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Conversion Efficiency in Re-Saw Wood Processing Mills of Akwa Ibom State, Nigeria

[1]OMOLE A.O and [2]B.M. IMOH
[1]Department of Forest Resources Management, University of Ibadan
[2]Department of Forestry and Wildlife, University of Uyo

Abstract
This study assesses the technical conversion efficiency (TCE) of thirty (30) wood re-saw mills purposively selected and grouped into six (6) locations in Akwa Ibom State. Three hundred (300) flitches obtained from fifteen (15) species of wood from Akwa Ibom State, Nigeria were examined. Variables such as wood species, flitch dimensions, saw blade thickness, sawyers' experiences and working environment factors were examined for efficiency determination. Information on operation and working environment were examined using ergonomics checklist. Data were generated using standard units of measurement, checklist and formulae. Data generated were subjected to statistical analyses using descriptive and multiple regression models. The study revealed that plank recovery ranged from 58.86% to 76.92% on individual flitch basis, percentage waste ranged from 23.08% to 28.26% and a mean plank recovery and percentages waste of 71.76% and 28.02% respectively for all sampled flitches. Variations in flitches dimension classes had significant influence on percentage wood recovery, saw dust, plank, at ($P < 0.05$). Significant correlation also exists between flitch dimension class and plank recovery. Noticeable variation in percentage wood recovery was observed among the various wood species. *Ceiba pentandra* had the highest mean plank recovery of 76.31% while *Mammea africana* had the least (58.31%). For reasonable reduction of wood waste generated in re-saw mills, greater use of flitches with higher thickness, routine maintenance of machines especially saw blade, experience sawyers are necessary.

Introduction

Although re-sawmilling was not as popular as sawmilling in the past but today it has become an established practice especially in Akwa Ibom State and environs. These modes of wood processing have been described by Kirbach (1974) as a system and an industry while Robichaud (1975) defined it as a process. As a process it involves converting flitches into planks of different sizes using different sawing machines like band saw and table saw (Patterson, 1984). A number of factors have been identified in saw-milling, few in re-sawmilling as the factors influencing product recovery. According to Wade *et al* (1992), factor influencing plank recovery include: flitches shape, flitches size, kind of re-sawing machine used, machine maintenance culture, experience of the operators and willingness of the operators to adopt innovations. Flitches straightness equally improves both yield and quality of plank produced (Salje and Meyer, 1975). Plank Recovery Factor (PRF) of re-sawmill to Flitches Recovery Factor (LRF) of sawmill according to Wade *et al* (1992) is the measure of the conversion efficiency of sawmills and is calculated as the nominal board feet (BF) of flitches recovered per cubic foot volume of log input to a sawmill. PRF is a measure of the conversion efficiency of re-sawmills. PRF is calculated as the nominal board feet (BF) of planks recovered per cubic foot volume of flitches input into a re-sawmill.

Recent observation shows that in Akwa Ibom State of Nigeria, there is no functional sawmill that can process round logs into lumber but instead we have re-sawmills. Primary conversion of wood occurs in the forest (in-situ) and only flitches are brought into the re-saw mills for further processing into smaller required dimensions. Investigation reveals that for over 20 years, the forestry directorate in Akwa Ibom State has been issuing forestry permits to timber merchants and also placing low tariff rate on harvesting, conversion and transportation of converted logs (flitches) to re-sawmills for further milling into planks of different sizes. Logs are converted to flitches by timber merchants using power chain saws at the stump sites. According to Udo (1998), this method of sawmilling was officially accepted to supplement production which unfortunately, was characterized by frequent mill closures in Akwa Ibom State and Cross River State before now. Lack of functional sawmill processing round logs has led to increased recognition of flitching and re-saw milling as a viable primary wood processing industries in the state. The method of re-sawing in Akwa Ibom State is economically convenient because unlike conventional saw milling, it does not require a lot of capital investment, labour,

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training and transportation of the logs to the factory. According to Udo, (1998), in Akwa Ibom State, primary conversion of wood is done at stump sites and for each power chain saw used, only the operator, an assistant and one or two men for conveying the pieces of sawn wood (Timber) to the (landings) loading points by the roadside are required. Secondary conversion is done at the re-sawmills situated in and around the timber markets of the state. Despite these favourable attributes of convenience, it is expedient to assess technically, the conversion efficiency of these re-sawmills in Akwa Ibom State.

Various studies on wood conversion efficiencies in the saw mills have been carried out and reported both within and outside Nigeria. Sanwo (1982) estimated recoveries of individual sawmills at between 40 and 42% while an average conversion factor of 47% was reported by FAO (1979) and FRIN (1984) for medium-sized sawmills in Nigeria. Although Heidkborn (1983) estimated a recovery factor in the range of 25 to 40% for sawmills in developing countries, and 60 to 70% for European mills which usually processed smaller dimension logs, recovery rates of 57.10% to 60.30% had been reported in Peninsular Malaysia (Lee, 1976), 52.40% in softwood sawmills in USSR (Kouchevckaya. 1980) and only 30-40% in Australian (Anon, 1971). Egbewole *et al* (2011) put 53.41%, 58.79% and 41.94% as the average technical performance efficiency for the small scale sawmill, medium and the large scale sawmills in Southern Nigeria respectively. The average flitch recoveries were 53.69%, 56.48% and 51.77% for large-sized dimension log, medium and small-sized dimension log.

However for in situ flitching, Adeleye (2007) recorded flitches Recovery Factor (LRF) ranging from 23.53% to 67.05% on individual log basis and a mean flitch recovery of 47% for all the sampled logs and waste partitioning of 28.54%, 2.22% and 20.02% for slabs proportion, sawdust and bark respectively. Findings show that very limited work has been done in the area of conversion efficiency in re-saw mills where these flitches are further processed into lumbers of smaller dimensions. This study was therefore initiated to assess technically the conversion efficiency in re-saw wood processing mill in the study area, with a view to determining the factors for improvement in technology for efficient conversion of flitches.

Materials and Methods

Description of the Study Area.

This study was carried out in Akwa Ibom State of Nigeria. The state has a total landmass of 8,412 km^2 (AKS, 1989; Akpan-Ebe and Amankop, 2001), It is situated between latitudes 4° 32' and 5°53' North and longitudes 7° 30' and 8° 25' East, and shares boundaries with Cross River, Rivers and Abia States. The state has a population of about 3.92 million people (FRN, 2007). Moving hinterlands from the coastline, four easily discernable ecological zones are recognized. These are; the mangrove swamp, the fresh water swamps, the lowland rain forest and the derived savanna which form mosaic with oil palm trees and farmlands (Akpan-Ebe and Amankop, 2001). Akwa Ibom State has four legally constituted forest reserves (FRS) totaling 318.5 km^2 (Etukudo *et al.* 1994). These include Stubbs Creek Forest Reserve in Ibeno/Esit Eket/Mbo Local Government Areas, Ogu Itu and Obot Ndom Forest Reserve both in Ini Local Government Area and Uwet Odot forest reserve in Itu Local Government Area. Both within and outside the Forest Reserve are various species of tropical tree like *Lophira alata* (Ironwood), *Albizia spp, Afzelia africana, Milicia excelsa, Nauclea diderichii, Terminalia spp Mitragyna ciliata, Symphonia globulifera, Oxysysteigma manii, Alstonia congensis, Staudtia stipitata, ceiba pentandra, Gmelina arborea,Triplochiton scleroxylon, Uapaca guinnensis, Mammea africana,* and many others. Akwa Ibom State is characterized by two seasons, namely the rainy reason which lasts from mid-March to October, (about 8months) and the dry season which lasts from November to February (four months). Rainfall is heavy, ranging from over 3,000 mm along the coast to 2,000 mm on the northern fringes of the state. Temperatures are uniformly high throughout the year with slight variation between 26°C and 28°C. High relative humidity between 75% and 95% are common across the length and breadth of the state (AKS, 1989).

Experimental Procedures

Six (6) Local Government Areas, Uyo, Abak, Ikot Ekpene, Itu, Oron, Eket were purposively selected from the thirty one (31) Local Government Areas in the State for this

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study. A re-saw wood processing mill was selected from each of the six local government areas. Three hundred flitches of wood from different wood species sample were selected with the selection process based on the following criteria: (i) flitches devoid of crookedness (clear and straight flitches) (ii) flitches from the most frequently used wood species and (iii) flitches devoid of excessive knots.

For all the 300 sampled flitches, the dimensions of each flitch were taken and the volume calculated and recorded before re-sawing. The procedures were repeated for all the 300 flitches sampled. Ergonomics checklist for work place was also used to collect information from operators and other workers in respective re-sawmills. Data collected daily from the re-sawmills were analysed separately and later pooled together for statistical processing. Correlation coefficient (r) was used to investigate the degree of association and the relationship between the measured variables. Multiple linear regressions were used as analytical tool to determine the effect of the factors like kerf thickness. The coefficient of determination (R^2) and standard error (SE) was also used to estimate mean square error (MSE) to determine the proportion of variation explained by the regression equation.

Data Analysis

The data collected daily from each re-saw mills were analyzed separately and later pooled together.

Total volume of the various dimension flitches obtained from the forest were determined using the model below:

$$V_2 = L \times B \times H \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation } 1$$

Where:

V_2 = *volume of sawn flitches* (m^3)
L = *Length (m)*
B = *Breath (m)*
H = *Thickness (m)*
n = *total number of flitches obtained*

The total volume of wood waste generated per day from the conversion of flitches (flitches) to plank was estimated using:

$$V_w = V_1 - V_2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation } 2$$

Where:

Vw = *volume of wood waste* (m^3)
V_1 = *Volume of flitches before conversion* (m^3)
V_2 = *volume of planks obtained after conversion* (m^3)

The efficiency of the re-sawmill (Flitches recovery factor (LRF) were calculated using the formula:

$$E\,mill = \frac{V2}{V1} \times \frac{100}{1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation } 3$$

Where:

E mill = Re-sawmill efficiency (%)
V_2 = Volume of planks obtain after conversion (m^3)
V_1 = Volume of flitches before conversion (m^3)

The multiple Linear Regression equation used for the data processing is as stated in the equation 4

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 \ldots\ldots\ldots\ldots\ldots \text{Equation } 4$$

where:

Y = *Plank recovery*
x_1 = *Kerf thickness*
x_2 = *Flitches dimension*
x_3 = *Density*
x_4 = *Flitches dimension ratio*
$a, b_1 \ldots b_4$ = *Regression coefficients (k)*

Effective duration of flitches conversion and the down time were taken in selected re-sawmills using stop watch thus:

Time taken in converting each of the flitches = effective working time (x hrs)

Down time = idle working time (y hrs)

Determinations of time, human and material efficiency as they affect plank recovery in selected mills were carried out as described by Jamieson, (1977). Time efficiency is an important component of the overall efficiency of a mill. Other components that were also considered include: efficiency of labour, managerial and conversion efficiency of machines. The effective duration of operation was estimated thus:

$$\frac{\text{Actual time of operation}}{\text{Expected time of operation}} \times \frac{100}{1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation } 5$$

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The time efficiency was determined by measuring the total sawing time (T_t), known as effective sawing period (T_e) and the down time, known as the idle time (T_i) for each of the flitches converted in line with the models developed by Fuwape (1985). Data collected daily from the re-sawmills were analyzed separately and later pooled together. Correlation coefficient (r) was used to investigate the degree of association and the direction of relationship between the measured variables, while multiple linear Regression analysis was used as analytical tool to determine the effect of the factors like kerf thickness. The coefficient of determination (R^2) and standard error (SE) was used to estimate mean square error (MSE) to determine the proportion of variation explained by the regression equation.

Results and Discussions

Table 1 shows the results of the species commonly converted in the study area and their local names while the average recovery rate per wood species is as presented in Table 2. From Table 1, it was discovered that fifteen wood species were the regularly converted wood in all the re-sawmill during the duration of the study. All the species are indigenous to the state except *Gmelina arborea* and *Pinus caribaea* that are exotic. As shown in Table 2, out of the 300 flitches sampled for the study, *Gmelina arborea* recorded the highest frequency of 52 representing about 17% while *Mammea africana* recorded the least frequency of 8 which represents only about 3%. Also from Table 2, the total volume of the 300 flitches used was 41.88 m^3 while the mean plank recovery per flitch for all the flitches and species was 3.28 per flitch.

Table 1: Tree Species Commonly Sawn in Akwa Ibom State Re-Saw Mills

SN	Species scientific name	Trade name/common name/local name
1	*Ceiba pentandra*	Coffin wood, silk-cotton tree, Ukim
2	*Gmelina arborea*	Melina
3	*Pterocarpus osun*	Camwood, Ukpa
4	*Milicia excels*	Iroko
5	*Triplochiton scleroxylon*	Obeche, Arere
6	*Mammea Africana*	African mammy apple
7	*Lophira alata*	Iron wood
8	*Mitragyna ciliate*	African linden, owen
9	*Uapaca guineensis*	Sugar palm
10	*Khaya spp*	Mahoganies
11	*Lovoa trichiloides*	African walnut
12	*Pinus caribaea*	Pine
13	*Terminalia superb*	Afara
14	*P. Africana*	
15	*Oxystigma mannii*	Oxystigma

Table 2: Average Wood Recovery per Tree Species

SN	Species Name	NF	VFU(m^3)	NPP	VPP(m^3)	VW(m^3)	APR
1	*Ceiba pentandra*	33	5.06	136	3.77	1.29	4.12
2	*Gmelina arborea*	52	7.36	194	5.31	2.05	3.73
3	*Pterocarpus osun*	25	3.60	99	2.72	0.87	3.96
4	*Milicia excels*	12	1.84	48	1.32	0.52	4.00
5	*Triplochiton scleroxylon*	25	3.52	94	2.57	0.96	3.76
6	*Mammea Africana*	8	0.96	24	0.64	0.32	3.00
7	*Lophira alata*	21	2.76	73	1.98	0.76	3.48
8	*Mitragyna ciliate*	17	2.22	60	1.63	0.54	3.53
9	*Uapaca guineensis*	15	1.97	52	1.41	0.54	3.47
10	*Khaya spp*	16	2.11	59	1.61	0.49	3.69
11	*Lovoa trichiloides*	20	2.43	63	1.70	0.65	3.15
12	*Pinus caribaea*	19	2.40	62	1.73	0.72	3.26
13	*Terminalia superb*	11	1.50	40	1.09	0.41	3.64
14	*P. Africana*	10	1.43	40	1.10	0.33	4.00
15	*Oxystigma mannii*	18	2.72	59	1.59	0.72	3.28
N		300	41.88	1103	30.15	11.17	

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Note: NF-number of flitches used , VFU-volume of flitches used, NPP- number of planks produced, VPP-volume of planks produced, VW-volume of waste generated, APR-average plank recovery

Plank recovery per flitch volume group as presented on Table 3 shows that flitch volume group of 0.15m^3 recorded the highest frequency and total plank recovery of 77 and 308 respectively. The least frequency and total plank recovery of 15 and 45 were recorded for flitch volume group of 0.11m^3. The percentage rate of recovery however ranged from 33 to 60% for all the FVG. In terms of density classification and recovery as presented in Table 4 it was discovered that plank recovery is affected by density of the wood being converted. Low density wood had the highest plank recovery factor of 74% while the least PLF of 58.46% was recorded for high density wood.

Table 3: Plank Recovery by Flitch Volume Class

FVG(m^3)	NF	TPR	ARG	RR (%)
0.16	40	138	3.45	55.2
0.15	77	308	4.00	60.0
0.14	63	252	4.00	56.0
0.13	45	180	4.00	52.0
0.12	60	180	3.00	36.0
0.11	15	45	3.00	33.0
N	300	1103	3.58	48.7

Note: *FVG = flitch volume group, NF = number of flitches, TPR = total plank recovery, ARG = average plank recovery for group, RR (%) percentage rate of recovery*

Table 4: Wood Density Classification and Wood Recovery

SN	Density Classes	Tree Species	Spp. Density (kg/m^3)	TPR	APR (%)	PLF(%)
1	High Density Wood (HDW)	*Lophira alata*	870	3.48	0.58	58.46%
		Mammea africana	850	3.00		
2	Medium Density Wood (MDW)	*Mitragyna ciliate*	580	3.53	0.66	66.67%
		Militia excels	660	4.00		
		Terminalia superba	560	3.64		
		P. Africana	635	4.00		
		Oxystigma mannii	530	3.28		
		Uapaca guineensis	600	3.47		
		Khaya spp	530	3.69		
3	Low Density Wood (LDW)	*Gmelina arborea*	480	3.73	0.74	74%
		Ceiba pentandra	350	4.12		
		T. scleroxylon	320	3.76		
		Pinus caribaea	480	3.26		
		Pterocarpus osun	460	3.96		
		Lovoa trichiloides	450	3.15		

Species densities were obtained from TRADA (1979). Timbers of the World

The results of the regression analysis performed to model the relationship between the significant dependent variable (plank recovery) and the independent variables are as listed in table 5. Plank recovery was positively and linearly correlated with flitch dimension, species density and saw kerf thickness. The multiple regression equations which relate plank recovery to the independent variables applied in this study with their corresponding coefficient of multiple determination (R) values are as in table 5 below:

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Table 5: Multiple Linear regression equation of dependent and independent variables

Y	a	b1	b2	R^2	R	SE
PR	0.89 (0.104)	-0.003 (0.0002)	-0.088 (0.021)	0.240	0.490	0.1002

$Y = a + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_4 x_4 + e$

The summary of the regression models are as shown in Table 6 while the stepwise regression equations are presented in Table 7. From Table 6 below the regression equations showing the relationship between plank recovery, flitch dimension (length, breadth, thickness) kerf thickness, flitch volume and species density revealed that the relationship was significant. The implication of this is that to a large extent, plank recovery depends majorly on flitch dimensions, species density and kerf thickness.

Table 6. Summary of the regression models on factors affecting Plank Recovery

	b_o	b_1	b_2	b_3	b_4	b_5	R^2	SE
Remark	**	**	***	***	***	**	0.57	0.08
	-0.92	1.69	0.17	0.62	0.00008	0.59		
Coefficient	-2.21	7.57	-0.096	-2.46	-0.00016	1.18		

** Significant at 5% *** Significant at 1%

Table 7: Stepwise regression of the relationship between recovery and independent variables

No	Equation	S	R^2	R
i	$Y= 0.44 + 84x_1$	0.99	0.24	0.29
ii	$Y = 0.496 + 0.866x_1 - 0.102x_2$	0.086	0.44	0.66
iii	$Y = 0.489 + 4.68x_1 - 0.97x_2 - 1.38x_3$	0.08	0.52	0.72
iv	$Y = 0.47 + 4.91x_1 - 0.087x_2 - 1.48x_3 - 0.0002x_1$	0.078	0.55	0.74
v	$Y = -2.21 + 7.57x_1 - 0.96x_2 - 2.46x_3 - 0.0002x_4 + 1.18x_5$	0.77	0.57	0.75

$Y = a + b_1x_1 + E$

The correlation matrix presented on Table 8 for the independent variables equally showed a significant relationship. From the various correlation matrices for the independent variables in the entire study site, plank recovery is positively correlated with the independent variables. This is expected because the efficiency of conversion of a flitch from a low density wood should be higher than flitch from a high density wood. The major factor responsible for this expected variation is the energy requirement during conversion.

Table 8: Result of correlation analysis between plank recovery and the studied variables

Variables	Plank Recovery	Flitch Recovery	Flitch Breath	Flitch Thickness	Density	Saw Kerf Thickness
Plank recovery	1.00	0.49*	0.45*	0.12	0.32*	0.43
Flitch length	0.49*	1.00	0.98*	0.14	0.16	0.03
Flitch breath	0.45*	0.98*	1.00	0.32*	0.18	0.07
Flitch thickness	0.12	0.14	0.32*	1.00	0.16	0.19
Density	0.32*	0.16	0.18	0.16	1.00	0.23*
Saw kerf thickness	0.43*	0.03	0.07	0.19	0.23*	1.00

* Significant at 5% level of probability

Discussion

A total of 300 flitches of timber of varying sizes source from 15 wood species were sampled in this study with Gmelina recording the highest frequency of 52 flitches while *Mammea africana* recorded the least of eight (8) as shown in table 2. Also observed in this study is that plank recovery factor ranges from 58.46% to 76.92% within the 30 selected re-sawmills of the State. In term of time efficiency, the percentage effective

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working time for flitch conversion operations (% EWT) ranged between 48.74 – 80%. The result of the percentage idle working time (% IWT) was however low with a range between 20-51.26%. (Table 9).

Although limited literature are available on conversion efficiency in a re-sawmilling, the observed conversion factor reported in this study is higher compared to the results of Egbewole *et al* (2011) in a similar study on conversion of round logs who reported that average recovery rates in small, medium and large sawmill in south western Nigeria were 53.69%, 56.48% and 51.55% respectively. Onchieku (2001), reported that recovery rates ranged from 27% for unskilled power-saw operators to nearly 60% for skilled bench saw operators. However, the result of correlation analysis between plank recovery, flitch dimension species density and saw kerf thickness indicate that there was significant difference (at $P<0.05$) in the technical performance efficiency of time, machine, and operators. The result is in conformity with Fuwape (1985) who got a result of idle working time ranging between 12.79-76.43%, effective working time ranging between 23.6-87.21% and mean lumber recovery of 56% in his evaluation of log conversion efficiency of 18 sawmills in Ondo State. It was also observed from the study that there existed positive relationship between flitch dimension and plank recovery. This implies that higher dimension flitches and low density wood give higher plank recovery.

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