Bread-slicing machine

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Abstract: This study developed a compact front loading machine for slicing loaves of bread. The machine is fast, efficient, safe and easy to operate. It was designed to accommodate a normal loaf of bread per pass. It works on the principle of gravity loaf in-feed system and the up-and-down reciprocating motion of the blade frame that carries 22 parallel cutting blades spaced at a regular interval of 14.5 mm apart. It is driven by a 2 horsepower electric motor via a V-belt power transmission system. The moving components are born on self-lubricating bearings and specially designed vibration absorbers; it automatically stops to save running cost once the loaf is completely sliced. It also incorporates a crumb collection tray to enhance the hygiene of the process. Evaluation tests revealed that increasing the cutting speed above the standard commercial bakery speed of 420 r/min increased bread wastage and reduced uniformity of slice thickness.

Keywords: bread slicing, sliced-bread, slicing machine, reciprocating blades

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1 Introduction

Bread is a staple food around the world that is prepared by baking dough of flour and water. It may be leavened or unleavened. Salt, fat and a leavening agent such as yeast are common ingredients; it may contain a range of other ingredients such as milk, egg, sugar, spice, fruit, vegetables, nuts or seeds. Adejugbe et al. (2012) reported that bread has become a common food and a cheap source of carbohydrate to all and sundry among Nigerians. Bread slicing prevents wastage, allows for even sharing, packaging for convenience and increased market value of the bread. However, the problem of sanitation during the slicing process (and indeed other bread production operations) has become a source of concern to stakeholders. A machine that will ensure that there is little or no human contact during this slicing operation is therefore a welcome development. Several approaches have been made in the past to produce a simple, efficient and reliable bread slicing device with varying degrees of achievement. The ability to provide adequate support for the bread loaf and guidance of the slicing knife requires a great attention.

Earlier studies on the improvement of bread-slicing machines have been reported (Adio and Oluwole, 2008; Tunji and Joba, 2008). Some models of existing bread slicing machines are shown in Figure 1. A bread-slicing machine makes it easier to slice bread without going through much stresses. It also helps to prevent wastage; allows for even sharing; packaging for convenience and increase market value of the sliced bread. The system consists of a relatively simple, efficient and reliable mechanism designed to reduce cost, decrease down-time, increase efficiency, improve alignments, achieve effective slicing and prevent the blade from deformation during operation.

Olatunji and Olowojoba (2008), Odior et al. (2009) and Oladejo et al. (2015) developed various models of a bread slicing machine that utilized a power screw to feed the bread loaf towards the reciprocating slicing blade and can be operated both manually and electrically. These

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machines are expensive due to incorporation of additional electric motor to drive the power screw; however, their major shortcoming is that the shaft power output is insufficient to cause the desired reciprocating action of the blade frame.

In order to realize the multi-functioning capacity objective of an existing slicing and shredding machine, which is a kind of food processing machinery widely used in the food processing industry, Zhang et al. (2013) modified and improved the machine by incorporating a gear and clutch drive system. Odior (2012), in an attempt to facilitate the processing of meat, developed a meat slicing machine which consists of a cutting blade, a meat feeder, a meat tray, a meat clamp, the crank mechanism and a control unit. The machine was designed to enhance the hygienic slicing of meat for both domestic and commercial consumption and it can accommodate from one to six cutting blades which are spaced 6.5 mm from each other to give a meat slice thickness of 5 mm per slice. It takes an average of four seconds to cut a slice and one hour for 2.673 tonnes of meat. Odior (2007) reported the development of a bread slicing machine using mainly some locally sourced materials; and it can accommodate a normal loaf of bread per pass. The machine is designed to accommodate twenty cutting blades which are spaced 14.5 mm from each other to give a bread slice thickness of 13 mm per slice. It takes an average of five seconds to slice a loaf of bread.

(a) (b) (c) (d) (e)

Figure 1 Bread slicing machines

Bindon and Thomas (1995) reported bread slicing guide appliance that supports and holds bread loaves of varying sizes while providing and alignment to the slicing knife; it incorporates an electric fan that facilitates debris collection by aspiration. Birmingham (1978) designed a bread slicer which accommodates loaf variability by provision of several grooves in the base plate that provided alternate position for the slicing guides. Also, no lateral holding force could be applied to the loaf during slicing as a result of loaf variability. In Hayman-Bread Slicer, the slicing guides were inserted in a series of grooves, thus allowing for a variable loaf size, as an end stop and side pressure clamping were not included; so the loaf is placed in position without standardization during slicing (Wenske, 2003). Kehinde (2002) designed and fabricated a bread slicer using local materials for affordability, but the slicer can only slice a particular length of loaf because the guide is fixed instead of being adjustable. Bayo (2006) and Abu et al. (2014) attempted to improve on the design by using a variable speed motor and making use of adjustable guide. The objective of this study is to develop a bread slicer with adjustable guides to enhance loaf alignment and produce an effective slicing operation with high efficiency.

2 Materials and method

2.1 Operational principle

The bread slicing machine makes use of a reciprocating motion derived from an electric motor through a slider-crank drive mechanism and gravity in-feed system. The machine consists of a set of parallel blades that is vertically arranged and mounted on a blade frame. The ends of the blades are secured to the blade frame with the help of fasteners M 6 × 5 mm (bolts and nuts). The blade frame is attached to the reciprocating drive mechanism which drives it up and down within a frame guide to create the cutting action on a loaf of bread. The loaf is fed in through the gravity in-feed system in the absence of a pushing plate, while the crumbs are collected through the crumb tray.

2.2 Design and strength calculation:

2.2.1 Selection of the drive motor

A single phase, 2 horsepower electric motor was used to power the blade frame. The motor runs at 1500 r/min (angular velocity (N_1), according to manufacturer's specifications). The selection involved the determination of the power required to drive the blade frame and the blade. It is desired to have 14 up and down (reciprocating) motions per second (r/sec), thus the required angular velocity, N_2, of the crank driving the connecting rod plus blade assembly was calculated as follows (Olatunji and Oluwajoba, 2008; Oladejo and Oriolowo, 2015):

$N_1 = 1500$ r/min

$$N_2 = \frac{14}{2} \quad r/\sec \tag{1}$$

Converting, N_2 in r/sec to N_2 in r/min

$$N_2 = 7 \quad r/\sec \times \frac{60s}{1\min} = 420 \quad r/\min \tag{2}$$

The weight of the connecting rod plus blade assembly (blade frame and the included blades), W_t, is calculated as:

$$W_t = \{(4 \times A_f\, f_f) \times (l + b) + (f_b \times t \times b_b \times l_b \times 8) + (2 \times A_c \times f_c)\} \times 9.81$$

$$= 14.5 \quad N$$

For a sprocket radius of 0.25 m, the linear velocity, V, of the crank pin on the sprocket that lifts the connecting rod plus blade assembly is given by

$$V = \frac{2 \times \pi \times 0.25 \times 420}{60} = 11 \quad m/s \tag{3}$$

Power (P) required to lift the connecting rod plus blade assembly is given as

$P = W_t \; x \; V = 14.5 \text{ x } 11 = 160$ W

Applying factor of safety of 6 (Khurmi and Gupta, 2005), the required drive power = 6 × 160 = 960 W. Since 750 W = 1 hp, a 2 horsepower drive motor is recommended.

2.2.2 Selection of V-Belt

Belts are employed to transmit power from one shaft to another where it is not necessary to maintain an exact speed ratio between two shafts. Power losses due to slip and creep amount to from 3% to 5% for most belt drives (Bindon and Thomas, 1995):

When the belt is rotating, there is always a tight side which sustains a tension, T_1, and a slack side which sustains tension, T_2, such that.

$$P = (T_1 - T_2) \times V \tag{4}$$

Taking into account the centrifugal effects of the mass of belt (M) in motion, the relationship of the forces is given as:

$$\frac{T_1 - MV^2}{T_2 - MV^2} = e^{\frac{\mu\beta}{Sin(\alpha/2)}} \tag{5}$$

Where β = angle of wrap of pulley around the smaller pulley and α = included V-angle of the driving V-pulley.

The average tension in the belt is given as:

$$T_0 = (T_1 + T_2)/2 \tag{6}$$

Selection of V-belt and pulleys in the design of the bread slicer was accomplished with the use of a manufacturer's catalogue *(Fenner Power Transmission Catalogue).* The basic variables required for the selection are transmission power, P, motor speed, centre distance and pulley diameter.

The length of the belt is calculated using the following Equation (7).

$$L = [\pi(D + d)/2] + [(D - d)^2 / 4C] + 2C \tag{7}$$

Substituting the diameters of the big and small pulleys (20 cm and 9.5 cm respectively), and the centre distance (C = 70 cm) into Equation (7), we have

L = (π (0.2 + 0.095)/2) + ((0.2 – 0.095)^2/4 × 0.7) + 2 × 0.7 = 1.867 m

A49 section belt was used for the transmission of power.

2.2.3 Shaft design

This primarily consists of the determination of the correct shaft diameter in order to ensure satisfactory strength and rigidity when the shaft is transmitting power under various operating and load conditions (Hall et al., 1980; Adetan et al., 2013). The shaft is made of ductile iron material.

(a) Torsional Moment (M_t):

M_t was calculated using:

$$M_{t(\max)} = (T_1 - T_2)R \tag{8}$$

ASME code equation for a hollow shaft was employed to determine shaft diameter.

$$d^3 = \frac{16}{\pi S_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \tag{9}$$

Based on this equation (9), 20 mm shaft diameter was recommended.

(b) Torsional rigidity

Torsional rigidity is based on the permissible angle of twist. The amount of permissible twist depends on the particular application and varies about 0.3 deg/m for machine to shafts to about 3 deg/m for line shafting (Petersen et al., 1996):

$$\theta = 584\frac{M_t L}{Gd^4}$$; for a solid circular shaft. (10)

Using the maximum permissible amount of twist of 3 deg/m for line shafting, the minimum diameter was obtained as d = 14 mm. Since this is less than the diameter of 20 mm earlier determined using equation (9), a 20 mm diameter solid shaft was chosen.

2.2.4 Keys design

Keys are employed to prevent relative motion between the shaft and the connected member (sprocket, pulley) through which torque was transmitted. A rectangular sunk key with head at one end (Gib-head key) was used because of the easy of removal (Bayo, 2006; Oladejo and Oriolowo, 2015). The usual dimensions (width, w_k, and thickness, t_k) of the gib-head key are obtained as:

Width of key, $w_k = d/4$ (11)

Thickness of key, $t_k = \frac{2w_k}{3} = \frac{d}{6}$ (12)

Using a shaft diameter, d, of 20 mm, from Equations (10) and (11), we obtain w_k = 5 mm and t_k = 3.33 mm.

2.3 Description of the Machine working components.

The bread slicing machine (gravity feed bread slicer) is shown in Figure 2. The dimension of the complete assembly of the machine is 600 mm × 500 mm × 1000 mm. It consist of a fixed frame and a reciprocating blade frame, crankshaft, driven shaft, crank wheel, connecting bars, in-feed and out-feed crumbs trays, keys, pulleys, plummer bearings, bolts and nuts, blade holder and blades.

2.3.1 Frames

The fixed frame is made of a 5 mm thick mild steel square pipe of cross-sectional dimension 40 mm × 40 mm. It is welded together to form a cuboidal structure of dimension 600 mm × 600 mm × 700 mm, having four stands suspended on dampers. The base plate of the electric motor is mounted at a vertical height of 200 mm, while the crankshaft is suspended at another vertical height of 400 mm on the fixed frame. The driven shaft transfers motion from the connecting bar to the two reciprocating frames of 400 mm × 200 mm, where blades were mounted as shown in Figure. 2.

2.3.2 Crankshaft

This is made of mild steel material of Θ 20 × 450 mm, as a driving shaft, driven by the electric motor through V-belt drive arrangement at one end. At the other end is mounted the crank wheel of 220 mm diameter, with the help of key-way of 6 mm × 5 mm × 30 mm. The crankshaft is positioned on the machine frame with the help of two plummer bearings, while the connecting rod is located at a distance of 50 mm out of the center of the crank wheel to facilitate the reciprocating motion of the blade mechanism.

2.3.3 Connecting bars

These are made of mild steel material of rectangular bars of 50 × 150 × 8 mm. They are two in number, bolted together with the help of the gudgeon pins and sleeves to facilitate frictionless reciprocating motion. The first connecting bar is connected to the crank wheel while the second bar is connected to the driven shaft of the blade mechanism. The connecting bars convert the rotary motion of the crankshaft to the reciprocating motion of the blade frame as shown in Figure 2.

2.3.4 Keys

It was a rectangular sunk key with a head at one end (gib-head key) was employed. The key material was made from **AISI 1020** cold-drawn steel of 6 mm × 5 mm ×30 mm.

2.3.5 Blades

The slicer blades are made of AISI 410 stainless steel material of 15 mm thickness, having serrated teeth; each blade is 15 mm wide and 250 mm long. They are independently mounted on the blade holder using fasteners of M 6 × 5 mm (bolts and nuts) to enhance replacement, and positioned at a gap of 14.5 mm to each other.

2.3.6 In-feed, out-feed and crumbs tray

They are made of AISI 410 Stainless Steel material of 2.5 mm thickness in order to eliminate corrosion, rust and wear and therefore prevent food contamination.

2.3.7 Bolts and nuts

They **we**re generally used to fasten the components described above together to enhance ease of disassembling and replacement of faulty parts.

2.3.8 Damper

A damper of rectangular shape of 100 mm × 100 mm × 30 mm was employed at the base of each stand in order to reduce noise and vibration during slicing operation.

Figure 2 Assembling of the bread slicer

3 Results and discussion

3.1 Testing and evaluation

3.1.1 Testing procedure

The performance evaluation of the bread slicer was based on the value of the overall efficiency of the slicer which is a function of loaves cutting ability, loss in weight of loaves and slice uniformity. The performance of the bread slicer was evaluated by load testing it with 170 mm (length) × 67 mm (breadth) × 80 mm (height) loaves (Specimen A) and 250 mm × 75 mm × 105 mm loaves (Specimen B). The results of the tests are shown in Tables 1, 2 and 3 below.

3.1.2 Time of cutting

The bread slicer was operated and the time taken for it to slice samples of Specimen A (170 mm × 67 mm × 80 mm loaves) and Specimen B (250 mm × 75 × 105 mm loaves) were obtained. The average cutting time was evaluated using the equation below:

$$\bar{\tau} = \frac{\sum \tau}{n} \qquad (13)$$

3.1.3 Weight loss

Weight loss was obtained by weighing the crumbs of samples on the weighing balance or alternatively by weighing samples of each specimen before slicing and weighing after slicing. These helped to evaluate the Percentage Weight Loss, (PWL), which is given as:

$$PWL = \frac{W_{bs}(A,B) - W_{as}(A,B)}{W_{bs}(A,B)} \times \frac{100}{1} \quad (\%) \tag{14}$$

$W_{bs}(A,B)$ = Weight before slicing loaves of Specimen A or B, kg,

$W_{as}(A,B)$ = Weight after slicing loaves of Specimen A or B, kg

3.1.4 Slicing uniformity

The thickness of each slice of specimens A and B were measured at the end of the slicing operation and the number of slices that did not conform to standard thickness (10 mm) was determined. Obtaining slicing uniformity helped to analyze for the conformity with respect to standard thickness for every 24 slices obtained from samples of both specimens. The equation for evaluating the percentage conformity (PC_{TS}) to standard thickness is given as:

$$PC_{TS} = \frac{N_c(A,B)}{N_T(A,B)} \times 100 \quad (\%) \tag{15}$$

The equation for evaluating the percentage that doesn't conform to standard thickness (PC_{NS}) is given as:

$$PC_{NS} = \frac{N_{dc}(A,B)}{N_T(A,B)} \times 100 \quad (\%) \tag{16}$$

During load testing, the slicer was operated at the speed of 450 r/min as for a standard commercial bakery, in-feed weight of 2.8 kg and at an in-feed angle of 57^o. The values obtained for the above load testing are recorded in Tables 1 and 2.

3.2 Efficiency of the bread slicer

The efficiency of the machine, $\eta_{(A,B)}$, was calculated based on $PWL_{(A,B)}$ of both specimens (A and B) using the following equations:

$$\eta_{(A,B)} = 100 - PWL_{(A,B)} \tag{17}$$

3.3 Overall efficiency of the bread slicer

The overall efficiency of the machine was calculated based on the efficiencies, η_A and η_B, obtained using equation (17) for both specimens (A and B). Thus, the formula for evaluating bread slicer overall efficiency, η_{BS}, is given as:

$$\eta_{BS} = \frac{\eta_A + \eta_B}{2} \tag{18}$$

$$\eta_{BS} = \frac{89.8 + 89.63}{2} = 89.715\ \%$$

Hence, with respect to calculated percentage loss in weight the bread slicer overall efficiency, $\eta_{BS} = 89.715\,\%$.

3.4 Performance of the bread slicer at different speeds

The bread slicer tested at cutting speeds varying between 420 and 500 r/min (Figures 3, 4 and 5) with a fixed in-feed weight of 2.8 kg, and an in-feed tray angle of 57^o. The test was carried out on 250 mm × 75 mm × 105 mm loaves (Specimen C). The purpose of the performance test was to determine the relationship between the speed (an independent variable) and the efficiency of the bread slicer for an effective slicing operation.

Table 1 Results of load testing of specimen A (170 × 67 × 80 mm of Loaves)

S/N	Parameters	S_{A1}	S_{A2}	S_{A3}	S_{A4}	S_{A5}	ATV_A
1	W_{bs}, kg	0.30	0.29	0.30	0.30	0.31	0.30
2	W_{as} , kg	0.27	0.26	0.27	0.27	0.28	0.27
3	Time of cutting (s)	15.00	16.00	17.00	16.00	16.00	16.00
4	N_T (slices)	24.00	24.00	24.00	24.00	24.00	24.00
5	N_c (slices)	15.00	16.00	16.00	15.00	16.00	16.00
6	N_{dc} (slices)	9.00	8.00	8.00	9.00	8.00	8.00
7	PWL_A, %	10.00	10.34	10.00	10.00	9.68	10.00
8	PC_{TS}, %	62.50	66.67	66.67	62.50	66.67	65.00
9	PC_{NS}, %	37.50	33.33	33.33	37.50	33.33	34.50
10	η_A, %	90	88.66	90	90	90.32	89.80

Table 2 Results of load testing of specimen B (250 × 75 × 105 mm of loaves)

S/N	Parameter	S_{B1}	S_{B2}	S_{B3}	S_{B4}	S_{B5}	ATV_A
1	W_{bs}, kg	0.55	0.53	0.53	0.54	0.55	0.540
2	W_{as}, kg	0.49	0.48	0.47	0.49	0.49	0.484
3	Time of cutting, s	19.00	20.00	22.00	19.00	20.00	20.000
4	N_T (slices)	24.00	24.00	24.00	24.00	24.00	24.00
5	N_c(slices)	15.00	16.00	16.00	16.00	15.00	16.000
6	N_{dc} (slices)	9.00	8.00	8.00	8.00	9.00	8.000
7	PWL_B, %	10.91	9.43	11.32	9.26	10.91	10.370
8	PC_{TS}, %	62.50	66.67	66.67	66.67	62.50	65.00
9	PC_{NS}, %	37.50	33.33	33.33	33.33	37.50	35.00
10	η_B, %	89.09	90.57	88.68	90.74	89.09	89.63

Table 3 Performance of bread slicer at different cutting speeds using specimen C (250 × 75 × 105 mm of loaves)

S/N	Parameter	S_{C1}	S_{C2}	S_{C3}	S_{C4}	S_{C5}
1	Cutting speed, r/min	420	440	460	480	500
2	W_{bs}, kg	0.55	0.54	0.55	0.53	0.53
3	W_{as}, kg	0.49	0.48	0.47	0.42	0.39
4	Time of cutting,	19.00	17.00	16.00	15.00	12.00
5	N_T (slices)	24.00	24.00	24.00	24.00	24.00
6	N_c (slices)	16.00	15.00	14.00	13.00	11.00
7	N_{dc} (slices)	8.00	9.00	10.00	11.00	13.00
8	PWL_C, %	10.91	11.11	14.55	20.75	26.42
9	PC_{TS}, %	66.67	62.50	58.33	54.17	45.83
10	PC_{NS}, %	33.33	37.50	41.67	45.17	54.17
11	η_C, %	89.09	88.89	85.45	79.25	73.58

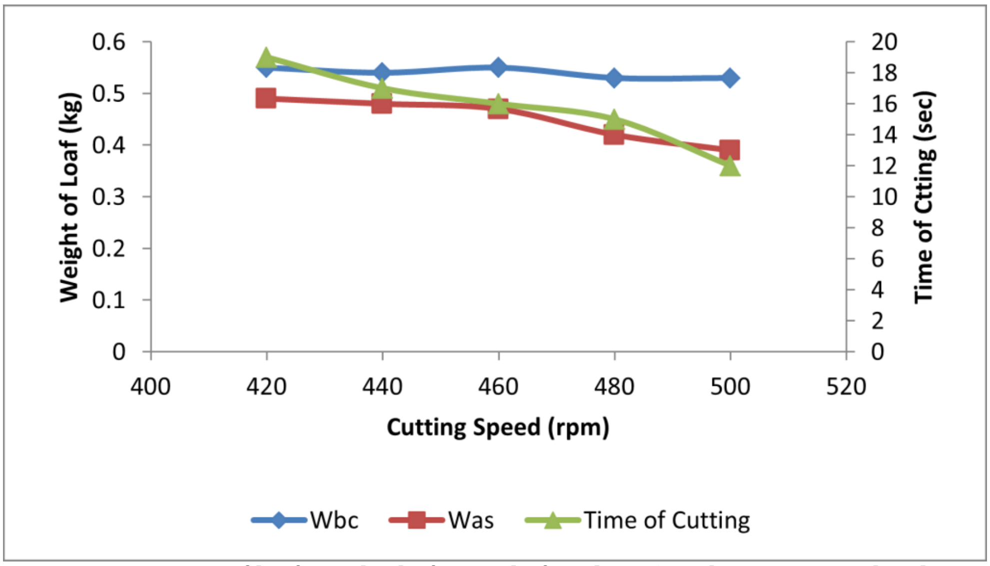

Figure 3 Variation of loaf weight (before and after slicing) with cutting speed and time

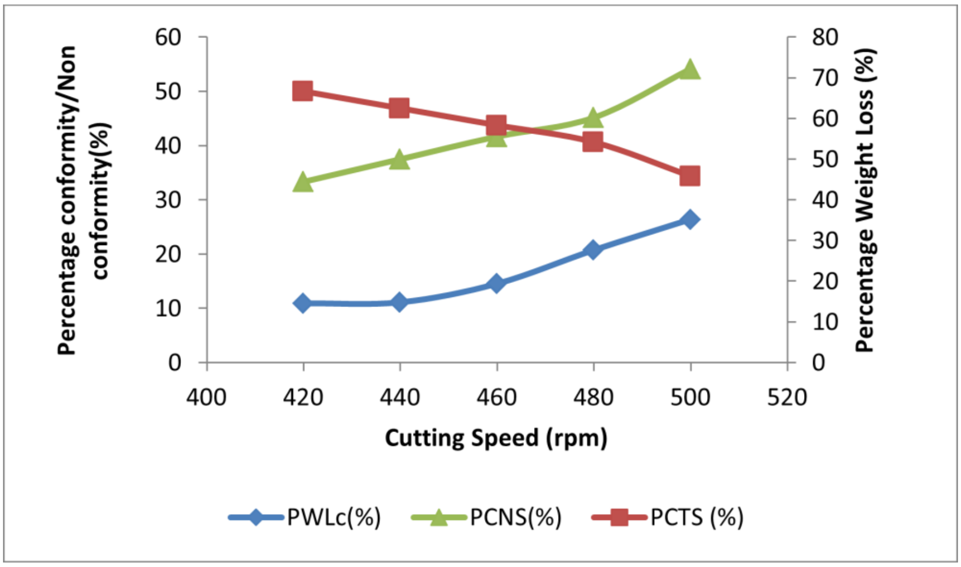

Figure 4 Variation of percentage conformity with standards and percentage weight loss at different cutting speeds

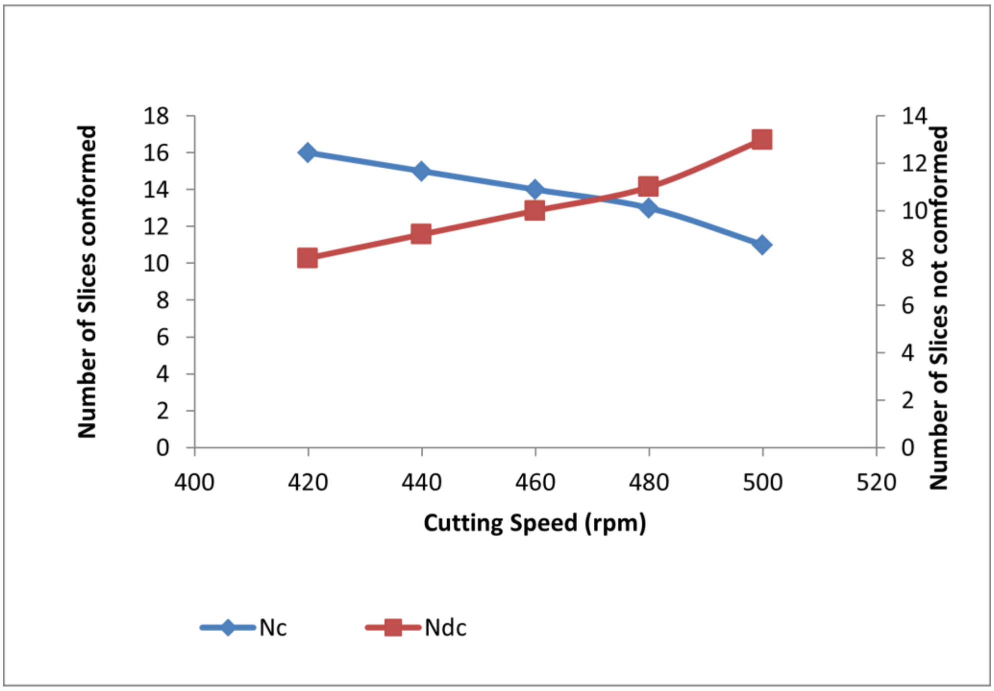

Figure 5 Conformity of sliced loaf at different cutting speeds

3.5 Evaluation of the bread slicer

The results revealed that PWL_C and PC_{NS} increased, while PC_{TS} and η (overall bread slicer efficiency) decreased with increase in cutting speed above the standard speed (420 r/min) as shown in Table 3. A reduction in the bread slicer efficiency may lead to early slicing equipment down time, losses in the slicing blade tension, parts deformation (blade frame), increased noise, increased vibration, misalignment and high cost of maintenance. The lower cutting speed leads to a better penetration rate, longer life of blades, increased load slicing time, reduced heat build-up, minimal blade breakage and smoother slices.

4 Conclusions

The development of the bread slicing machine in this study involved the design and fabrication of some principal components which include the cutting blades (22 set), blade frame, in-feed and out-feed tray, crumbs tray, in-feed weight, and the drive mechanism. Considering the results of the performance test, it was observed that the machine will best serve the purpose of slicing operation at reduced vibration, minimum noise generation, reduced cost and clean slicing environment with optimum efficiency as very smooth slices were obtained when run at the standard speed of 420 r/min. The gravity in-feed tray, out-feed tray and crumbs tray could be motorized so that the bread slicer will be fully automatically operated to reduce the stress imposed on the operator. Government should encourage the mass production of satisfactorily efficient locally made bread slicers such as the one reported in this article because they are cost effective compared to imported bread slicers.

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Nomenclature

AISI *American Iron and Steel Institute*

CAD *Computer Aided Design*

CIM *Computer Integrate Manufacture*

A_f *Cross sectional area of the frame, m*^{2}

A_c *Cross sectional area of connecting rod,m*^{2}

b *Width of frame, mm*

f_c *Density of connecting rod, kg/m*^{3}

f_b *Density of the blade material, kg/m*^{3}

$N_c(A)$ *Number of slices that conform to standard thickness*

N_{dc} *(A)* *Number of slices that do not conform to standard thickness*

$\bar{\tau}$ *Average time taken, s,*

t *Blade thickness, mm*

$W_{bs}(B)$ *Weight before slicing loaves of Specimen B, kg*

$W_{as}(B)$ *Weight after slicing loaves of Specimen B, kg*

θ *Angle of twist, deg,*

SA5 *Samples of Specimen A*

G *Torsional modulus of elasticity for steel, GN/m*^{2}*,*

ATVB *Average Total Value of Specimen B*

) Percentage Weight Loss with respect to Samples of Specimen C

Length of shaft, mm,

ASME *America Society of Mechanical Engineer*

f_f *Density of frame, kg/m*^{3}

l_b *Blade length, mm*

b_b *Blade width, mm*

D *Crank Diameter, mm*

l *Length of frame, mm*

N_2 *Angular velocity of the reduced speed, rpm*

η_c *Bread Slicer Efficiency with Respect to Samples of Specimen C,*

η_b *Bread Slicer Efficiency with Respect to Samples of Specimen B,*

Bread Slicer Efficiency with respect to Samples of Specimen A

K_t *Combined shock and fatigue factor Applied to torsional moment-1.0*

K_b *Combined shock and fatigue factor Applied to bending moment-1.5*

) *Weight after slicing loaves of Specimen A,*

$W_{bs}(A)$ *Weight before slicing loaves of Specimen A, kg*

$\sum(t)$ *Sum of time taken*

ATVA *Average Total Value of Specimen A*

) Percentage Conformity (PCTS) to standard thickness (10mm)

PC_{NS}*(%) Percentage that doesn't Conform (PCTS) to standard thickness (10mm)*

d *Shaft diameter, mm*