American Journal of Mechanical and Materials Engineering
2017; 1(1): 5-9
http://www.sciencepublishinggroup.com/j/ajmme
doi: 10.11648/j.ajmme.20170101.12

Development of a Temperature-Controlled Paddy Rice Parboiler

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To cite this article:

Imonigie P. S., Yusuf K. A., Atanda E. O. Development of a Temperature-Controlled Paddy Rice Parboiler. *American Journal of Mechanical and Materials Engineering*. Vol. 1, No. 1, 2017, pp. 5-9. doi: 10.11648/j.ajmme.20170101.12

Received: January 31, 2017; **Accepted**: February 28, 2017; **Published**: March 24, 2017

Abstract: Parboiling is a major processing factor affecting the quality of milled rice. In this study, a paddy rice parboiler was designed, fabricated and its performance evaluated. During the design and fabrication, of the parboiler considerations were given to the cost of fabrication, simplicity of operation by the local farmers, portability and easy mechanism of loading and offloading the paddy. Performance testing of the machine was carried out at three different levels of steeping temperature (60, 70 and 80°C) andat different steeping time of 2.5, 3.0 and 3.5hrs respectively to determine the effects of steeping temperature and time on the parboiling efficiency and the milling quality of the parboiled rice grains. The optimum parboiling efficiency of 95% and corresponding milling quality of 91% was obtained at 70°C steeping temperature and at 3hrs of steeping time. The results of the statistical analysis of the data obtained from the performance evaluation of the machine revealed that both the steeping temperature and time has significant effects on the parboiling efficiency and the milling quality of the rice grains at 0.05 confidence limit. The production cost of the parboiler is $275.

Keywords: Parboiling, Steeping, Steaming, Milling, Temperature-Controlled

1. Introduction

Rice (*Oryza sativa*) is one of the worldleadingfoodcrops eaten all over the world, it is a cereal crop for human consumption and it's a staple food andapproximatelyone – half of the world population eats rice (Reeves, 2002). This makes it the most widely consumed cereal in the world. The Parboiling stage of rice involves a hydration conditioning of paddy before milling by removing the husk and polishing the final product. Paddy rice is only fit for consumption when its outer seed has been removed through the process of hulling. Parboiling may take place before or after this process. However, parboiling is necessary so as to obtain rice which is of good quality in terms of its physical, chemical and sensory properties.

Parboiling results in significant changes in the physico-chemical and cooking characteristics of rice grain. Parboiling fills the void spaces and cements the cracks inside the endosperm, making the grain harder and minimizing internal fissuring and thereby breakage during milling (Correa *et al.*, 2006).

The market value of milled rice as a product depends largely on its physical qualities after the processing. The percentage of whole grain is the most important parameter in the rice processing industry (Marchezan, 1991). Broken grain has half the market value of head rice, which is defined as grains between 75 and 100% the length of whole kernels Storage of rice grains is a crucial stage in the processing of paddy rice for consumption. The duration of the storage period depends on the objectives of the producers and marketers.

Major reasons of parboiling are; Parboiling reduces breakage and also facilitates the breakdown of protein bodies as well as adding a characteristic color, texture and flavor to the rice and also increasing the nutritive value, as during parboiling, the nutrients embedded in the husk layer is now absorbed by the rice grain. It also increases the market value, as most consumers in Africa tends to favor parboiled rice in terms of making of choice of which to consume (Sarkurai *et al*, 2006). Parboiling impacts hardness on the seeds and making it resistant to pests and it also reduces milling breakages (Raghavendra, And Juliano, 1970). Well Parboiled rice also results in proper swelling and softness of the seeds after boiled. Milling is the process wherein the rice grain is transformed into a form suitable for human consumption, therefore, has to be done with utmost care to prevent breakage of the kernel and improve the recovery. Brown rice is milled further to create more visually appealing white rice. After harvesting and drying, the paddy is subjected to the primary milling operation which includes de-husking as well as the removal of bran layers (polishing) before it is consumed. In this process the rice which is obtained after milling is called raw rice (Poonam, 2014).

Rice farmers in rural areas in Nigeria adopt the traditional method of rice parboiling which has to do with the soaking of the paddy in drums filled with water at an ambient temperature and steaming the rice at 100˚C to gelatinized the starch, while the rice seed expands until the hulls start to give way and the entire process adopted by the traditional farmer is very cumbersome.

Another improved method involve the use of hot water in soaking at 60°C which is far below the gelatinization temperature for a few hours toreduce the cases of aflatoxin contamination during the soaking process which is often facilitated by the leaching of the nutrients in the hot water (yap *et al*., 1987)

Presently in Nigeria, rural farmers who are the major producers of rice still parboil rice using the traditional methods of parboiling the paddy which involves soaking the paddy in cold water in mud pot, or drums for 2-3days which the paddy is now steamed for hours and later dried and milled. This traditional method, results often to improper gelatinization, discoloring and low market value as well as low market acceptability of the milled rice because of a lot of inadequacies in the parboiling process such as the non uniformity in temperature monitoring which might affect the milling and quality of the rice after some certain period of storage (Raghavendra, And Juliano, 1970).

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 (Umogbai, 2013).

Rice being the second largest consumed cereal after wheat shapes the lives of millions of people; more than half the world's population depends on rice for about 80 percent of its food calorie requirements. Rice has been a good partner to mankind. The adaptations in terms of ecological, economical and technological changes around rice facilitated this "partnership between man and rice" (Braun, 2006). Parboiling is 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 (USDA, 2010).

The traditional method is time consuming and often laborious, and the end products are always below the required quality desired by the consumers. The traditional parboiled rice still do not meet the required standard of storage, Hence there is need to develop an improved method of parboiling rice.

2. Materials and Methods

2.1. Description of the Machine

The rice parboileris made up of a cylindrical drum, which is divided into two compartments by a thick plate. The upper part of the drum comprise of a cylindrical pipe that would aid easy conveyance and distribution of steam during steaming and the lower part where the heating element be attached, will comprises of water to heat the paddy rice during steeping and also to steam the rice during steaming. The pictorial view of the parboiler is as shown on figure 1. During the operation of the parboiler, the water is introduced into the steaming chamber and allowed to rise up to half of the steeping chamber and the heat supplied to increase the temperature of the water to the required temperaturebefore a clean, washed and weighed paddy rice is introduced into the steeping chamber and was allowed to boil for required number of hours at any steeping temperature which was determined with the aid of thermometer.

Figure 1. *Pictorial view of the paddy rice parboiler.*

2.2. Design of Machine Elements

2.2.1. Design for Paddy Rice Compartment

The paddy chamber is a cylindrical pipe that's formed from mild steel of thickness of 8mm, inner diameter 350mm and height of the paddy chamber to be 136.5mm. It has an opening at the top through which the paddy will be introduced into the compartment.

Assuming a 30kg of paddy rice will be processed per turn over and the Paddy rice compartment is a cylindrical pipe, determining the diameter of the compartment:

$$\text{Volume} = \pi r^2 \text{h} \quad (1)$$

$$\text{Bulk density of paddy rice } (BDP_r) = \frac{massofthepaddyrice}{volumeofthepaddyrice} \quad (2)$$

$$BDP_r = \frac{massofthepaddyrice}{\pi r^2 \text{h}} \quad (3)$$

Assuming a radius of 350mm

Bulk density of paddy = 571kg/m³

$$571\text{kg/m}^3 = \frac{30\text{kg}}{\pi r^2 h}$$

$$571\text{kg/m}^3 = \frac{30}{\pi x 350^2 \text{x h}}$$

$$\text{h} = \frac{30}{571 \text{x} \pi \text{x} 350^2}$$

h = 136.5mm

The paddy chamber is a thick cylindrical pipe and it will be under radialpressure exerted on it since 30kg of the paddy is assume per turnover which is equivalent to 300N therefore the force exerted in the chamberwill be

$$\text{Pressure (P)} = \frac{force}{area} \quad (4)$$

$$Area = \frac{\pi d^2}{4} \quad (5)$$

$$Area = \frac{\pi x 350^2}{4}$$

$$Area = 96211.27 mm^2$$

$$\text{P} = \frac{0.3}{96211.27}$$

P = $3.11\text{x}10^{-6}$ KN/mm²

=$3.11\text{x}10^{-6}$ N/m²

2.2.2. Estimating the Stress the Paddy Exerts on the Chamber

The circumferential stress (δ) acting on the cylindrical pipe is given as

$$\delta_1 = \frac{PR_i}{t} \quad (6)$$

Where,

p = maximum pressure applied on the cylindrical pipe is given as = $3.11\text{x}10^{-6}$ N/m²

R_i = radius of the paddy chamber

t = thickness f the cylindrical pipe = 2.5mm

Substituting the values in the equation we will have;

$$\delta_1 = \frac{3.11\text{x}10^{-6} \text{ x } 350\text{x}10^{-3}}{2.5\, x 10^{-3}}$$

$$\delta_1 = 4.35 x 10^{-10} \text{MPa}$$

However, the longitudinal stress of the paddy acting on the cylindrical pipe (δ_2) is given as;

$$\delta_2 = \frac{PR_i}{t} \quad (7)$$

$$\frac{3.11\text{x}10^{-6} \text{ x } 350\text{x}10^{-3}}{2(2.5\, x 10^{-3})}$$

$$\delta_2 = 2.177\text{MPa}$$

$$(\delta_3) = -\, 4.35\, x 10^{-10} \text{ MPa}$$

2.2.3. Design for the Steam Conveying Pipe

The steam conveying pipe is cylindrical pipe made up of mild steel of thickness 2.5mm, its placed inside the paddy chamber so as to distribute the steam effectively from the steaming chamber to the paddy chamber

Since the height of the paddy chamber = 136.5mm

Volume = $vol = \pi r^2 h$

Where,

h = 136.5 mm; 0.1365m

= πr^2 x 0.1365

$r^2 = \frac{3.25\text{x}10^{-3}}{0.1365\pi}$

$r^2 = 7.57\text{x}10^{-3} r = \sqrt{7.57\text{x}10^{-3}}$

r = 0.087m ≈ 87mm

Therefore the diameter of the pipe will be given as 174 mm

2.2.4. Design for Steam Distribution Pipes

The smaller distribution pipes are attached to the steam conveying pipe, this pipes are further perforated for easy distribution of the steam to the entire paddy chamber

Total volume to be distributed= $3.25\text{x}10^{-3}$ m³

Assuming that 40% of the curve surface area conveying pipe will be conveyed with steam distribution pipe

Therefore, the curve surface area to be = $\frac{40}{100 \text{ x } 2\pi \text{rh}}$

$$\frac{40}{100 \text{ x } 2 \text{x} \pi \text{x} 87 \text{x} 136.5} = 29846.3 \text{ mm}^2$$

Assuming the radius of the distribution pipes to be 20 mm

Therefore, the area of the circle

$$A = \pi r^2$$

$$= \pi 20^2$$

$$= 1256.8 \text{ mm}^2$$

Total number of pipes required = $\frac{29846.3}{1256.8}$ = 24 pipes

2.3. Evaluation Procedure

The dried paddy rice (Figure 2) used for testing the machine was purchased from Agenebode market in Etsako East local government of Edo State, Nigeria. The paddy rice were washed and weighed before parboiling.

During evaluation of the parboler, the water is inside the perboiler was preheated and maintainedatthe required temperature of 60, 70 and 80°C which was determined with the aid of temperature regulator before the introduction of the paddy into the cabinet. The paddy was then steeped for 2.5, 3.0 and 3.5 hours before a constant steaming time of 30 minute throughout the experiment.

Figure 2. *Sample of the Dried Paddy Rice used for the Study.*

2.4. Measurements and Calculation

2.4.1. Determination of Parboiling Efficiency

The parboiling efficiency is defined as the ratio of weight of parboiled grains to that of total weight of the sample parboiled in single batch. Mathematically;

$$parboiling\ efficiency(\%) = \frac{\text{weight of parboiled grains}}{\text{total weight of the sample}} \times 100 \quad (8)$$

2.4.2. Determination of Milling Quality

The milling quality is ratio of weight of cracked grains after milling to the total weight of milled rice. Mathematically;

$$Milling\ quality\ (\%) = \frac{\text{weight of cracked grains}}{\text{total weight of milled rice}} \times 100 \quad (9)$$

3. Result and Discussion

The data obtained from the calculated values of the average parboiling efficiency and milling quality at different steeping temperature and time is as shown on the table 1.

Table 1. *Average Value of Parboiling Efficiency and Milling Quality at Different Steeping Temperature and Time.*

Steeping time (hrs)	Steeping temp (°C)	Parboiling efficiency (%)	Milling quality (%)
2.5	60	65.45±0.153	52.70±0.400
	70	79.97±0.153	63.57±0.116
	80	75.93±0.306	59.93±0.153
3	60	74.87±0.256	77.53±1.721
	70	95.47±0.153	91.27±0.666
	80	81.13±0.209	79.40±0.100
3.5	60	74.20±0.985	79.30±0.100
	70	89.74±0.252	85.20±0.100
	80	79.34±0.153	76.67±0.153

Each value is the mean of triplicate ± standard deviation

3.1. The Analysis of Variance (ANOVA)

The data obtained were subjected to statistical analysis by considering the experiment as a 3×3×3 factorial design with two factors being investigated i.e. the steeping temperature and steeping time. The analysis of variance for the effect of steeping temperature and steeping time on parboiling efficiency and milling quality is as shown on the Tables 2 and 3 respectively. The tables reveal that the steeping temperature, steeping time and interaction between them have significant effects on the parboiling efficiency and milling quality of the parboiled rice at 0.05 confidence limit.

Table 2. *Analysis of Variance for the Effect of Steeping Temperature and Steeping Time is as shown on the parboiling efficiency.*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Steeping Time (St)	484.287	2	242.143	1.643E3	.000
Steeping Temperature (ST)	1289.802	2	644.901	4.375E3	.000
St * ST	91.138	4	22.784	154.568	.000
Error	2.653	18	.147		
Total	172800.950	27			
Corrected Total	1867.880	26			

Table 3. *Analysis of Variance for the Effect of Steeping Temperature and Steeping Time is as shown on the milling quality.*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Steeping Time (St)	3241.045	2	1620.523	1.788E3	.000
Steeping Temperature (ST)	579.001	2	289.500	319.432	.000
St * ST	142.964	4	35.741	39.436	.000
Error	16.313	18	.906		
Total	152379.430	27			
Corrected Total	3979.323	26			

3.1.1. Effects of Steeping Temperature and Time on the Parboiling Efficiency

The effects of steeping temperature and time on the parboiling efficiency of the machine are as shown on figure 3. It can be deduced from the curve that the optimum parboiling efficiency was obtained at steeping temperature of 70°C and 3hours steeping time.

3.1.2. Effects of Steeping Temperature and Time on the Milling Quality of the Rice Grain

The effects of steeping temperature and time on the milling quality of the parboiled rice grains of are as shown on figure 4. It can be deduced from the curve that the optimum milling quality was achieved when the steeping temperature was 70°C and 3hours steeping time.

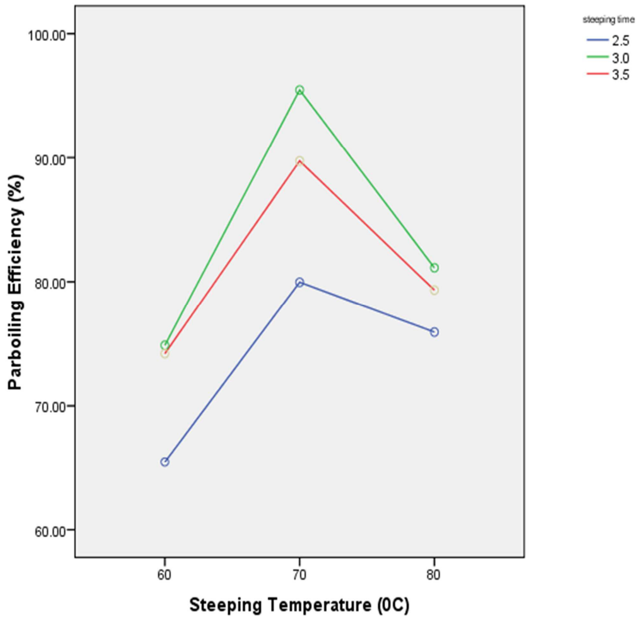

Figure 3. *Effects of Steeping Temperature and Time on the parboiling efficiency.*

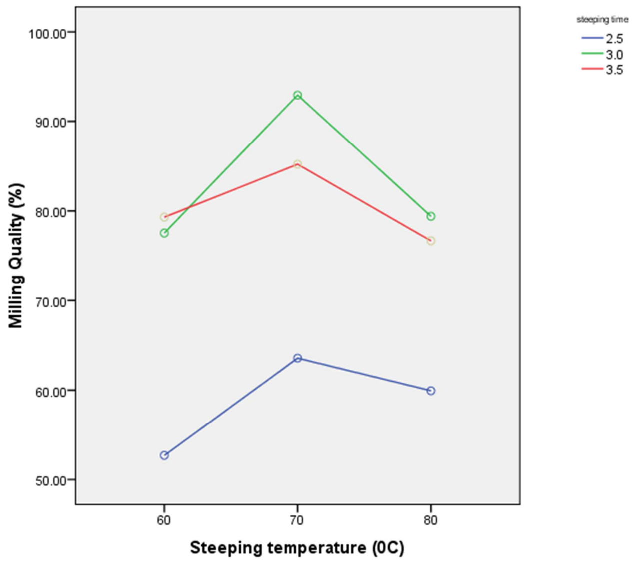

Figure 4. *Effects of Steeping Temperature and Time on the Milling Quality.*

4. Conclusion

A temperature-controlled paddy rice parboiler was designed, fabricated and evaluated in the Department of Agricultural and Bio-Environmental Engineering Technology, Auchi Polytechnic Auchi Edo State Nigeria. The parboiler was simple enough for local fabrication, operation, and maintenance and was found capable of parboiling paddy rice at an appreciable efficiency. The optimum parboiling efficiency of 95% with corresponding milling quality of 91% was obtained during the performance testing of the machine. The result of the statistical analysis shows that the steeping temperature and time has significant effects on the parboiling efficiency and milling quality of the parboiler at 95% confidence level. The parboiler has a production cost of *$275*.

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