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RESEARCH ARTICLE

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SEQUENTIAL PEROXIDE-OXIDATION AND ADSORPTION TREATMENT OF CASSAVA PROCESSING WASTEWATER: PROSPECTS AND LIMITATIONS IN AUGMENTATION OF WATER BUDGETING PRACTICES

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ABSTRACT

Cassava processing is an industry common to most West African countries as well as in other tropical countries of the world. The processing of cassava is known for its high consumption of water resources. This study therefore investigates the potential for cassava processing water conservation using combined peroxide-oxidation and adsorption recycling processing technology. A Sequential Peroxide-Oxidation and Adsorption treatment process was established by producing cassava peel carbon and activated carbon from waste cassava peels. This was used in the adsorption of pollutant parameters in oxidized cassava processing wastewater. The study further went on to estimate the volume of water that could be conserved in Nigeria through the employment of the Sequential Peroxide-Oxidation and Adsorption treatment process with the aid of a 3-scenario water-based estimation techniques. The research revealed that the estimated volume of water employed in processing cassava through fermentation process is about 1,525 l/ton while that for non-fermentation process is about 960 l/ton. However, an estimated 104,951.36, 100,195.20 and 95,639.04 million litres of water could be conserved considering each of the three cassava process combination scenarios. The study concluded that if cassava industry could make use of the combined peroxide-oxidation and adsorption recycling processing technology described as in the experimental procedure, substantial volume of water resources could be conserved and recycled for other uses such as irrigation, as well as groundwater recharge thereby improving water budget.

Keywords: *activated carbon, Cassava processing, oxidation, wastewater, water budget*

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INTRODUCTION

Water is very essential for survival and balance of ecosystem on planet earth. The earth's surface is covered by 70% of water which has its major constituent (97.5%) as water from oceans and seas that are usually regarded as being too salty for consumption and agricultural purposes. It has also been observed (Czarra, 2003) that of the remaining 2.5% of water, 68.7% exists as glaciers and ice-caps, 30.1% is ground water, 0.43% is permafrost thus leaving about just 0.77% fresh water for consumption and agricultural use (Figure 1). Water is also a vital resource on which human activities depend upon in areas such as agriculture, industry, transportation, domestic uses etc. (Awomeso, 2010).

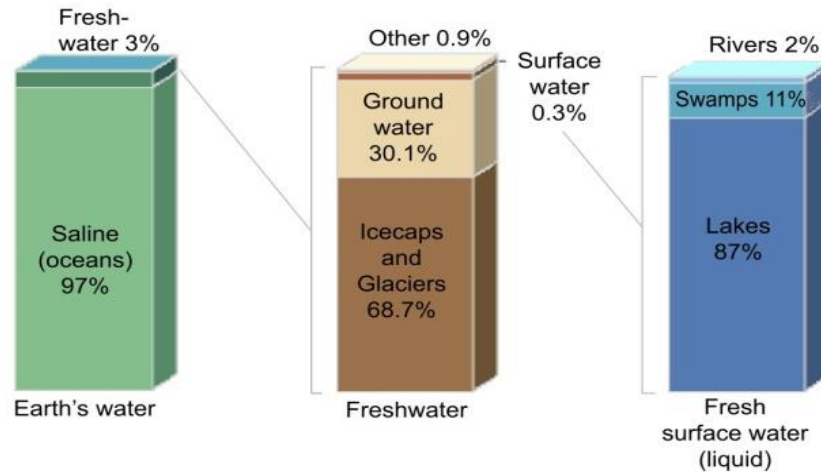


Figure 1: Distribution of Earth's Water

Source: McMichael (2014)

However, water represents the most abused, poorly managed and polluted resource by human activities (Fakayode, 2005). It has been observed that fresh/clean water demand and supply is one major problem of concern in most parts of the world especially in Africa (Ahiablame *et al.* 2011; Behr, 2008). Research showed that even though Africa has 5 trillion m³ of fresh water resources available annually, only 3.8% of this supply has been developed, leaving 300 million African people without access to safe drinking water (Ford, 2008). This situation has been noted to be endemic in most parts of sub-Saharan Africa particularly, Sudan, Chad, Niger and Nigeria where majority of their populations are resident in the rural areas and are dependent on seasonal water supply sources such as rivers, streams and ponds.

RAINFALL, AGRICULTURAL PRODUCTION AND WATER RESOURCES FOR IRRIGATION

One of the major uses of water worldwide is for agricultural purposes. It can be used during production or processing. Water needed during production can be supplied either by rainfall or by irrigation. According to Omogbai (2010), when considering water requirement by various crops, rainy days appears to be relatively more important than the amount. However, the numbers of rainy days have increasingly become erratic due to global warming phenomenon, thus making rainfall prediction unreliable. As a result, there is an urgent need to salvage as much of this resource (freshwater) as possible and use it wisely. The unreliability of rainfall prediction will also result in a greater dependence on fresh water supply for irrigation purposes during agricultural production.

Going by FAO (2001) statistics between year 1970-2000, the area of land under irrigation increased from less than 200 million ha to more than 270 million ha worldwide. Out of Nigeria's total land mass of about 923,768 km², survey by Japan International Cooperation Agency (JICA) in the 1980s showed that 39% (360,269.52 km²) of the Nigerian land mass is potentially suitable for agriculture, of this land mass, between 4.0-4.5 million ha (approximately 4.5-5.0% of the land) are adjudged suitable for irrigated agriculture. Nigeria is adjudged the most populous country in Africa with an estimated population of over 168.8 million (The World Bank, 2014). The country is endowed with enormous water resource and the span of water bodies within Nigeria is estimated at 900 km² (Ekiye and Luo, 2010). Nigeria's internal freshwater resources per capital is estimated to be 1,346 m³ and only 4.7% of this value (63.26 m³) is the total freshwater withdrawal while agricultural freshwater withdrawal accounted for 53% of the 63.26 m³ (The World Bank, 2014). This country water resources data put enormous pressure in reducing water withdrawal for use in the agricultural sector as the statistics suggests that one of the major uses of water in Nigeria is for agricultural purposes.

One of the most common staple food crops in most tropical countries, including Nigeria is cassava (*Manihot esculenta* Crantz). Ugwu and Odo (2008) stated that it is the 7th most important food crop in the world and constitutes a staple food for about 12.50% of the world population. According to Nwaogwu *et al.* (2011) the annual cassava production is about 84 million tons. The peels of cassava, an inedible part of cassava is the major constituent of waste, and in some cases, it can be the only waste product obtained from cassava processing. According to Obadina *et al.*, (2006), cassava peels account for up to 10% of the wet weight of cassava tubers. However, some authors (Jekayinfa and Olajide, 2007; Kniper *et al.*, 2007) have reported that with hand peeling which is common among subsistence farmers, volume of the peels could be as high as 20% of the total weight of the tuber. Considering the above information on cassava production in Nigeria this implies that with hand peeling process which is predominantly used, annual cassava peel production could be as high as 16.8 million tons of cassava peels. This large volume of waste could be a source of problem especially in cassava processing communities; however recent research (Omotosho, 2012) shows that this cassava peels can be processed into activated carbon and further used in the effective treatment of wastewater from the same industry.

WASTEWATER PRODUCTION AND DISPOSAL ISSUES

Other uses of water in agriculture are for crop processing. Thus, wastewaters are unavoidable by-products of any processing activity and whatever processing procedures are used, there will always be an aqueous liquid as by-product (Asia and Akporhonor, 2007). According to Al-Rekabi *et al.* (2007) wastewater can be classified into four major types namely; Domestic, Industrial, Storm Water and Infiltration/Inflow.

One of the by-products of cassava processing is the effluent and if allowed to move freely within soil, contaminates surface water as it percolates into ground water and sub soil with serious adverse effect on human, fauna and the flora (Ogundola and Liasu, 2007). In Nigeria, recent national policy by the government on cassava cultivation for domestic, industrial and export purposes have resulted in production increase and processing thereby increasing effluent discharge to the environment.

Hence, there is need to take care of effluent discharge from cassava processing operations in order to prevent pollution of both surface and groundwater sources which have been observed to be major sources of water supply in most Nigerian communities. Protecting available fresh water from contamination is also important because once ground water becomes contaminated; it can take years or decades for self or natural remediation.

SEQUENTIAL PEROXIDE-OXIDATION AND ADSORPTION RECYCLING PROCESS

Waste treatment is generally classified into four levels: primary, secondary, tertiary, and quaternary treatment with each treatment level aimed at removing a more specific class of contaminants (Okonko *et al.*, 2006). Proper waste management through the provision adequate of solid waste and wastewater treatment facility is therefore non-negotiable (Adewole, 2009). The combined peroxide-oxidation and adsorption recycling process (Figure 2) utilizes solid waste in form of cassava peels from cassava processing as a precursor in treatment of the processing effluent for safe discharge into watercourse or irrigation use. The process not only takes care of discharge effluent but also solid waste which has gradually become a source of concern.

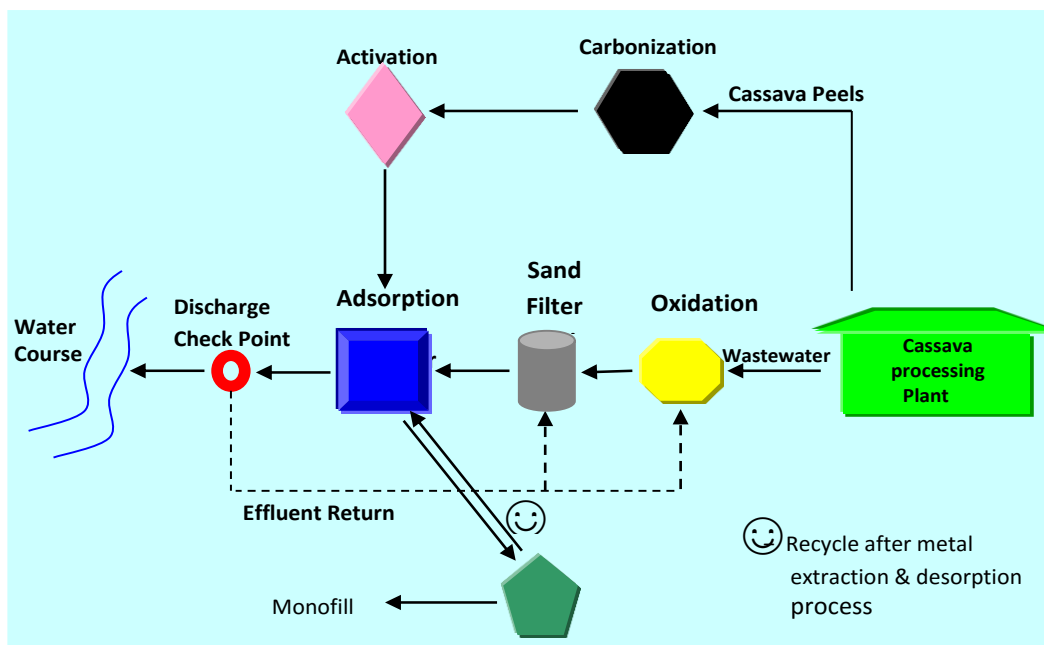


Figure 2: Schematic Diagram of the Sequential Peroxide-Oxidation and Adsorption Recycling Process
Source: Omotosho,(2012)

MATERIALS AND METHODS

PILOT SCALE STUDY

Cassava peels and cassava processing wastewater were collected from a cassava processing industry in Ibadan, Nigeria. The cassava peels were inspected, washed and sundried to a moisture content of between 8-11% dry-basis (M_{db}) by using the equation 1

$$M_{ab} = \frac{M_1 - M_2}{M_2} \times 100 \quad (1)$$

Where M_1 is the weight of fresh cassava peels, M_2 is weight of dry cassava peels. Dried cassava peels were then carbonized using a muffle furnace (Carbolite, England Model AAF 11/18) at 420°C for 90 mins. It was then allowed to cool overnight under inert conditions. The cassava peel carbon (CPC) size was then reduced to 500 μ m. The powdered carbon material was pre-washed to remove any form of dirt that may have been attached during size reduction process and later dried in the oven at 120°C for 8 hrs. A weighed sample of carbon material (0:1) was kept in a jar and three other samples of the same weights were activated using $ZnCl_2$ at activation ratios of 1:3, 2:3 and 1:1 and also stored in jars (Plate 1) to preserve them till used.

0.5M NaOH was added to the collected wastewater sample until the pH of 10.0 was achieved thereafter Hydrogen peroxide at 50% concentration was then added at a dose of 0.5 grams H_2O_2 per gram of CN^- oxidized. The wastewater was left for 2 hrs to ensure a reasonable level of oxidation and cyanide destruction before filtration was done in an intermediate sand filter column of length 120 cm. the oxidized wastewater was released simultaneously into four adsorption columns containing the CPC (0:1) in one column and Cassava Peel Activated Carbon (CPAC) at activation levels 1:3, 2:3 and 1:1 in the other three columns at the rate of 0.378 l/hr. Water samples were strained from the adsorption columns after a period of 2, 4, 6 and 8 hrs respectively for the four adsorption columns. The discharged effluent parameters were then compared with the Federal Environmental Protection Agency (FEPA) now referred to as National Environmental Standards and Regulations Enforcement Agency (NESREA) interim standard on discharge into surface waters and also standards for irrigation water.



Plate 1: Cassava Peel Carbon (CPC) and Cassava Peel Activated Carbon (CPAC) materials stored in jars

ESTIMATION OF WATER USE IN CASSAVA PRODUCTION PROCESS

This research compared estimated volume of effluent discharge from cassava processing activities within the country with the country's annual fresh water availability data. Data on water usage was obtained by taking an average value of cumulative measurement of water usage from three randomly selected cassava processing plants within Ibadan metropolis of Oyo state in Nigeria. Water use pattern was recorded for the soaking (fermentation) and the non-soaking method as practiced in these cassava processing industries.

Average water usage per tone was obtained by weighing processed cassava and taking equivalent water usage using the equations below

$$\sum \frac{W_T}{N} \quad (2)$$

$$W_T = \frac{V_P}{M_C} \times 1000 \quad (3)$$

Where W_T is water use per tonne, V_p is volume of water used for process, M_c is mas of cassava processed. N is number of observations. Average water use per ton was multiplied by the value of estimated cassava production in the country and used as a basis for obtaining the estimated total water usage.

SCENARIO ANALYSIS OF WATER USAGE

For the purpose of this study three scenarios were created to simulate possible combinations of cassava processing techniques. The three main scenarios considered in the fermentation and non-fermentation cassava processing techniques were:

- a. **Scenario 1 (60:40% Soaking: Non-soaking):** this is the condition when the cassava processing factory processes 60% of its total cassava intake by soaking method while the remaining 40% is done by non-soaking processing method.
- b. **Scenario 2 (50:50% Soaking: Non-soaking):** this condition simulates a situation where processing of cassava is done in equal volumes for both soaking and non-soaking processing methods
- c. **Scenario 3 (40:60% Soaking: Non-soaking):** under this scenario the cassava processing factory is assumed to process about 40% of its cassava by soaking method while the remaining 60% is processed by non-soaking processing method,

Selection of these scenarios was done to simulate three out of the possible processing combination methods in cassava processing industries. These scenario situations were as a result of varying dietary constitution of residents and also recent government policies on cassava production and industrial utilization.

RESULTS AND DISCUSSION

EFFICACY OF THE COMBINED PEROXIDE-OXIDATION AND ADSORPTION TREATMENT PROCESS

Before and after the treatment process a comparison of the characteristics of wastewater was made with FEPA/NESREA interim standard on discharge for all classes of industry and also standards for discharge to watercourse (Table 1). The outcome showed that after adsorption, all the parameters considered met required

Table 1: Comparison of Raw Wastewater and Effluent from Treatment Process after 8 Hours Contact Time with FEPA/NESREA Discharge Standards

Parameter	FEPA/NESREA Standard*	Raw water*	Effluent Condition after 8hrs Contact			
			0:1	1:3	2:3	1:1
Temperature (°C)	< 40	28	☐	☐	☐	☐
Colour (Lovibond Units)	7	12	X	X	☐	☐
Total Dissolved Solids (TDS)	2,000	2,870	☐	☐	☐	☐
Total Suspended Solids (TSS)	30	2,300	X	X	X	X
pH	6-9	4.2	☐	☐	☐	☐
BOD ₅	50	252	X	X	☐	☐
S ²⁻	0.2	0.03	☐	☐	☐	☐
CN ⁻	0.1	0.3	☐	☐	☐	☐
SO ₄ ²⁻	500	5.9	☐	☐	☐	☐
NO ₃ ⁻	20	12.5	☐	☐	☐	☐
Fe ³⁺	20	0.7	☐	☐	☐	☐
PO ₄ ³⁻	5	17.9	X	X	☐	☐
Mn ²⁺	5	0.05	☐	☐	☐	☐
Phenol	0.2	-	●	●	●	●
Cl ⁻	600	19.5	☐	☐	☐	☐
Cd ²⁺	< 1	0.02	☐	☐	☐	☐
Hg	0.05	-	●	●	●	●
Ni ³⁺		0.03	☐	☐	☐	☐
Mg ²⁺	200	15.5	☐	☐	☐	☐
Ca ⁻	200	79	☐	☐	☐	☐
Zn ²⁺	< 1	0.14	☐	☐	☐	☐

☐: Met FEPA Discharge Standard X: Did not Meet Discharge Standard ●: Not Detected in Wastewater Sample

*All parameters are in mg/l except where otherwise stated

standard discharge with the exception of suspended solids; this was however corrected with the incorporation of a sedimentation tank after adsorption chambers to separate the suspended particles. The effluent also met the standard for irrigation water use. This result showed that based on the considered physical parameters (Table 1), the treatment method can be well suited for the treatment of cassava industry effluent. This means that valuable water resource can be effectively conserved through this treatment process. The process was also able to reduce the weight of cassava peels by about 61% while the volume reduction was as high as 80% thereby leading to a more efficient utilization of space and easier waste handling.

CASSAVA PROCESSING AND WATER BUDGET

For the purpose of this study water budget under cassava production is classified into two, these include;

- i. internal water budget
- ii. external water budget

Internal water budget relates to the water requirements within the production process, cassava processing can either be by soaking (fermentation) or non-soaking (non-fermentation) methods and water usage differs distinctly with each process as shown in Table 2. The table shows the average water demand these values included water requirements for sanitation activities during the processing.

Table 2: Estimated water Budget for Cassava Processing

Process Method	l/ton *
Fermentation*	1,525
Non-Fermentation	960

* values obtained from cumulative process observations

SCENARIO ANALYSIS OF ESTIMATED WATER USE IN CASSAVA PROCESSING

Analysis of water use based on the established 3-scenario system (Section 2.3) composing of the two processing methods (soaking and non-soaking) and based on the 84 million ton annual cassava production capacity of the nation revealed that Scenario 1 estimate gave an estimated water requirement for fermentation process to be 76,860 million litres while non-fermentation process accounts for 32,256 million litres process water. Scenario 2 estimate showed that 64,050 million litres of water are used. Under scenario 3 51,240 million litres of water was used in fermentation process method while 48,384 million litres were used in non-fermentation process (Table 3). The scenario analysis makes use of the estimate of 1,525 litres of water per tonne for fermentation process while the non-fermentation process utilised 960 litres of water per tonne of cassava processing. The total estimated wastewater discharge from scenarios 1, 2 and 3 were 104,751.36, 100,195.20 and 95,639.04 million litres respectively. This shows that the system would be able to recycle or treat a minimum of 96% of the water utilized in the processing cassava annually for reuse, discharge and irrigation purposes considering the use of the above stated scenarios. A quantitative intra-scenario analysis of the above water use estimation showed that within scenario 1 fermentation process consumed 70.4% of the total water use while non-fermentation process consumed 29.6% of the total use, under scenario 2 fermentation process accounted for 61.4% of total water use while non-fermentation process was 38.6% finally the scenario 3 showed 51.4% total water use for fermentation while non-fermentation used 48.6% of the total water use as shown in figure 2. Based on the three scenarios considered in table 3, it was observed that the estimated water usage in the fermentation processing is inversely proportional to the non-fermentation processing in the industry.

Table 3: Estimate of water budget for the different considered cassava processing scenarios

	Percentage	Estimated Annual Processing (tonnes)*	Process	Estimated Water Usage (l/tonne)	Estimated Water Usage (l)	Estimated Water Loss (l)*	Estimated Total Annual Water Usage (l)
Scenario 1	60	50.4 x10 ⁶	Fermentation	1,525.0	76,860 x 10 ⁶	3,074.40 x 10 ⁶	104,751.36 x 10 ⁶
	40	33.6 x10 ⁶	Non-Fermentation	960.0	32,256 x 10 ⁶	1,290.24 x 10 ⁶	
Scenario 2	50	42 x10 ⁶	Fermentation	1,525.0	64,050 x 10 ⁶	2,564.00 x 10 ⁶	100,195.20 x 10 ⁶
	50	42 x10 ⁶	Non-Fermentation	960.0	40,320 x 10 ⁶	1,612.80 x 10 ⁶	
Scenario 3	40	33.6 x10 ⁶	Fermentation	1,525.0	51,240 x 10 ⁶	2,049.60 x 10 ⁶	95,639.04 x 10 ⁶
	60	50.4 x10 ⁶	Non-Fermentation	960.0	48,384 x 10 ⁶	1,935.36 x 10 ⁶	

* water loss is taken as 4% of estimated water usage

** Total estimated annual cassava production = 84 x10⁶ tonnes

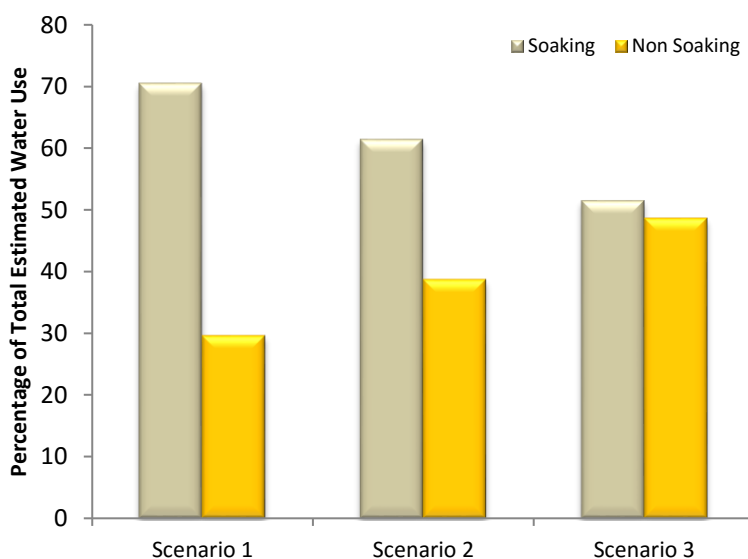


Figure 2: Analysis of water use within scenarios

CONCLUSION AND RECOMMENDATION

The study showed that annual water usage in the cassava processing industry in Nigeria is of substantial quantity, thus wastewater could be harnessed for irrigative purposes thereby helping to boost food production. The system also has the advantage of taking care of both solid and effluent waste which could have been a problem if discharged carelessly. In the event of discharge to watercourse, the system would prevent pollution of adjacent water bodies which would take a long time to dilute to safe level due to its high polluting strength. Such discharge could also pollute groundwater sources in processing areas rendering such sources unfit for abstraction. Since most cassava processing plants within the country are still making use of wells, springs and other shallow groundwater sources, groundwater budget is usually affected due to pumping; thus, the adoption of this treatment method will assist in the safe recharge of groundwater thereby improving yield from wells in such areas both in quality and quantity.

It is therefore recommended that the combined peroxide-oxidation and adsorption method of waste treatment in cassava production be adopted as opposed to the current indiscriminate solid and effluent disposal. Processing of cassava is usually done all year round therefore the recycled water from the system could be utilized during the dry season for irrigation farming with the aim of increasing food production.

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