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Development of a Farm Level Paddy Rice Parboiling Device

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Abstract- ***The need to improve on parboiling techniques by rural farmers in Nigeria has led to the development of a parboiling device at the Department of Agricultural and Environmental Engineering, University of Agriculture, Makurdi. Design and construction of a paddy rice parboiler was carried out using an empty 200 litres metal drum. It has a soaking chamber of 0.1378 m^3 with perforated floor of 570 m^3 and a steaming chamber of 0.0919 m^3. The steaming chamber is directly below the soaking chamber and it is provided with two drain plugs to drain water off from the paddy mass and the steaming chamber. A rotating grid is incorporated to serve as a stirrer. The parboiler is mounted on a titling frame for ease of evacuation of the paddy after parboiling. Firewood was used as the source of fuel. The evaluation of the parboiler was done using 50 kg of the long grain rice (SIPPI). The performance of the developed parboiler was compared with the traditional method of parboiling using empty drums and the industrial method. A water uptake test was carried out for the products of the developed parboiler, traditional and industrial methods. Panel subjective test was used to compare the quality of the rice parboiled with the developed parboiler, the traditional and industrial parboiler. The developed parboiler, parboiled 50 kg of rice in 30mins. The quantity of fuel (firewood) used in parboiling was 3.6 kg at a parboiling temperature of 95^0C. The traditional parboiler parboiled 50 kg of rice in 3 hours and the quantity of fuel (firewood) used in parboiling was 9.8 kg at a temperature of 105^0C. Panels' assessment showed that the quality of rice produced by the developed parboiler is good when compared to the traditional and industrial methods of parboiling. Overall results show a significant improvement, less time of operation and a cheaper cost using the developed parboiler. A 0.05 significant level used to test the null hypothesis concluded that there is no significant difference in the water uptake of the rice parboiled using the developed, industrial and traditional parboilers at varying temperatures. With a production cost of ₦15,750:00 (fifteen thousand, seven hundred and fifty naira only) and an operating cost of ₦400:00 (four hundred naira) which is equivalent to an average of 4.2 tons/month capacity of 35 tons of parboiled paddy per year, the developed parboiler gives a higher economic benefit than the traditional parboiler which cost ₦3,500:00 (three thousand, five hundred naira) with an average output of 10 tons of parboiled rice per year, which is equivalent to an average of 0.83 tons/month.***

Key Words: Device, Paddy, Parboiling, Rice.

I. INTRODUCTION

Parboiling of rice which is a hydrothermal treatment given to raw paddy, is a common feature in traditional rice processing widely practiced in Nigeria. Presently in Nigeria, rural farmers who are the major producers of rice still parboil rice using the traditional methods of soaking the paddy in cold water overnight in a mud pot or half drum for two or three days after which the paddy is steamed for hours and later dried and milled. This traditional parboiling process commonly results in improper gelatinization, discolouring and low market acceptability of the milled rice, due to defects and inadequacies in parboiling process. The method is also time consuming and highly laborious. This necessitates the need to develop a paddy rice parboiler to improve upon the existing traditional method of parboiling in order to carry out parboiling operations within a short period of time and to get better quality rice with good market acceptability.

The parboiling techniques for paddy originated in India. It is now widely employed all over the world. [1] – [3]. It involves a hydrothermal treatment by soaking, steaming and drying before milling. Basically, this is done to gelatinize the starch, remove air voids from the kernel and heal the cracks. This process reduces milling breakage, facilitates disintegration of protein bodies, impacts hardness to the grains and makes them more resistant to pest [4].

Parboiling is also important in reducing the losses of starch, vitamins, and minerals in cooking, destruction of infestation molds and insects, and inactivation of lipases to improve the shelf life of rice bran [5], [6].

Parboiled rice has a characteristic texture, flavour. Colour, taste, and cooking behaviour. As at 1972, about 25 to 30 % of the world paddy is parboiled [7], [8].

II. PARBOILING TECHNIQUES

Several traditional and improved methods of parboiling exist. The traditional methods involve variety of problems such as development of odours, fermentation, excessive leaching of soluble solids, decolouration of grains and microbial infections. The conventional parboiling methods using a drum involves the cleaning and prolong soaking of paddy rice in cold water for about 20 hours to give it a moisture content of 30-35% after which the rice is put in parboiling equipment with fresh cold water and boiled until it begins to split. The rice is then dried on woven mats, cooled and ready for milling [9], [10].

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The dry parboiling method developed at the International Rice Research Institute, Manila, Philippines involves drying of paddy at high temperature (200 ^{0}C) by mixing with sand. Prolonged soaking or steaming is eliminated in this process [11]. In 1910s, German-British scientist Eric(h) Huzenlaub (1899-1964) invented a form of parboiling which held more nutrient in the rice, now known as Huzenlaub process. In this method of parboiling, the whole grain is vacuum-dried, then steamed, followed by another vacuum drying and husking. This method makes the rice more resistant to weevils and lesser cooking time [12]. In later methods of parboiling, the rice is soaked in hot water, and then steamed for boiling which only takes 3 hours rather than 20 hours of the traditional method [13]. In Nigeria, apart from the traditional method which is inefficient and laborious, paddy can also be parboiled in industries by using the direct soaking parboiling method. In the direct soaking parboiler method, about 16 tons of paddy is parboiled per batch [14]. Paddy to be parboiled is collected from the intake bridge and transported to the pre-cleaning machine for the removal of impurities. The pre-cleaning machine is made up of four filters of different sizes arranged in layers to separate the paddy from impurities such as stones, dust, chaff and other foreign materials. A blower fan is also incorporated on the pre-cleaning machine to aid the cleaning. The clean paddy from the pre-cleaning machine is transferred to the buffer tank through the buffer elevator to store the paddy in preparatory for soaking. The soaking tanks are directly under the buffer tank. Water from the water tank is heated by steam from the boiler house which is transferred to the tank by pipes. The hot water is transferred to the soaking tanks through pipes by opening the valves. The shutter of the buffer tank is opened and the paddy stored in the buffer is emptied into the soaking tanks. The paddy is soaked for 7 hours at a soaking temperature of about 75-80 ^{o}C depending on the moisture content of the paddy [14].

After soaking, the water from the soaking tank is discharged through a water discharge pump. The paddy in the soaking tank is steamed for 15-25 min. After steaming, the paddy is discharged by opening the discharge valve for drying [14]. The industrial method is an imported technology and it is not available for use by bulk of the rural farmers which produce 80 % of the rice consumed in Nigeria.

III. PREVIOUS DESIGNS OF PARBOILERS IN NIGERIA

In an attempt to alleviate the setback suffered by the local rice processing using the traditional method of rice parboiling in Nigeria, using drums, fired with wood. Obobi and Anazodo designed a parboiler of 0.15 tons/batch capacity that occupies 4.3 m space. The equipment consists of three major units made of 2.5 cm galvanized iron pipes and six suitably located 2.5 cm control valves. The component parts are 0.26 m^3 parboiling compartment, which holds 150 kg of paddy, one 261 litres boiler and one 188 litres reservoir. An automatic whistles warning relief protects the machine and guides the operator. A furnace fires this equipment [15]. The design had some advantages such as, ease of parboiling, saved time, high cooking quality and parboils paddy in large quantities per batch. Despite the level of success achived, the design also had some disadvantages. They include:

- The developed parboiler had a bogus capacity which was not attractive and was difficult to transport it from the construction site to the desired site of operation.
- The cost of constructing and purchasing the parboiler was high thus the local farmers could not afford it and the aim of the innovation was defeated.

The National Cereal Research Institute (NCRI) Badeggi, also reported the development of an electric rice parboiler plant that is made of galvanized sheets with lid. The parboiling plant has both inner and outer cans with insulating materials in between for the conservation of heat. There is a support (false bottom) on which perforated crates of rice paddy is placed. A number of water heating elements are incorporated depending on the capacity of the plant. Also a thermometer is attached to the lid. An electric hood is mounted on one side of the plant mainly for electric controlling purposes. There are also control valves connected to the pipe network for steam and hot water control [16]. The designs had some notable advantages such as, ease of parboiling, saved time, high cooking quality and high market acceptability, pleasant smell and colour. Despite the above stated research breakthrough the design also recorded some disadvantages which led to the design of the farm level paddy parboiling equipment. They include:

- The cost of constructing and purchasing the parboiler was high thus the local farmers could not afford it and the aim of the innovation was defeated.
- Due to the epileptic power supply in Nigeria, the electric rice parboiler could not be effective both in the rural and urban centres.

Materials and Methods

Design Considerations

In the design of the parboiler, the followings were considered.

IV. CHARACTERISTICS OF THE RICE GRAINS

Sizes of the grains of paddy to be parboiled were considered. They should be uniform and from the same variety. This is important because the grain size determines the depth of which the water penetrates into the grain. The caryopsis of the grains was also considered to be entirely covered by the husks, because if the caryopsis is exposed, the shape and colour of the paddy grain will be distorted [17], [18]. The long grains (variety-SIPPI) were used in evaluating the developed parboiler. The grains were purchased from North Bank Market, Makurdi.

V. MATERIALS FOR CONSTRUCTION

The major material for the construction of the parboiler is the readily available 200 litres metal drum made of galvanized sheet metal of 1.5 mm thickness. The galvanized pipes, 2×2 inches angle metal, Taps were selected based on their availability, simplicity, ease of construction and operational principles and conductivity of the material.

Inputs

Water and energy are the necessary inputs for processing paddy into edible parboiled rice. Gariboldi [8] reported that the amount of energy required to process raw paddy into edible parboiled rice varies according to the variety, the degree of starch gelatinization in the edible rice and the technology utilized in the hydrothermal and mechanical process. Because of the availability and cheap cost of firewood, it was considered suitable for heating of the parboiling equipment.

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VI. QUALITY TEST

A quality test was conducted in order to compare the quality of the rice parboiled using the developed parboiler, industrial and the traditional parboilers. A panel of five students, and five market women was used to compare the quality (smell, taste and colour) of the rice parboiled using the different parrboiling methods.

VII. DESCRIPTION OF THE PARBOILER

The parboiler was designed to parboil a maximum of 70 kg of paddy per batch, and occupied an area of about 1 m^2 with total weight of 38 kg. It was made out of a standard 50 gallon metal drum (200 litres) which was divided into two chambers; namely the soaking (steeping) chamber and the steaming chamber. The soaking chamber has perforated floor of 570 mm diameter and a grid which is made of one vertical perforated pipe of 25mm diameter and two lateral pipes of 20 mm diameter. The grid is made to rotate to serve as the stirrer. The steaming chamber is directly below the soaking chamber and is provided with two drain plugs (the upper and lower drain plugs) as recommended by NCAM [17], to drain the water off from the paddy mass and the steaming chamber after 3-4 hours of soaking and 15-20 minutes of steaming respectively. Wood was used as the fuel for operating the device. The sectional view of the parboiler is shown in Figure 1. The parboiler is mounted on a tilting frame which serves as a stand and ease evacuation of the paddy after parboiling. A pictorial view and photograph of the developed parboiler are shown in fig. 2 and fig. 3 respectively.

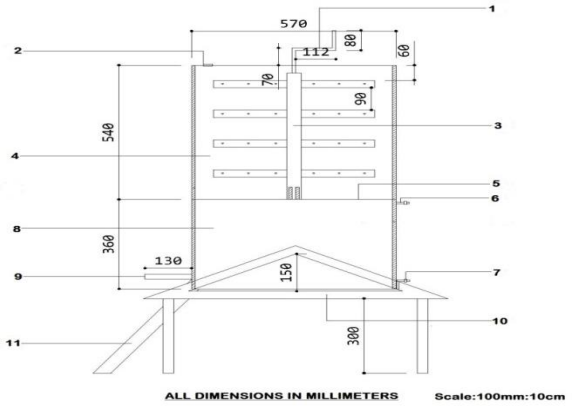

Fig. 1: Sectional View of the Developed Parboiler

1. Stirrer	4. Soaking chamber	7. Lower drain plug	10. Tilting frame
2. Sensor hole	5. Perforated floor	8. Steaming chamber	11. Support stand
3. Grid	6. Upper drain plug	9. Tilting handle	

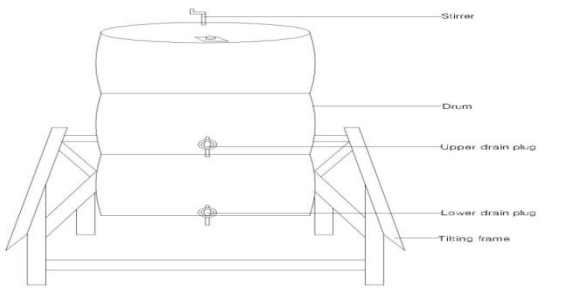

Fig. 2: Pictorial drawing of the developed parboiler (Not to Scale)

Fig. 3: Photograph of the developed parboiler

Design Equations

The amount of heat required to accomplish a cooking operation was estimated using the equation:

$$q_u = MCp\frac{\delta T}{\delta t}\ \text{KJ/min [17]} \qquad (1)$$

Where:
q_u= useful heat required for a parboiling operation.
M = mass of paddy, kg.
C_p = specific heat capacity of water. (kJ/kg^{0}C)
δT = temperature ^{o} C
δt = time taken for parboiling. (mins.)
The volume of steam flowing from the lower chamber to the upper chamber was calculated from the equation:

$$Q = AV\ m^3\ [17] \qquad (2)$$

Where:
Q = volume of steam flowing in the pipe for a period of time, m^3 / sec.
A= cross - sectional area of the pipe, m^2.
V = the average velocity of flow in a pipe. (m/s)
However the following was assumed:

i. The flow is steady and internal and one dimensional flow.
ii. The steam is incompressible and Frictionless.

The velocity at which the steam travelled within the pipe to ensure even distribution of steam for effective steaming is given by:

$$V = \left[\left(\frac{P1 - P2}{4ul}\right)\left(\frac{D^2}{4} - r2\right)\right]\ \text{m/s [17]} \qquad (3)$$

Where:
D = pipe diameter, m.
L = length of pipe over which the pressure change is to be determined, m.
u = the coefficient of friction.

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P = mass density, kg/m ^{3}
r = radius of pipe, m
(P_1 - P_2)= pressure change, N/m ^{2}
V = the average velocity of flow in a pipe (m/s)

VIII. OPERATION AND TESTING

The paddy to be parboiled (50 kg) was cleaned and weighed. The parboiling equipment was mounted on the heating furnace and was filled with water up to half of the chamber. The furnace was ignited and the water was allowed to attain a temperature of about 85 ^oC, and the paddy was poured into the hot water. On pouring in the paddy, the temperature of water-paddy mass was measured to ensure that it does not go below the soaking temperature of 70 ^oC as reported by Gariboldi [8].

The paddy was allowed to soak for 3 hours. Within this period of soaking, the temperature was not allowed to go below 70 ^oC [7]. After soaking, the upper drain plug was opened to drain off the hot water from the upper chamber.

Then the heat was increased by reintroducing the quantity of firewood removed to generate steam from the water in the lower chamber of the device. As soon as the steam was observed from the upper chamber, the steaming was allowed to continue for 20 minutes [17], to complete the parboiling process. The paddy was stirred at various intervals. The steam temperature was measured to 95 ^oC using a thermometer.

After the steaming, the lower drain plug was opened to allow water to drain off from the lower chamber. Thereafter, the fire source was removed and the parboiler was tilted for easy evacuation of the parboiled paddy.

The parboiled paddy was evacuated from the upper chamber by connecting a wooden lever to the bottom pipe and overturning the equipment. The parboiled paddy was then sun dried for milling.

IX. COST OF PRODUCTION

The total cost of producing the device which include material cost of ₦12,500.00, labour cost of ₦2,000.00 and 10 % contingencies is ₦15,750.00. This is equivalent to U.S $262.50 at the current exchange rate one US dollar to Sixty Naira.

X. RESULTS AND DISCUSSIONS

The results obtained from calculating some design parameters of the developed parboiler are shown in table 1. The volumes of the soaking and steaming chamber were 0.1378 m^3 and 0.0919 m^3 respectively. This gave a total volume of 0.2297 m^3 for the soaking and steaming chambers. The amount of heat required to accomplish parboiling using the developed parboiler is 465.500 KJ in 30mins and the velocity of heat flow is 0.162 m^3/s.

The results obtained during the testing of the developed parboiler shows that raw paddy was boiled in 30 minutes at 95 ^oC and 3.6 kg of fuel (firewood) was used as shown in table 2. Also, 50 kg of paddy was parboiled in 3 hours at 105^oC and 9.5 kg of fuel was consumed using the traditional method of parboiling. The time taken and quantity of fuel used to parboil paddy rice using the developed parboiler is low compared to the traditional method of using the conventional drum.

The panel assessment tests carried out on the products from the developed parboiler, traditional and industrial parboilers showed a favourable level of rice parboiled using the developed parboiling device as given in table 3. The rice parboiled using the developed and the industrial parboiler have good smell and taste with golden colour. The rice parboiled using the traditional parboiler have bad smell and taste with a whitish-yellow colour.

Table 1: Results of design calculations

Parameters	Quantity	Units
Volume of soaking chamber	0.1378	m^3
Volume of steaming chamber	0.0919	m^3
Total volume of parboiler	0.2297	m^3
Amount of heat required	465,500	kJ/min
Velocity of flow of steam	0.162	m^3/s

Table 2: Test Results

S/NO	Parameters	Units	Developed parboiler	Traditional parboiler	Industrial parboiler
1	Mass of sample(paddy rice)		50 kg	50 kg	16 tons
2	Time taken for soaking	Hours	3	18	7
3	Soaking temperature	^0C	70	32	75
4	Time taken for parboiling	Hours	0.5	3	0.3
5	Parboiling temperature	^0C	82	32	80
6	Water temperature after 45 mins	^0C	75	33	75
7	Water/paddy temperature after 10 mins	^0C	95	105	90
8	Quantity of fuel(firewood)	kg	3.6	9.8	NA

NA – Not Applicable

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Table 3: Panel Subjective Test Result on Taste, Smell, and Colour

Developed parboiler			Traditional parboiler			Industrial parboiler		
Smell	Taste	colour	Smell	Taste	colour	Smell	Taste	colour
Good	Good	Golden yellow	Bad	Bad	Whitish yellow	Good	Good	Golden yellow
Good	Good	Golden yellow	Bad	Bad	Whitish yellow	Good	Good	Golden yellow
Good	Good	Golden yellow	Bad	Bad	Whitish yellow	Good	Good	Golden yellow

Table 4: Water Uptake of Rice at 60 ^{0}C and 100 ^{0}C.

Time (Mins)	Developed parboiler Weight(g)		Industrial parboiler Weight(g)		Traditional parboiler Weight(g)	
	60 ^{0}C.	100 ^{0}C.	60 ^{0}C.	100 ^{0}C.	60 ^{0}C.	100 ^{0}C.
50	4.9	12.8	7.0	12.5	10.8	20.4
100	5.2	14.0	8.2	16.8	8.2	20.0
150	7.5	15.2	5.0	17.3	7.5	25.0
200	8.0	27.0	7.8	22.0	8.0	24.9

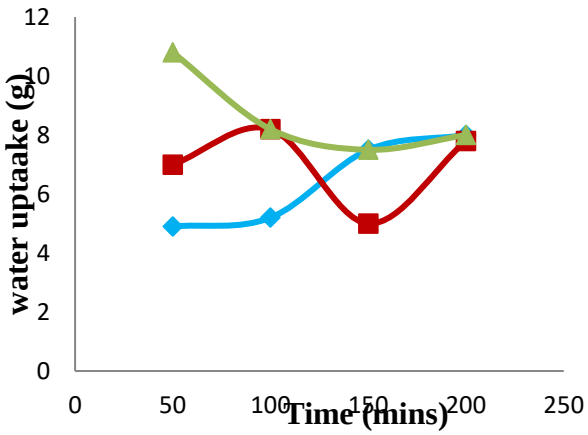

Fig.4: Comparism of water uptake of the developed parboiler with industrial & traditional parboilers at 60^{0}C

KEY

A water uptake for the improved version

B water uptake for the industrial version

C water uptake for the traditional version

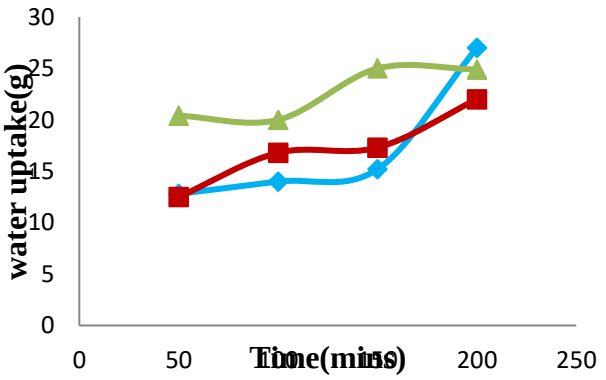

Fig.5: Comparism of water uptake of the improved parboiler with commercial & traditional version at 100^{0}C

KEY

A water uptake for the improved version

B water uptake for the industrial version

C water uptake for the traditional version

Table 6: Anova for the developed, traditional and industrial parboilers on water uptake of rice

Source of variation	Sum of square	Degree of freedom	Mean of square	F-Ratio	Remark
WEIGHT	77.54	2	38.77	2.2	P < 0.05
WATER UPTAKE	758.25	1	758.25	41.3	P >0.05
ERROR	235.8	20 23	18.376 46.59		
TOTAL	1071.59				

Microsoft Excel 2007
Statistical Analysis [19]
Significance level = 0.05 (i.e. 95%)
Testing of hypothesis
Weight F $(0.05)_2$, 20 =3.49

Since F_{cal} =2.2 < F_{tab} =3.49 The null hypothesis is accepted and it is concluded that the difference in water uptake of the rice is not significant.

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Temperature F $(0.05)_{1,}$ 20 = 4.35
Since F_{cal} = 41.3 > F_{tab} =4.35, the null hypothesis rejected and it is concluded that there is a significant difference in the temperature of the rice.
The products from each of the methods were subjected to a water uptake test at 60 ^{0}C and 100 ^{0}C water temperatures respectively for various periods as recommended by Obobi and Anazondo [15]. Table 4 shows the water uptake of rice at 60 ^{0}C and 100 ^{0}C at a period of 50mins intervals. From table 4, the water uptake of rice parboiled using the developed, industrial and traditional parboilers at 60 ^{o}C and 100 ^{o}C was determined at an interval of 50mins. The difference in weight for each sample gives the water uptake at that period.
The results were subjected to statistical analysis using a two way ANOVA. Table 5 shows the analyses of variance (Anova) for the different parboiling methods on water uptake of rice. From the table, a 0.05 significant level was used to test the null hypothesis and was concluded that there was no significant difference in the water uptake of rice parboiled using the developed, industrial and the traditional parboilers at varying temperatures.
Figure 4 and 5 also shows the results of the water uptake tests for the developed, industrial and traditional parboilers at 60 ^{o}C and 100 ^{o}C respectively. The graphs of the result obtained from the water uptake test of the rice parboiled using the developed, industrial and traditional parboilers show that the points are closely distributed. This confirms that there is no significant difference in the water uptake of the rice parboiled using the developed, industrial and traditional parboilers.
With an initial production cost of N15,750 (fifteen thousand, seven hundred and fiftyNnaira only) and an operating cost of N400 (four hundred naira) which is equivalent to an average of 4.2 tons/month capacity of 35 tons of parboiled paddy per year, the developed parboiler produces a higher economic benefit than the traditional parboiler which cost N3500 (three thousand five hundred naira) with an average output of 10tons of parboiled rice per year, which is equivalent to an average of 0.83 tons/month.

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