ISSN:
Print - 2277 - 0593
Online - 2315 - 7461

Journal of Natural Science, Engineering and Technology

DEVELOPMENT AND PERFORMANCE EVALUATION OF A RICE DE-STONING MACHINE USING VIBRATING SIEVES

S.B. ADEJUYIGBE AND B.O. BOLAJI

Department of Mechanical Engineering, Federal University of Agriculture, Abeokuta. Nigeria
***Corresponding author**: bobbolaji2007@yahoo.com **Tel:** +2348035785662

ABSTRACT

A rice de-stoning machine using vibrating sieves was designed, fabricated with locally sourced materials and tested. The performance of the machine was evaluated and the results obtained showed that the feed regulator opening has significant effects on the de-stoning rate, de-stoning efficiency and rice losses. The best performance was obtained at feed regulator opening of 20 mm. Above 20 mm opening, the higher the feed regulator opening the higher the de-stoning rate and grain losses, and the lower the de-stoning efficiency. The average capacity of the machine was found to be 31.84 g/sec. and the average efficiency also was 98.3%.

Keywords: rice, de-stoning machine, fabricated, performance and efficiency, vibrating sieve.

INTRODUCTION

The popular cereal crops of the world include wheat, barley, oats, rice, maize, sorghum and millets, but the major cereals of the developing countries are rice, maize, sorghum and millets (Olugboji, 2004). Rice (*Oryza sativa*) is a leading cereal crop grown in all the continents of the world. It is often considered to be a tropical crop although it is grown in the temperate zone; in Asia, North America and Southern part of Europe (Li and Jiangzhe, 1986). Hence, rice is a universal food grown and eaten in all part of the world.

Rice has been part of the staple diet in eastern countries for thousands of years. It was first eaten in China some 5,000 years ago (Akintunde, 2007). Japanese rated rice very highly, as reflected in the many thousands of shrines, which may be seen across the country side, which are built to Inari, their rice god (Khan, 1973; Anping, 1989). For centuries, rice was a standard of wealth and was often used in place of money. When Japan invaded China, "coolies" were paid in rice. The growing of rice and the success or failure of the crop affected the history, art, literature, ceremonials and the very way of life of the people of India, China and Japan for centuries (Yan and Wenming, 1989; Akintunde, 2007).

Asian countries were the world largest producer of rice in 2002. Typically, China and India together produce about 50% of the world rice. In 2000, United States exported about 37% of the 8.7 million tons it produced, and Pakistan exported about 28% of the 7.2 million tons it produced. Thailand exported significantly more rice than any other country (FAO, 2004).

Major rice-importing countries include Nigeria, Cote d'Ivoire, Philippines, Saudi Arabia and Indonesia. Some rice-importing countries buy rice when drought, floods, or any other condition reduces the yield of their own rice crop, but Nigeria imports rice on a regular basis. Indonesia had been the worlds largest importer of rice until 2004 when it becomes self-sufficient in the commodity (FAO, 2004). Nigeria is currently the largest rice importer in the world. Nigeria imported rice to the tune of 1.8 million dollars alone in 2002. The annual demand for rice in the country is estimated at 5 million tons, while domestic production is 3 million resulting in a deficit of 2 million tons (Erenstein *et al*., 2003).

The importance of rice as a staple food in Nigeria has risen dramatically in the last four decades. Today, rice is hawked on the street of all cities and villages in the country and for many families; it is a daily item on the menu. Hence, any research on the improvement of the locally produced rice is not misdirected. Reasonable quantities of rice are produced yearly from different rice fields in Nigeria, but many Nigerians prefer imported rice. This is partly attributed to the fact that about 80% of rice produced locally in Nigeria contain stones. This is so, because most of rice produced locally is processed manually or with inefficient methods. The greater part of stones in Nigeria rice is introduced during winnowing, drying and milling.

Harvesting and post harvest handling methods introduce contaminants such as stones, sticks, chaff and dust into grains, which needs to be cleaned (Ogunlowo and Adesuyi, 1999). Threshed grains require considerable additional cleaning before it can be used as food. The cleaning process presents more difficulties than the actual threshing process. Pneumatic cleaning is the process of using air to lift light, chaffy and dusty materials out of the grain while heavier materials move downward. Air is generated by natural or mechanical fan. However, the limitation of natural wind method for cleaning is its unpredictable direction, speed and continuity, high labour requirement and rather imprecise degree of separation (Aguirre and Garray, 1999).

Sieving is a process in which material mixture is moved over a perforated surface with openings of specified shape and size. Air is used to separate light and heavy materials from mixtures. Aerodynamic characteristics of particle mixtures are important for cleaning. The cleaning process would turn to an aspiration process when air speed is high thereby separating grains and chaff by differences in terminal velocity and drag coefficient. At low feed rates, aerodynamic separation of grain from straw and chaff takes place over the sieve and at higher feed rate, material particles are no longer supported aerodynamically, because they form a mat on sieve and increase grain losses (Simonyan and Yiljep, 2008).

Jekayinfa *et al*. (2003); Adejuyigbe and Bolaji (2005); Bolaji *et al*., 2008 have reported that for mechanization of agriculture in Nigeria to succeed, it must be based on indigenous designs, development and manufacture of most of the needed machines and equipment to ensure their suitability to the crops as well as to the farmers technical and financial capabilities. Therefore, in this work, rice destoning machine with vibrating sieves is designed and fabricated using locally sourced materials for the purpose of removing stones and other impurities from the locally produced rice. This paper also presents the testing and performance evaluation of the machine.

MATERIALS AND METHODS

The Location and Design Consideration

The rice de-stoning machine was designed and fabricated in the Department of Mechanical Engineering Workshop, Federal University of Technology, Akure, Nigeria.

The machine components were selected based on the most important characteristics required to be considered for engineering components as stated by Waterman (1979). These properties include: (i) mechanical properties such as stiffness, strength, fatigue and toughness; (ii) corrosion susceptibility and methods of corrosion protection; (iii) wear resistance and friction properties; and (iv) special properties such as thermal, electrical and magnetic properties.

Design of Machine Components

Hopper design

The hopper design is based on the volume of frustum of a pyramid (Fig. 1). The volume of frustum of a pyramid can be obtained as follow:

Volume of the big pyramid of base ABCD and vertex IJ = $\frac{1}{3}c^2(h+y)$

Volume of the small pyramid of base EFGH and vertex IJ = $\frac{1}{3}k^2 y$

Volume of frustum = $\frac{1}{3}\left[c^2(h+y)-k^2 y\right]$ (1)

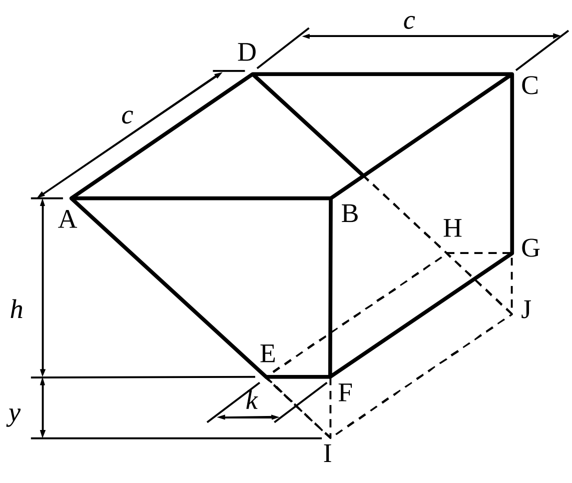


Fig. 1: Hopper design

Where, h = height of the frustum (m); y = height of the small pyramid (m); c = length on one side of the square base of te big pyramid (m); and k = length of the reduced side of the rectangular base of the small pyramid (m).

The height of the small pyramid (y) can be obtained by using similar triangular formulae as:

$$y = \frac{hk}{c-k} \quad \text{or} \quad y = \frac{h}{c/k - 1} \qquad (2)$$

The recommended angle of repose for gravity discharge of rice ranges between 15^o and 20^o (Eugene and Theodore, 1986). In order to allow free flow of rice, a hopper slant angle of 30^o, this is 10^o above the angle of repose. Assuming hopper base of 45 mm x 450 mm, therefore, k = 45 mm and c = 450 mm. Using Eqs. (1) and (2), y = 26 mm, h = 234 mm and the volume of the hopper is 17.53 litres.

Design of vibrating sieve

The degree of vibrating movement depends on the number of vibration per seconds (frequency) and on the shaking distance. Vibration of the sieve separates grains of different weight. The sieve is designed to vibrate by the work of electric motor, and the vibrating movement loosen a mixture of grains and at the same time the grains are transported along the inclined sieve. The sieve design consists basically of the determination of diameter 'd' of the sieve (Akintunde, 2007):

$$d = \sqrt{\frac{D^2(3\pi - 2C_o)}{C_o}} \qquad (3)$$

where, D = maximum diameter of rice grain size (3 mm); and C_o = coefficient of opening (3.5). Therefore, d = 2.5 mm.

Blower design

The theoretical air flow rate (Q_T) is given as (Hall *et al*., 1988):

$$Q_T = vD_pw \qquad (4)$$

Where, v = velocity of air (m/s); D_p = depth of air (m); and w = width over which air is required. The actual air flow rate (Q_A) required will be higher than the theoretical and is obtained using Eq. (5) (Hall *et al*., 1988):

$$Q_A = \frac{Q_T}{\eta} \qquad (5)$$

Where h = efficiency of blower. "v = 5.6 m/s" is chosen such that it is higher than "5.3 m/s" the terminal velocity of rice (Ogunlowo and Adesuyi, 1999). Considering a depth of air of 0.42 m, air width of 0.42 m and blower efficiency of 80%; therefore, from Eqs. (4) and (5), Q_T = 0.988 m^3/s and Q_A = 1.23 m^3/s.

Power required to drive the fan (blower)

Power required from the motor shaft to drive the fan is given by (Adejuyigbe and Bolaji, 2005):

$$P = Tv = Wr \times v \quad (6)$$

where, T = torque (Nm), W = weight of fan blades (N), r = radius of the fan (m), and v = angular velocity (rad/s.). The mass and angular velocity rating of fan with required air supply width are 5.7 kg and 26 rad/s, respectively. From Eq. (6), power required = 0.305 kW. Angular velocity is given as (Hall *et al*., 1988):

$$\varpi = \frac{2\pi N}{60} \quad (7)$$

where, N = angular speed (248 rpm). Therefore, an electric motor of 0.305 kW and 248 rpm is required, but the motor chosen was 0.5 kW and 250 rpm, which was the closest capacity found in market.

Assembly of Machine Description of Major Components

The frame of the machine was erected with rigid structures at the four corners in order to ensure stability. The de-stoning unit was mounted in the main frame and the hopper was mounted on the top of the frame. The screens and their accompany trays were suspended in the frame at inclined angle. Also, the electric motor was fastened using bolts and nuts on the base prepared for this purpose. The fan blades were fixed directly on the electric motor, which eliminates the use of belt and pulley. The schematic diagram and general view of the rice de-stoning machine are shown in Fig. 2 and Fig. 3, respectively. The machine is powered by electricity. It is made up of six major components, the hopper, sieves, blower, power unit, collecting trays and the machine frame.

The hopper

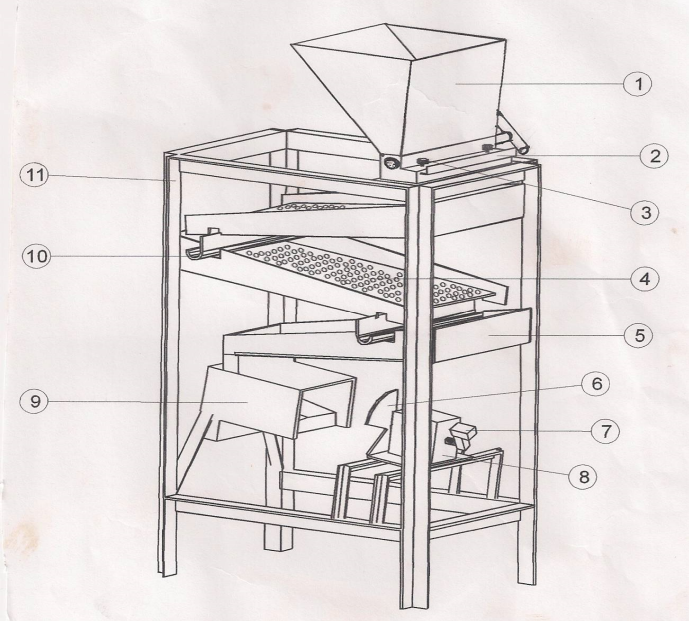
The hopper is the device through which the machine is fed or charged with impure rice grains. It has only one slanted side. It has a square base on which an inverted hollow frustum is attached. It is constructed from 1.5 mm thick galvanized metal sheet and the square base is constructed with mild steel angle bar of 3 mm thick. Feed regulator is located at the base of the hopper. The feed control regulates the feed rate of the grain mixture passing into the machine through the hopper.

Vibrating sieves

The machine has two mechanically agitated sieves. It was constructed from 1.5 mm thick galvanized metal sheet. The sieves and the accompany trays were suspended in the frame at an inclined angle (20^o). The size of openings of the sieves were made in such a way that they will allow stones of smaller size (less than 3 mm) to pass through them into the collecting trays under the sieves. Other stones of equal size with rice and above (greater than 3 mm) move to the last cleaning stage.

Blower

The blower is a centrifugal fan made of mild steel plate. It is located in the lower part of the machine and mounted at an angle of 35^o to the horizontal opposite to the flow of rice grains. The centrifugal fan comprises of four straight impellers, all in an involute casing attached to the shaft of electric motor.



(1) Hopper, (2) Feed regulator, (3) Bolt, (4) Sieve, (5) Collecting tray, (6) Blower, (7) Vibrator, (8) Electric motor, (9) Outlet tray, (10) Stone passage, (11) Frame.

Fig. 2: Schematic diagram of the rice de-stoning machine

Fig. 3: General view of the rice de-stoning machine

Power unit

The arrangement of power unit eliminates the use of belts and pulleys. The blower was mounted directly on the shaft of electric motor. The electric motor is the prime mover of the machine. It is a single phase 0.5 kW motor with speed of 250 rpm. It was mounted on the frame with its seat inclined at an angle of 35° to the horizontal. The motor was fastened to the machine frame with bolts and nuts.

Collecting trays

Collecting trays were fabricated from 1.5 mm thick galvanized metal sheet. They were four in number. Two of the trays were fitted below the sieves to collect small stones that are sieved from the grain mixture. The remaining two sieves were installed in the de-stoning section; one is to collect the pure rice grains and the second is for the collection of stones of equal size with rice or bigger, which travel along with rice grains to de -stoning section.

Machine frame

The machine frame carries every other component of the machine. It is fabricated from 70 mm x 70 mm x 5 mm thick angle bars welded together. The four legs of the frame form the machine stand. The overall length, width and height of the machine frame are 750 mm, 475 mm and 1380 mm, respectively.

Testing and Evaluation

The machine requires only one operator since it is easy and simple to operate. Before the operation of the machine, it must be ensured that all the parts are properly set and fixed or bolted together. The machine is switched on and a charge of mixture of rice and sand is fed into the machine through the hopper. As the motor operates, it vibrates the sieves and the grain mixture flows from the hopper through the vibrating sieves to the de-stoning section. In this section, the blower (blast fan) supplies air stream across the flowing grains. The air stream gives the mixture grains and stones velocity that changes their directions and causes them to experience different projectile motions. The range of projectile motion of rice grains is greater than that of stones due to higher weight of stones; therefore, pure rice grains are collected in a tray that is farther than that of stones. The machine was tested with a single-phase 250 rpm, 0.5 kW electric motor. The machine was loaded with 3000 g of local rice grains mixed with 30 g of sand through the hopper. At various sizes of feed regulator opening (10, 15, 20, 25, 30, 35, 40 and 45 mm), mixture of rice and sand of total weight of 3030 g were fed to the machine. The time taken for the de-stoning, and the weights of the rice and stone separated were noted.

RESULTS AND DISCUSSION

From the test results, it was observed that an increase in the feed regulator opening results in corresponding increase in the de-stoning rate of the machine (Fig. 4). The decrease in feed regulator opening restricts the flow of the grain mixture through the machine, thereby reducing the de-stoning rate. Fig. 5 shows the variation of de-stoning time with feed regulator opening. The smaller the feed regulator opening, the higher the time needed for the separation of rice grains and stones.

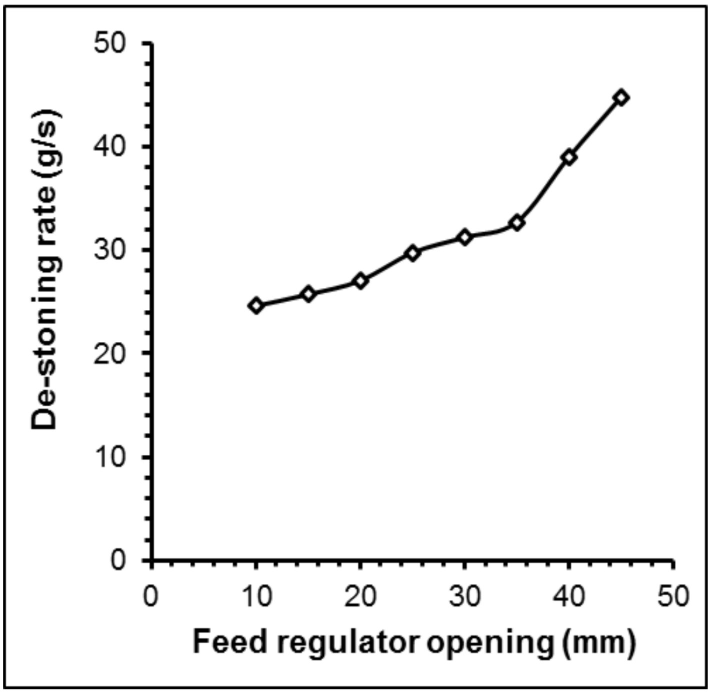


Fig. 4: Variation of de-stoning rate with feed regulator opening

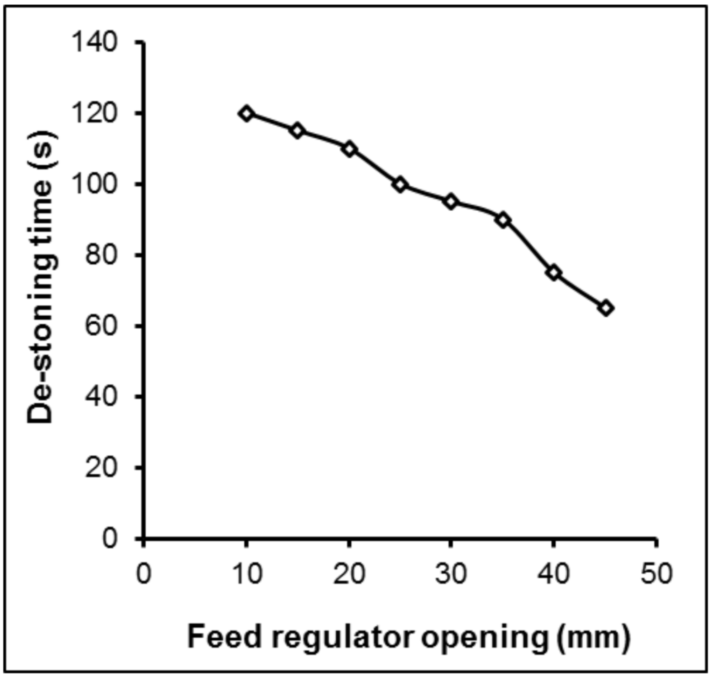


Fig. 5: Variation of de-stoning time with feed regulator opening

Figs. 6 and 7 show the relationship between the weight of separated rice grains and stones with the feed regulator opening, respectively. Initially, in Figs. 6 and 7, as the feed regulator opening increases the weight of separated rice grains increases and the weight of separated stones reduces. Later, as the opening increases beyond 20 mm, the weight of separated rice grains start to decrease, while the weight of separated stones start to increase. This shows that feed regulator opening has significant effects on the performance of the machine. It was observed that at various feed regulator openings, the separated stones contained some rice grains, except at 20, 25 and 30 mm openings when few or no rice was found in the stones collecting tray.

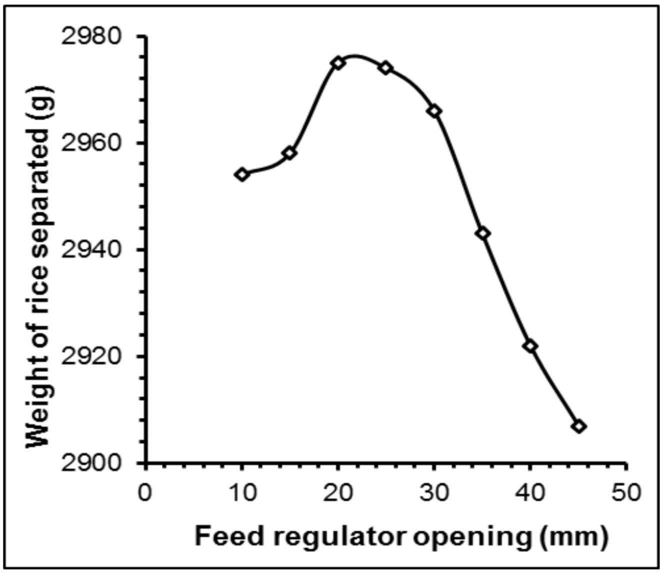


Fig. 6: Variation of weight of rice separated with feed regulator opening

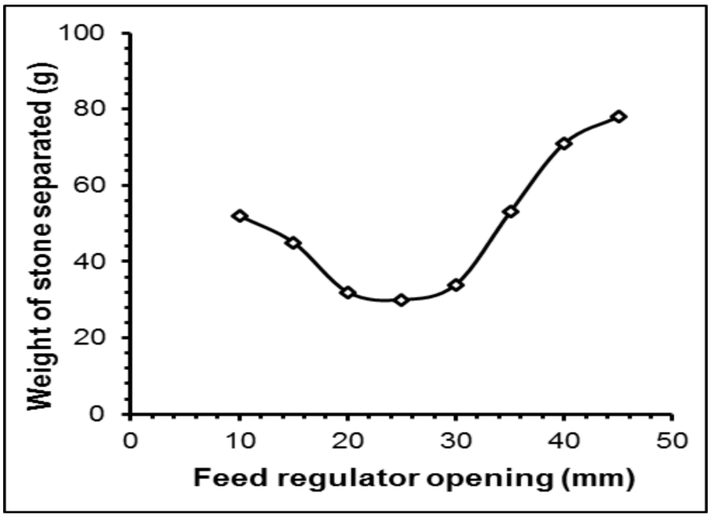


Fig. 7: Variation of weight of stone separated with feed regulator opening

Fig. 8 shows the relationship between loss of rice grains and feed regulator opening. It was also deduced from this figure that at initial stage, as feed regulator opening increases the loss of rice reduces. The minimum loss was obtained at 20 mm regulator opening. Beyond 20 mm opening, the rice losses increase as the feed regulator opening increases.

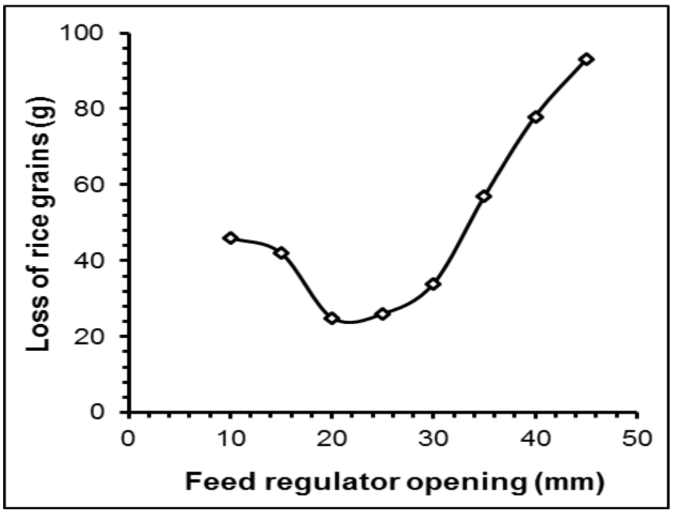


Fig. 8: Variation of loss of rice grains with feed regulator opening

The variation of de-stoning efficiency with the feed regulator opening is shown in Fig. 9. It shows that beyond 20 mm opening, the higher the feed regulator opening the lower the de-stoning efficiency. Rice grains drifting and losses occur at higher openings, which reduced the de-stoning efficiency. Comparison between Fig. 4 and Fig. 9 revealed that the choice of feed regulator opening size for the machine will be a compromise between de-stoning rate (capacity) and de-stoning efficiency.

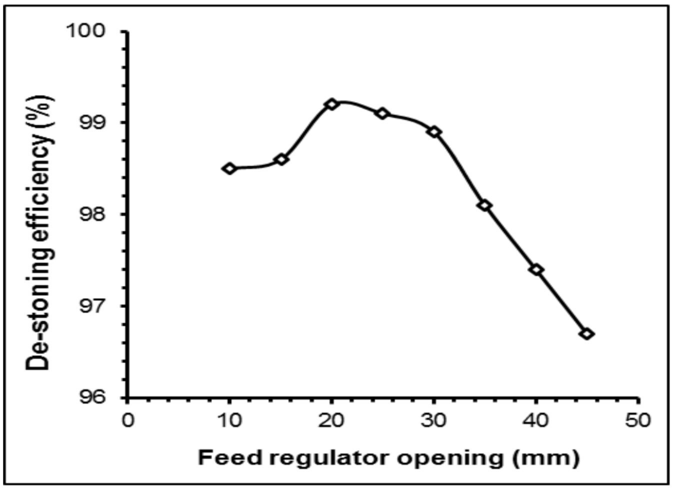


Fig. 9: Variation of de-stoning efficiency with feed regulator opening

Overall evaluation showed that the performances at feed regulator openings of 20, 25 and 30 mm were satisfactory. The maximum de-stoning efficiency of 99.2% was obtained at a feed regulator opening of 20 mm and de-stoning rate of 27.05 g/s. The average capacity and average efficiency of the machine were found to be 31.84 g/s and 98.3%, respectively. These results justified the reduction in power loss through the elimination of belt and pulley when compare with the work of Akintunde (2007) who developed a rice polishing machine and reported a maximum machine capacity of 25 g/s.

CONCLUSION

A rice de-stoning machine was designed, fabricated, tested and its performance was evaluated. The test results showed that an increase in the feed regulator opening beyond 20 mm resulted in decrease in weight of de-stoned grains and de-stoning time, and increase in de-stoning capacity and grain losses. The results also revealed that the higher the feed regulator opening beyond 20 mm the lower the de-stoning efficiency. Therefore, the choice of feed regulator opening size for the machine will be a compromise between de-stoning capacity and de-stoning efficiency. Maximum out put of de-stoned grains and minimum grain losses were obtained at a feed regulator opening of 20 mm. Also at this opening, maximum de-stoning efficiency of 99.2% was obtained. Average capacity of the machine was found to be 31.84 g/s and average efficiency of the machine was found to be 98.3%.

ACKNOWLEDGEMENT

The authors wish to acknowledge the assistance of Mr. V.O. Awhewhejiri, former student of the Department of Mechanical Engineering, Federal University of Technology, Akure, Nigeria in the collection of data used for this work.

REFERENCES

Adejuyigbe, S.B., Bolaji, B.O. 2005. Design, fabrication and performance evaluation of bean dehuller. *Journal of Science and Technology, KNUST, Kumasi, Ghana*, 25(1): 125-132.

Aguirre, R., A. E. Garray. 1999. Continuous flowing portable separator for cleaning and upgrading beans seeds and grains. *Agricultural Mechanization in Asia, Latin America and Africa* 30(1): 59-63.

Akintunde, M.A. 2007. Development of a rice polishing machine. *AU Journal of Technology*, 11(2): 105-112.

Anping, P. 1989. Discussion of paddy rice remains in Pengtoushan culture and Chinese prehistoric paddy rice agriculture. *Agriculture Archaeology*, 2: 102-108.

Bolaji, B.O., Adejuyigbe, S.B., Ayodeji, S.P. 2008. Performance evaluation of a locally developed cassava chipping machine. *South African Journal of Industrial Engineering*, 19 (1): 169-178.

Erenstein, O., Lançon, F., Akande, S.O., Titilola, S.O., Akpokodje, G., Ogundele, O.O. 2003. *Rice production systems in Nigeria*: A survey. WARDA, Abidjan, Cote d'Ivoire.

Eugere, A.A. and Theodore, B. 1986. *Standard Handbook for Mechanical Engineering*. McGraw-Hill, New York.

Food and Agriculture Organization (FAO). 2004. *Strengthening farm-agribusiness linkages in Africa*. Summary results of five country studies in Ghana, Nigeria, Kenya, Uganda and South Africa. Edited by Alexandra Rottger. FAO, Rome. http://www.fao.org

Hall, A.S., Holowenko, A.R., Laughlin, H.G. 1988. *Theory and problems of machine design, Schaum's Outline Series*. S.I. (Metric) Edition, McGraw-Hill Book Company, New York.

Jekayinfa, S.O., Olafimihan, E.O., Odewole, G.A. 2003. Evaluation of pedal-operated cassava grater. *LAUTECH Journal of Engineering and Technology*, 1(1): 82-86.

Khan, A.U. 1973. Rice drying and processing equipment for Southeast Asia. *Transaction of America Society of Engineers*, 16: 1131-1135.

Li, A.P., Jiangzhe, A.K. 1986. Research on rice origin. *Agriculture Archaeology*, 2: 232-247.

Ogunlowo, A.S., Adesuyi, S.A. 1999. A low cost rice cleaning and destoning machine. *Agricultural Mechanization in Asia, Africa and Latin America* 30(1): 20-24.

Olugboji, O.A. 2004. Development of a rice threshing machine. *AU Journal of Technology*, 8(2): 75-80.

Simonyan, K.J., Yiljep, Y.D. 2008. Investigating Grain Separation and Cleaning Efficiency Distribution of a Conventional Stationary Rasp- bar Sorghum Thresher. *Agricultural Engineering International: the CIGR Ejournal*, Manuscript PM 07 028. Vol. X. August, 2008.

Yan, A.Y., Wenming, M.P. 1989. New discussion of Chinese cultivated rice origin. *Agriculture Archaeology*, 2: 72-83.

Waterman, N.A. 1979. *The selection of materials: engineering design guide*. University Press, UK.

(Manuscript received: 6th July, 2011; accepted: 15th May, 2013).