moisture ratio, $MR_{pre,y}$ is they^{th} predicted moisture ratio, $MR_{exp_{ave}}$ is average value of the experimental moisture ratio, N_{Total} is the total number of experimental data points, and C represents the various constants within each model.

2.3. Determination of Particle Size Distribution

The particle size distribution was determined using a digital sieve shaker and an analytical weighing balance. After each of the sieves had been cleaned and weighed, they were stacked above one another in order of increasing sieve particle sizes (0.300, 0.425, 0.500, 0.710 and 1.000) mm. 50g of the dried sawdust samples was carefully emptied into the top sieve and the lid placed on it. The stack of sieves was gently mounted on the digital sieve shaker and set for 10min at an amplitude of 0.9mm. After a 10min agitation the stack of sieves was gently carried off the shaker and carefully dissembled. Each sieve with its retained sawdust were weighed and recorded. The total sawdust retained was computed by adding the individual weights retained on each sieve.

3. Results and Discussion

The parameters for the nineteen empirical and semi-empirical drying models (Eqns 3 - 21) for the experimental drying characteristics of the two sawdust samples were calculated using MS Excel Solver. For the Rubber Tapping sawdust, the R^2 ranged from 0.97039 to 0.99997 while that for the *Achi Mkpuru* ranged from 0.9764 to 0.99973. The specific values for each model can be found in Okorie[47]. For both saw dusts, the modified Henderson and Pabis (Eqn 14) gave the highest value of R^2 at each drying temperature. The parameters for Eqn 14 are summarized in Tables 1 and 2 for Rubber Tapping and *Achi Mkpuru* saw dusts respectively.

Table 1 Modified Henderson and Pabis model parameters for Rubber Tapping Sawdust

Temp, ^{O}C	a	b	c	g	h	k	R^2
80	0.485964	0.65127	-0.137273	0.034056	0.799911	0.010640	0.99961
90	2.237306	-1.27593	0.038627	0.036043	1.009900	0.027925	0.99959
105	0.768766	8.55477	-0.188213	0.203605	1.000000	0.034879	0.99997

Table 2 Modified Henderson and Pabis model parameters for *Achi Mkpuru* Sawdust

Temp, ^{O}C	a	b	c	g	h	k	R^2
80	3.541554	-2.522919	-0.018620	0.008274	1.300000	0.009427	0.99938
90	4.605721	-3.535219	-0.070301	0.011244	1.011904	0.012407	0.99929
105	1.256541	-0.068221	-0.188213	0.006378	1.000000	0.025340	0.99973

The experimental moisture ratio values are shown in Figs 1 and 2 as symbols respectively for Rubber Tapping and *Achi Mkpuru* saw dusts at the different temperatures. The solid lines shown in these figures are the corresponding values calculated using Eqn 14. Figs 1 and 2 clearly confirm that the modified Henderson and Pabis model is a good fit for the experimental and validate the high values of R^2 shown in Tables 1 and 2.

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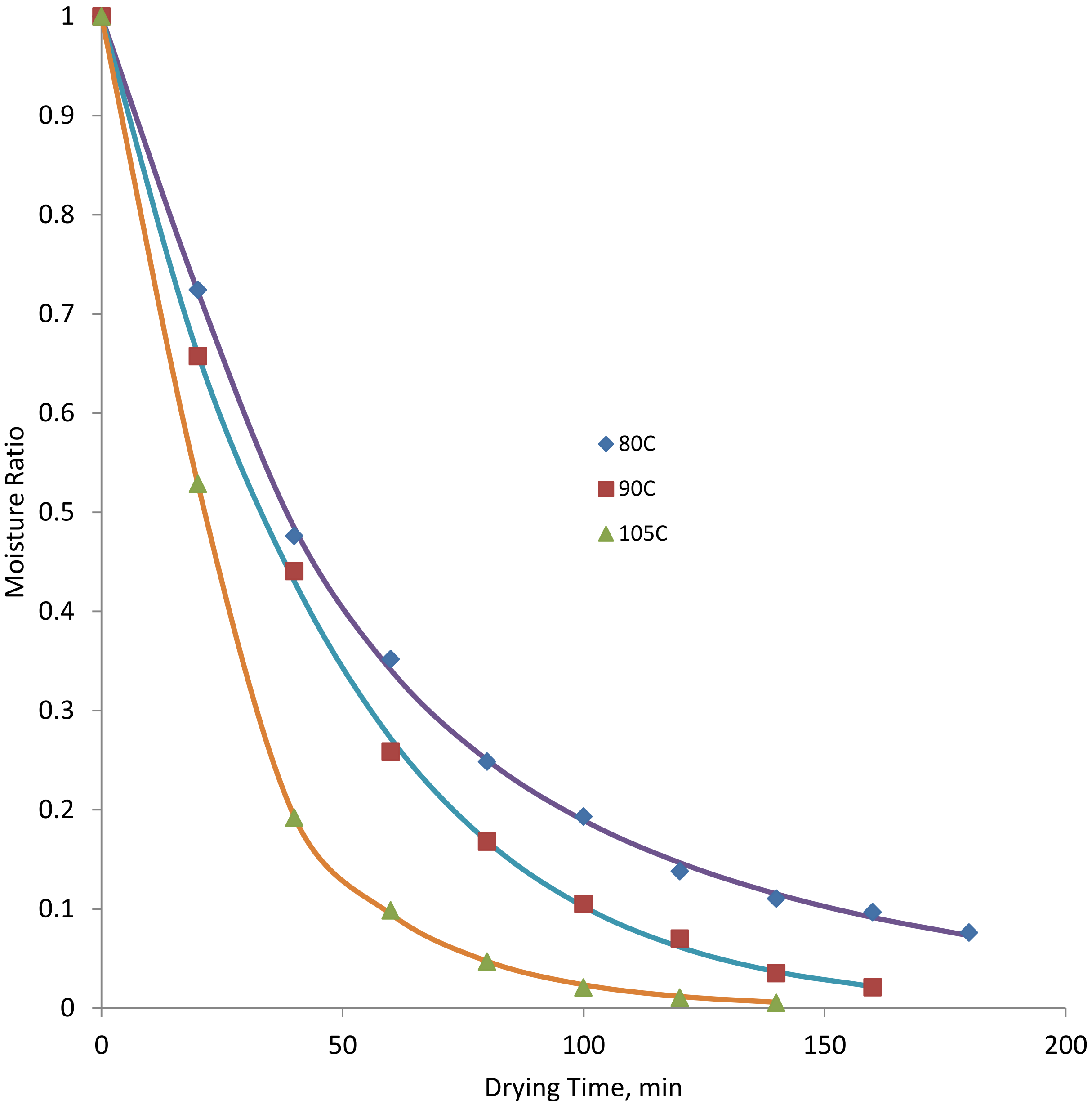

Fig 1: Moisture Ratio Curve of Rubber Tapping Sawdust at different drying temperatures.

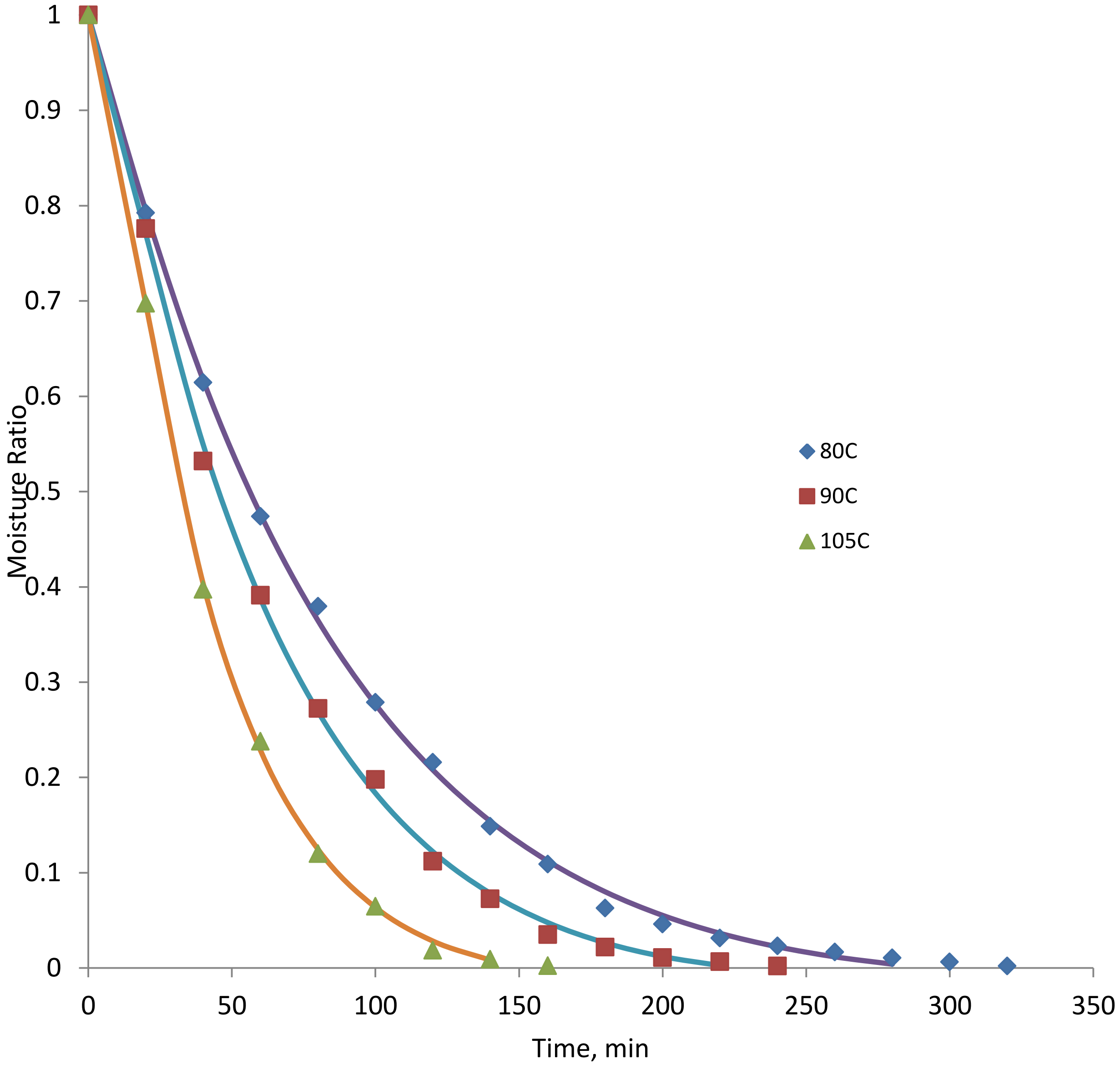

Fig 2: Moisture Ratio Curve of *Achi Mkpuru Sawdust* at different drying temperatures

3.1 Particle Size Distribution

Particle size distribution of Rubber Tapping and *Achi Mkpuru* sawdusts at different temperatures are shown in Figs 3 and 4. These figures indicate that drying temperatures had minimal effect on the particle size distribution for both samples. Furthermore, it can be deduced that about 73% and 61% of Rubber Tapping and *Achi Mkpuru* respectively passed through the sieve diameter of 1mm at all three drying temperatures. Thus, about 27% of Rubber Tapping and 39% of *Achi Mkpuru* are greater than 1mm in size. The implication of these results is that Rubber tapping and *Achi Mkpuru* sawdust would only require drying when they would be used for bio oil production;

grinding may not be necessary. As noted earlier, the use of small sawdust particle sizes (<1mm) as feedstock for bio-oil production through fast pyrolysis is necessary for higher bio-oil yields[48].

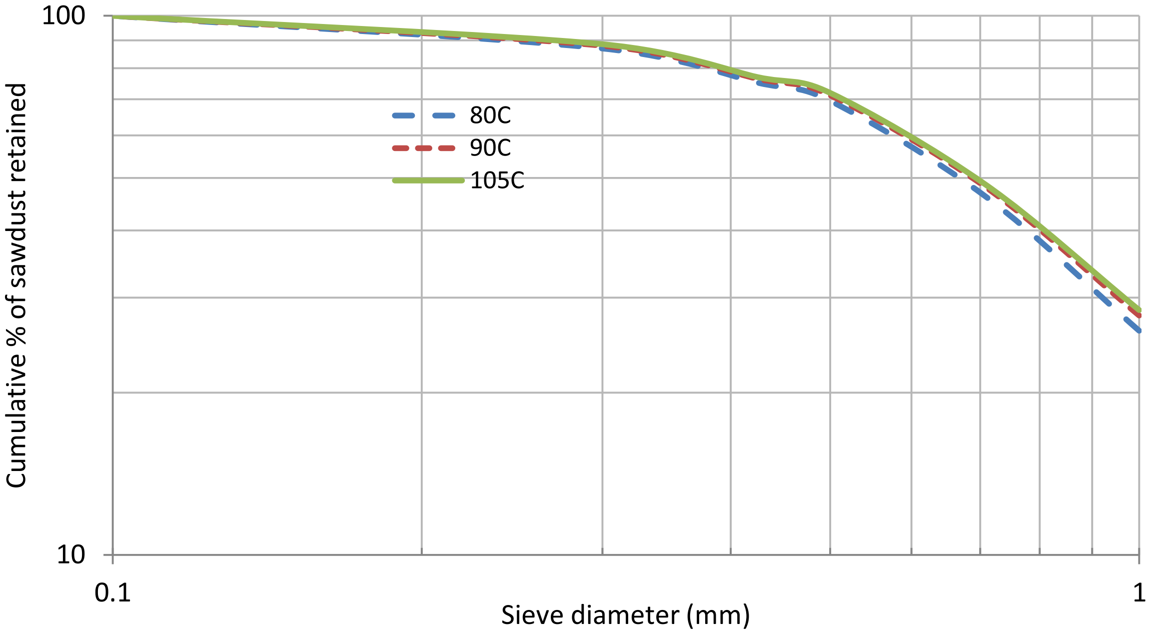

Fig 3 Particle–Size Distribution Curve of Rubber Tapping sawdust at different temperatures

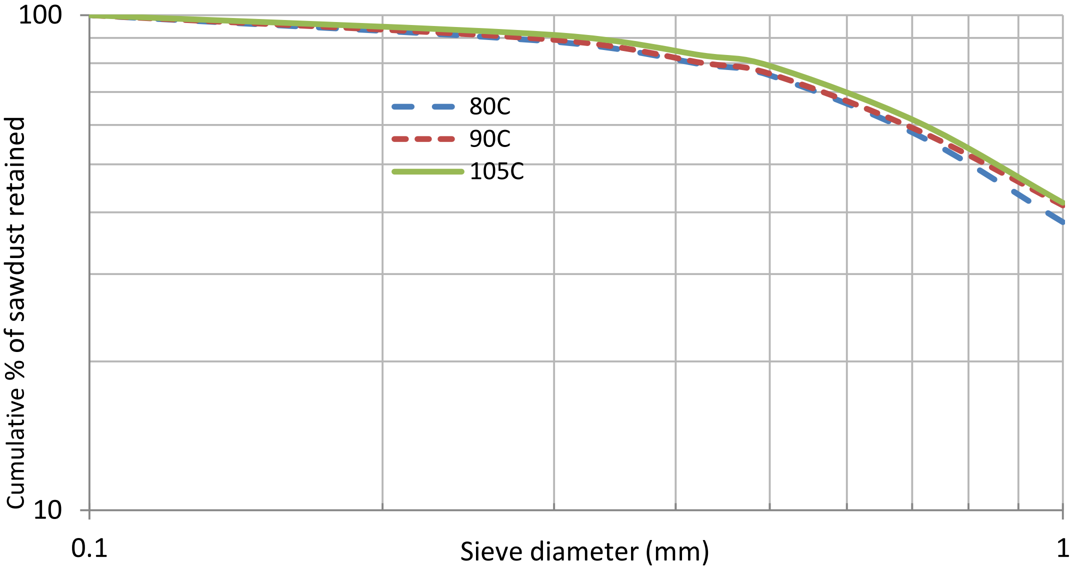

Fig 4 Particle–Size Distribution Curve of *Achi Mkpuru* sawdust at different temperatures

4. Conclusion

The results obtained from this work indicate that the modified Henderson and Pabis model fits the experimental drying data for Rubber Tapping and *Achi Mkpuru* very well. The coefficient of determinations for any of the drying temperatures is greater that 0.999. The sieve analysis of the

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[48] Jahirul et al, 2012

samples also indicate that more that 60% of the particles have diameters less than or equal to 1mm thus showing that there may not be any need for grinding when they are used for bio-oil production.

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