Design And Fabrication Of A Mono-Bloc Mixer Extruder Machine For The Production Of Gum From Cassava Starch

S. A. Omotehinse*‡, P. O. Akpaka **

*Department of Production Engineering, University of Benin, Benin City, Nigeria.

** Research Support Services Department, Rubber Research Institute of Nigeria, Benin City, Nigeria.

(drsamayodeji@gmail.com, akpakaphilip@gmail.com)

‡ S. A. Omotehinse; Tel: +234-803-597-1630,

Fax: +90 312 123 4567,corresponding@affl.edu

Received: 15.09.2019 Accepted:26.03.2020

Abstract- The machines for gum production from cassava starch are very expensive and complex which made it difficult for local cassava farmers to procure, install and operate. A simple machine known as Monobloc mixer extruder machine for the production of gum from cassava starch was designed and fabricated using locally available materials. Several experimental procedures were carried out which include the selection of materials for the machine, design calculations for the various parts of the machine, performance evaluation test and efficiency determination. Performance evaluation test and observation revealed that for best results, the cooking time of the starch solution with other gum additives should be □ 30minutes and the cooking temperature had to be in the range 800C – 950C (within the dextrinization zone). The results also revealed that the designed and fabricated machine could produce gum from cassava starch effectively and easy to install, operate and maintain. The machine produced had a capacity of producing 5.175litres of dextrin gum per minute and an efficiency of 85%.

Keywords White dextrin; dextrinization temperature; machine design; fabrication; mono-bloc mixer.

Özet- Manyok nişastasından sakız üretimi için makineler çok pahalı ve karmaşıktır, bu makinelerin tedariki, kurulumu ve çalıştırılması yerel manyok çiftçilerine pahalıya mal olmaktadır. Manyok nişastasından sakız üretimi için Monoblok karıştırıcı ekstruder makinesi olarak bilinen basit bir makine, yerel olarak mevcut malzemeler kullanılarak tasarlandı ve üretildi. Makine için malzeme seçimi, makinenin çeşitli parçaları için tasarım hesaplamaları, performans değerlendirme testi ve verimlilik belirleme gibi çeşitli deneysel prosedürler gerçekleştirilmiştir. Performans değerlendirme testi ve gözlemi, en iyi sonuçlar için nişasta çözeltisinin diğer sakız katkı maddeleri ile pişirme süresinin 30 dakika olması ve pişirme sıcaklığının 800 ° C - 950 ° C arasında (dextrinizasyon bölgesi içinde) olması gerektiğini ortaya koymuştur. Ayrıca, sonuçlar tasarlanan ve imal edilen makinenin manyok nişastasından sakız üretebileceğini ve kurulumu, çalıştırılması ve bakımı kolay olduğunu ortaya koydu. Üretilen makine dakikada 5.175 litre dekstrin sakızı üretme kapasitesine ve % 85 verimliliğe sahiptir.

Anahtar kelimeler Beyaz dekstrin; dekstrinizasyon sıcaklığı; makine tasarımı; yapılışı; monoblok karıştırıcı.

1. Introduction

Cassava is a root tuber crop that is rich in starch. Nigeria is the world largest producer of cassava and it is the most economic source of starch in the country [1]. The starch produced from cassava is known as native starch or un–processed starch. It has been discovered that native starches, irrespective of their source, are undesirable for many applications [2] because of their inability to withstand processing conditions such as extreme temperature, diverse pH, high shear rate and freeze-thaw variation. In order to improve on its desirable functional properties, native starches are often modified. Cassava starch should thus be focused for modification [3] as modified starches have wide applications as binders, fillers, emulsion stabilizers, consistency modifiers and adhesives (gumming applications). Gums are either hydrophobic or hydrophilic high molecular-weight molecules, which possess colloidal properties that in a suitable solvent or swelling agent produce gels, highly viscous suspensions or solutions at dry substance content [4]. Gums may generally be classified according to their source such as natural gums and prepared gums. The natural gums are plant and animal based and include seaweed extracts, plant exudates, seed gums, plant extracts and animal extracts. Prepared gums on the other hand include biosynthetic gums, starch fractions and derivatives and cellulose derivatives which are being consumed in exceeding large quantities by industries and individual users around the world [5-7]. Gums are used to bind materials together at their contact surfaces in a sense that they provide forces of adhesion at the interface. Based on this concept gums may be referred to as adhesives. Gums bond materials together by maximizing the intermolecular forces of attractions at the interface. The need to add value to the finishing of a product continues to increase over the years and this has caused the growth of gum consumption hence the need for the production of gum. [4] op. cit. worked on the production of starch dextrins and its suitability for use in different applications. Their investigation showed that starch when roasted at increasing temperatures under dry conditions can change from white dextrin through yellow to British gum with suitable additives needed for gum production. The term dextrin generally refers to products produced by heating starches either dry or with some suitable acid or alkaline catalyst. White dextrin gums possess good adhesive strength, odourless and tasteless properties, and viscosities and solubilities which make them suitable for top-quality work. White dextrin gums have wide applications in the textile, paper and cardboard, and adhesive industry (in bill posting, bag seam, carton sealing, envelope gumming, laminating paste). Similar researchers in this area includes: [8-10]. In [11] a single screw extruder was designed and analyzed using Finite Element Method (FEM) and Computational Fluid Dynamics (CFD). [12] carried out a numerical analysis of extruder screw in extruder machine while [13] looked at the concept of monoblock in endodontics. It is obvious from the reviewed literature that works on production of dextrin from cassava starch exits but there appears to be a dearth research effort on the use of mono bloc mixer extruder machine to produce gum from cassava starch which this study seeks to address. The aim of this study therefore is to design and fabricate a simple machine using locally available materials for the production of gum from cassava starch that will be affordable for the locals since the Federal Government of Nigeria has placed a total ban on importation of finished product.

2.1. Cassava Starch Gum Production Process Description

Dextrin grades and types can be manufactured by controlling the starch source, moisture, catalyst, maximum dextrinization temperature attained and the duration of heating at the dextrinization temperature zone. These are all process variables on which the final product depends. White dextrin gums according to [4] are prepared by heating starch with appreciable amounts of an acid catalyst, usually hydrochloric or ethanoic acid. Heating is done progressively until a temperature of 790C is attained during which dextrinization of starch takes place. The dextrinization temperature zone of starch is 790C to 1210C. When starch is dextrinized and subsequently treated with particular adjuncts, the resulting product will have solubility, fluidity and tackiness that make it suitable for gumming applications. White dextrin gum during manufacture undergoes progressive agitation during the thermal conversion stage. This makes possible heat transfer to all parts of the mixture and prevention of localized heating. As soon as the temperature gets to the dextrinization temperature zone, the mixture is maintained in this temperature range for 30 to 180mins during which dextrinization is complete. Heating is then stopped while agitation is continued. The dextrin is allowed to cool naturally to room temperature and gum adjuncts are added to enhance plasticity, tackiness and shelf life. After some additional mixing, the discharge gate valve is opened and the gum discharged into a screw extruder. The screw extruder is designed such that further cooling is achieved in the extruder. The extruder consists of a ribbon screw in the first 90% of the screw length and an extruding screw in the last 10% of the screw length. The ribbon screw performs further mixing of the gum as it is cooled further to room temperature. The gum is extruded out through a narrow orifice that controls the filling rate into plastic cans.

2.2. Machine Description

Several design concepts were considered from which a final design based on a mono-bloc mixer extruder concept was selected. The mono-bloc mixer extruder concept is an integrated system comprising of a jacketed change-can mixer and a screw extruder. In the jacketed change-can mixer, the raw materials are introduced. They are thermally converted into dextrin by a heating and mixing operation. After dextrinization has been completed, the heating stops and the dextrin are allowed to cool. Cooling in the mixing vessel is allowed to take place at ambient condition during which gum adjuncts are added to the dextrin, resulting in the formation of gum. The gum mixture flows to the ribbon extruder where further cooling and mixing are done and finally the gum is extruded through a narrow opening. Figure 1.0 below shows a schematic view of the mono-bloc mixer-extruder.

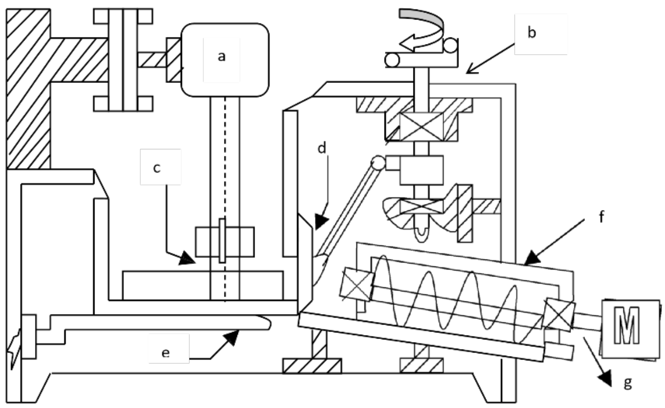

Fig. 1. Schematic view of the mono-bloc mixer extruder machine. a - electric motor, b - mechanism for opening mixer gate, c - mixing impeller, d - mixer gate, heating element, f - screw extruder, g - material discharge

2. Materials and Methods

2.1. Materials

The materials used can be grouped into two namely:

(1) Materials for fabrication of the machine (Table 1).

(2) Materials used for the production of the gum from cassava starch.

2.1.1 Materials for the Fabrication of the Machine and Its Associated Cost

The materials used in the fabrication of the machine and their associated costs are shown in Table 1.

Table 1. Materials for fabrication of the machine and its associated cost

S/N	MATERIALS/ DIMENSIONS	WHERE USED	UNIT	COST (N)
1	710mm x 45mmx2mm mild steel plate	Mixing chamber	1	2, 200
2	250mm x Φ10mm steel rod	Mixing shaft	1	700
3	140mm x Φ5mm steel rod	Mixer blade	1	600
4	300mm2 heating coil	Heater	3	1, 000
5	300 x 10mm x 2mm mild steel plate	Mixing vessel	1	650
6	200mm x 10mm2 mild steel plate	Hopper	1	300
7	150mm x 10mm perspex	Mixing vessel	4	800
8	100mm2 x 10mm flat bar	To hold mixing shaft in position	1	950
9	100mm2 x 15mm flat bar	Motor housing	1	400
10	800mm flat bar	To hold DC motor and mixer shaft	1	700
11	Φ10mm screws	Fasteners	8	160
12	84w gear type DC electric motor	Mixing process	1	3, 800
13	440mm coil spring	Mixing chamber support	1	200

2.1.2 Materials Used for the Production of the Gum Cassava Starch

The materials include: (i). Starch (ii) Dilute Hydrochloric (HCl) acid (iii) Sodium tetraborate decahydrate or borax (iv) Urea (v) Sodium formaldehyde, all are of commercial grade.

2.2. Method

2.2.1 Design Calculations

The mono-bloc mixer-extruder concept was adopted and the detailed designs were carried out as follows:

2.2.2 Design of the Mixer

The machine consists of two sections. The first section has a change-can mixer that incorporates a heating jacket. The figure 2.0 shows the schematic view of the mixer section.

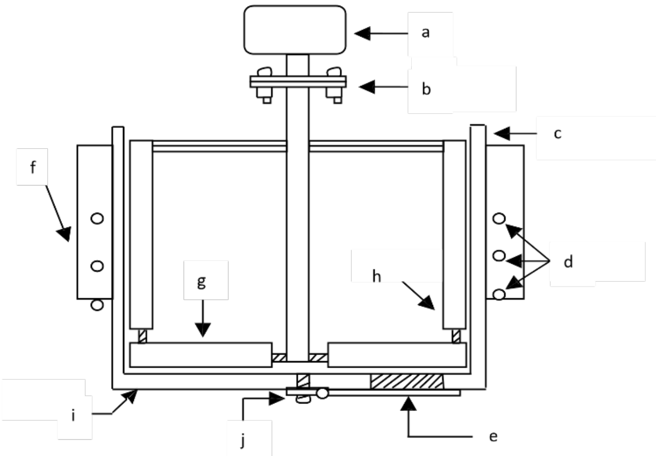

Fig. 2. Schematic view of the mixer section. a - electric motor, b - rigid coupling, c - mixing vessel wall, d - heating coils, e - swing check valve, f - heating jacket, g - horizontal pitched blade, h - vertical pitched blade, i- H=115mm,Φ235mm, j - holding screw

The design of the mixer comprises several steps as outlined below:

Step 1: Selection of a suitable vessel material and size

An aluminum pot of diameter 235mm was selected as the mixing vessel. The vessel is well rounded with smooth surfaces.

Step2: Selection of blade materials.

The blades were made of two materials, steel and perspex. The steel bars were welded to anchor impeller frame while the perspex bars were bolted to the steel bars. The Perspex bars (since it can be adjusted) ensured maintenance of very small clearances between the vessel surface and the vertical and horizontal pitched blades.

Step 3: Selection of mixing speed

The production of dextrin gum involved heating starch slurry with excess acid until dextrinization was attained. For a controlled process, it was desired that the mixing should take place in the laminar zone.

For the mixing to remain in the laminar zone, it was necessary to consider the impeller speed with respect to the viscosity of the mixture in the mixer and also on the intended discharge rate.

For fluid mixing, Reynolds Number was defined as (McCabe et al., 2001).

$$Re = \frac{nD^2\rho}{\mu}$$

where $Re = Reynolds\ number, n = revolutions\ per\ minute,\quad D = impeller\ diameter, \rho = density, \mu = viscosity.$

For non-Newtonian fluids such as starch paste the following values $, n = 60\, rpm,\ \ \mu = 160\, Pas,\ \ \rho = 1500\ {}^{kg}/_{m}, D = 230\ mm = 0.23\ m$ were selected.

$$Re = \frac{1 \times 0.23^2 \times 1500}{160}$$
$$Re = 0.5$$

In order to compute the Power Number, values were extrapolated

At $Re = 10$, Power Number $N_p = 7.5$; at $Re = 2$, $N_p = 49$;

Extrapolating, at $Re = 0.5$, $N_p = 57$;

The power needed by the impeller is given by the relation as:

$$Re = N_p n^3 D^5 \rho$$

where $P = power,\quad N_p = power\ number,\quad , n = revolutions\ per\ minute,\quad D = impeller\ diameter, \rho = density.$

Now, for $Re < 10$, flow is in the laminar range and density plays no factor

$$N_p = \frac{K_L}{Re}$$

$K_L = 44.5$ for four pitched blade turbine mixer, hence

$$P = K_L n^2 D^3 \mu$$
$$P = 44.5 \times 1^2 \times 0.23^3 \times 160$$
$$P = 86.63\ W$$

Electric motor power specifications were stated below:

P = 87 W and rotational speed required is 60 rev/min

2.2.3 Design of the Extruder

Figure 3 shows a schematic section of the screw extruder with ribbon flighting.

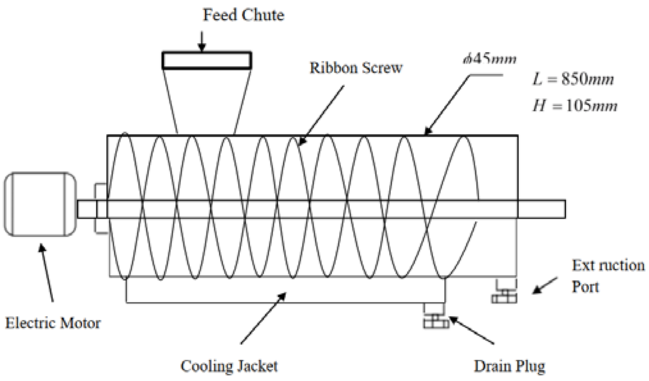

Fig. 3. Schematic section of ribbon screw extruder.

Two factors determined the design considerations of the screw extruder and these were the screw size and rotational speed (rpm) of the screw. The choice of screw size depends on the screw diameter, shaft diameter, radial clearance and pitch type of helical flight. The conveying of gummy substances may not be characterized by the presence of lumps and as such the screw size has no limitation of any kind and may depend on the projected throughput. The throughput may thus depend on the size of feed chute and the discharge port size. A screw conveyor casing of internal diameter, d = 90 mm, was selected based on the size of casing desired for the machine, r = 45 mm.

This equivalent to a fluid height of $\frac{30\times45}{100} = 13.5\ mm.$ In the trough as shown in Fig. 4. Below.

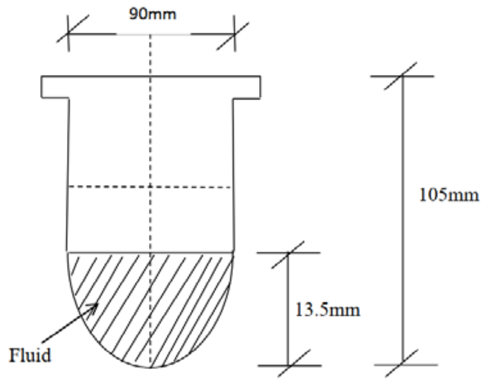

Fig. 4. Schematic section of extruder showing fluid height for maximum situation.

The cross sectional area of the moving bed of paste (gum) is given as

$$A_X = \frac{(d_x)^2 A}{d}$$

Where A_X is cross sectional area of moving bed of paste(gum) at 30% height, A is cross sectional area of moving bed of paste at 50% height, d and d_x are the respective heights for A and A_X.

$$A = \frac{\pi d^2}{2}, d = 45mm = 0.045m$$

$$A_X = \frac{(d_x)^2 A}{d} = 0.0032\frac{(13.5)^2}{45} = 0.00115m^2$$

Next, a suitable rotational speed was selected, $N = 60\,rpm$ and screw pitch $\lambda = 50mm = 0.05m$.

$$N = \frac{60}{60} {rev}/_{s} = 1\, {rev}/_{s}$$

$$\lambda = 0.05\,m$$

Average velocity, $u = \lambda N = 0.05 \times 1 = 0.05\, {m}/_{s} = 50\, {mm}/_{s}$

Where $u = average\ velocity$, $\lambda = screw\ pitch$, $N = revolutions\ per\ minute$.

Volumetric throughput of the screw extruder is given by the relation

$$\dot{V} = A_X \lambda N$$

Where $\dot{V}$ is volumetric throughput of screw extruder, A_X is Cross sectional area of moving bed of paste (gum) at 30% height, λ is screw pitch, N is revolutions per minute.

$$\dot{V} = A_X U = 0.013 \times 0.05 = 0.0000575\, {m^3}/_{s}$$

Mass flow rate of gum;

$$\dot{M}_S = \rho \dot{V}_S$$

Where $\dot{M}_S$ is mass flow rate in screw extruder, ρ is density and $\dot{V}_S$ is the volumetric flow rate of screw extruder.

$$\dot{M}_S = 1500 \times 0.0000575 = 0.08625\, {kg}/_{s}$$

For a ribbon flight screw extruder, the capacity factor CF_f of the flight is

$$CF_f = 1.15$$

Hence, the modified mass flow rate is

$$\dot{M}_g = \frac{\dot{M}_S}{CF_f}$$

where $\dot{M}_g$ is mass flow rate of gum, $\dot{M}_S$ is mass flow rate in screw extruder, CF_f is capacity factor.

$$\dot{M}_g = \frac{0.08625}{1.15} = 0.075\, {kg}/_{s}$$

Power requirement for the extruder motor is given as

$P_T = P_{gum} + P_{friction}$
$P_T = Power\ required\ to\ transport\ gum\ in\ the\ extruder$
$P_{gum} = Power\ to\ transport\ gum\ freely$
$P_{friction} = Power\ to\ overcome\ friction\ during\ gum\ transportation$

where, $P_{friction} = 50 D_{SC} L$

$D_{SC} = screw\ diameter = 45\ mm = 0.045\ m$
$L = screw\ length = 750\ mm = 0.75\ m$

Hence, $P_{friction} = 50 \times 0.045 \times 0.75 = 1.70W$

And $P_{gum} = F_s F_m g M_g L$

where, $F_s = screw\ factor = 1.7$, $F_m = material\ factor = 1.8$, $L = screw\ length = 0.75\ m$, $g = acceleration\ due\ to\ gravity = 9.81\, {m}/_{s}$, $P_{gum} = 1.7 \times 1.8 \times 9.81 \times 0.075 \times 0.75 = 1.70W$

$$P_T = 1.70 + 1.70 = 3.40W$$

Finally, the drive efficiency between 85 – 95% was considered and $\eta = 0.85$ was selected as the drive efficiency. Also an overload factor F0 is also necessary to protect against any overload effects. Therefore, Power required by extruder motor is given as

$$P_{motor} = \frac{P_T F_0}{\eta}$$

where P_{motor} is power required by extruder motor, F_0 is overload factor, P_T is power to transport gum in the extruder, η is drive efficiency.

Choosing a high $F_0 = 3.5$

$$P_{motor} = \frac{3.40 \times 3.5}{0.85} = 14W$$

The isometric view of the fabricated monobloc mixer machine for the production of gum from cassava starch is show in Figure 5 below:

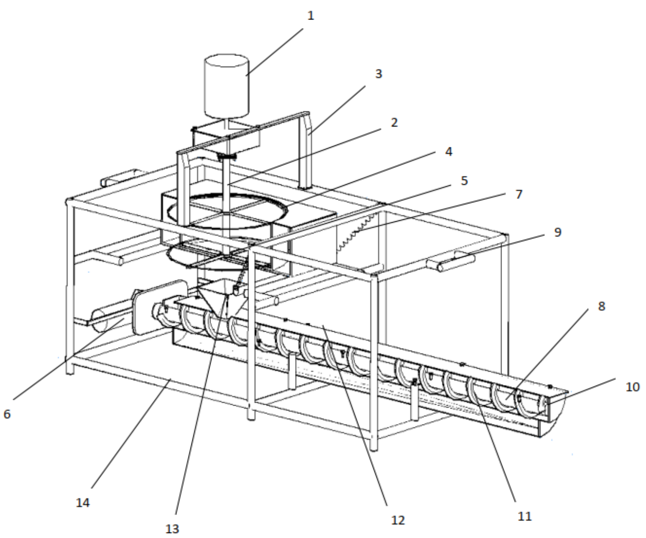

Fig. 5. Isometric view of the Mono-bloc Mixer Extruder Machine. 1-DC motor, 2-mixer shaft, 3-supporting stand, 4-mixing chamber, 5-mixing blade, 6-DC motor, 7-spring, 8-helical threaded shaft, 9-handle, 10-extruder shaft housing, 11-thread, 12-bolt, 13-hopper, 14-supporting frame

2.3. *Performance Evaluation*

2.3.1. Test Production of Gum

1. Some quantity of cassava starch mass was put into a plastic bath and water added to obtain a ratio 2:1 of starch to water. 0.3M HCL was then added to the suspension formed to obtain slurry made up of starch suspension/acid ratio of 1:1, by volume. The slurry was then stirred thoroughly to form a uniform slurry, and sodium tetraborate decahydrate i.e. borax (10% by weight of the starch present) added. The resulting mixture was then divided into three parts: A, B and

C, so as to enable their investigation under different cooking temperatures and time (within the dextrinization zone).

2. Sample A was put into the mixing bath and heat applied (with progressive mixing) for 180minutes until the maximum temperature range of 116oC -120oC was attained. The exercise was repeated for samples B and C for 180minutes (at maximum temperature range of 96C –115C) and 30minutes (at maximum temperature range of 80C – 95C) respectively.
3. After dextrinization has been completed, the sample mixture was allowed to cool to room temperature (with progressive mixing). Gum adjuncts such as urea (3% by volume of mixture) and sodium formaldehyde (10% by volume of mixture) were added to increase water resistance and shelf life respectively. After sufficient mixing at room temperature, the gum was discharged manually through a swing gate valve into a ribbon screw extruder where additional mixing was done prior to actual extrusion of the gum into small plastic bottles. Thereafter, each sample was inspected for quality.

2.3.2. Efficiency Determination

The efficiency of the machine was determined by measuring the volume of gum produced/extruded (output) to the volume of starch solution (input) per minute for each operation. The loss for each operation per minute ranged from 0.14 to 0.15 litres. The mean value gave 0.145litres ≡ 0.15litres representing a loss of 15%. Since the loss was 15%, then the efficiency of the machine would be 85%, by subtracting the percentage loss from the maximum expected percentage (100%).

3. Results and Discussion

The results of the performance tests are presented in Table 2 below:

3.1 Discussion

It can be seen that an increase in the cooking time and a reduction in the cooking temperature (within the dextrinization zone) reduce the viscosity of the gum which is the resistance of the gum to flow. For the gum to be effective in the application to which it is intended, it was discovered that the lower the viscosity the more effective was the gum. Sample C had low viscosity at a cooking time of 30minutes and cooking temperature (within the dextrinization zone) 80oC – 95oC. It was also seen that the tackiness increased as the cooking time was increased and cooking temperature (within the dextrinization zone) reduced. For the gum to be effective in its application, it has to have excellent tackiness which is the ability to stick materials together. Therefore, it was discovered that for this to occur the cooking time has to be 30minutes and cooking temperature (within the dextrinization zone) 80oC – 95oC. Sample C was found to be within this range. It was also seen that the solubility of the gum increased, that is its tendency to dissolve on the material of application when there was an increase in the cooking time and reduction in the cooking temperature (within the dextrinization zone). From the experiment carried out also, it was discovered that the cohesion ability of the gum was also being increased from sample A – C in that order alongside the clarity making Sample C the best of all. For the gum to be effective, that is to have excellent cohesion properties and clarity, it has to have cooking time and temperature as stated above. The gum from sample C was odourless, tasteless, and colorless which are the properties of any good gum. The machine was able to produce gum from cassava starch.

4. Conclusion

A simple machine for the production of gum from locally available materials was designed and fabricated. The machine had all the various stages of conversion of the starch (raw material) to the gum (finished product) built into a mono-bloc i.e. one unit. We found out that starch can be used to produce gum easily using this machine. For best results, the test results and observation carried out revealed that the cooking time of the starch solution with other gum additives had to be 30minutes and the cooking temperature had to be in the range 800C – 950C (within the dextrinization zone). The production test also showed that the cohesion ability of the gum was also being increased alongside the clarity. The gum produced can be used in the paper and cardboard industry and also for some light application work like bill posting, carton sealing, envelope gumming, laminating paste and bottle labeling operations. The machine had a capacity of producing 5.175litres of gum per minute and was found to be 85% efficient. The gum had similar properties with the one in the market and the advantage here was that the cost of production of the machine was very low when compared to the cost of procuring similar machine. The cost of producing the machine was N52, 960 and when mass produced, it would become far lesser considering the fact it was cheaper for us to buy in whole than in pieces. This made the machine to be easily affordable especially to small scale cassava farmers who are the major target of this research. The machine had simple operation technique and is portable.

The parts can be easily disassembled and assembled in case of maintenance. The low cost of acquiring the machine will help reduce the capital investment that is needed to go into the production of gum and this will encourage many local cassava farmers to venture into the production of gum thereby increasing the profit they make from their cassava farm and creating job opportunities for those that are unemployed.

References

[1] B. Daramola and B.A Osanyinlusi, “Investigation on modification of cassava starch using active components of ginger roots”, African Journal of Biotechnology. Vol. 5, No.10, pp 917 – 920, 2006.

[2] Y.J. Wang, P.P. White, J.I. Jane, “Characterization of starch structures of 17 maize endosperm mutant genotypes

with Oh 43 inbred line background". Cereal Chem. 10: 171-179.

[3]J.N. BeMiller and W. Lafayette, "Starch Modification: Challenges and Prospects." Starch and Starke, Vol. 49, No. 2, pp. 127 -131, 1997.

[4]R.W. Satterwaite, and D.J. Iwinski, "Starch Dextrins" In Industrial Gums, Whistler R.L. and BeMiller J.N. (eds). Second Edition. Academic Press, New York. 1973, pp.577 – 599. Meer, et al.,"A handbook on the Production of Gum". Second edition Academic press London.

[5]R.L. Whistler, "Factors influencing gum costs and applications." In: Industrial Gums. Whistler R.L and BeMiller J.N. (eds.). Second edition. Academic Press, New York. 1973, pp. 5 – 18.

[6] W.H. McNeely, and K.S. Kang, "Xanthan and some other biosynthetic gums," In: Industrial Gums. Whistler R.L. and BeMiller J.N. (eds.). Second Edition. Academic Press, New York. 1973, Pp. 474 – 495.

[7] A.L. Woiciechowski, C.R. Soccol, S.N. Rocha, A. Pandey, "Xanthan gum production from cassava bagasse hydrolysate with Xanthomonas campestris using alternative sources of nitrogen". Appl Biochem Biotechnol., 118(1-3):305-12, 2004.

[8] B.A. Aliyu, and K.B. Aliyu, "Re-inventing the production of adhesive from Cassava starch as a career opportunity in chemistry education. International Letters of Natural Sciences", Vol. 18, pp 12-19, 2014.

[9] O.S. Azeez, "Production of Dextrins from Cassava Starch. Leonardo Journal of Sciences", issue 7, pp.7-16, 2005.

[10] A.J. Gunorubon, "Production of cassava starch based adhesive", Research Journal in Engineering and Applied Sciences 1(4): pp. 219-214, 2012.