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THE DESIGN, FABRICATION AND PRELIMINARY TESTING OF AN INDIGENOUS SINGLE SCREW EXTRUDER

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Abstract

Developing countries including Nigeria have become dumping grounds of unserviceable and broken down imported machineries because of poor adaptation. Detailed study and design of machines to suit local conditions will prevent poor adaptation of imported machines and high initial costs. In this study, a single screw starch extruder was designed, fabricated and tested using locally available materials. The extruder is the dry type and it has 27.12 kg/s capacity, a compression ratio of 4.5: 1 and is powered by a 5.5 kW electric motor. It consists of a hopper, feeding screw, extruder screw rotating in a barrel and variable die, all made of stainless steel. A unit of the machine costs N 470, 390.00.00 as at April 2015. When used to process cassava flour, a maximum temperature of 114°C was attained through viscous dissipation, up to an actual screw speed of 98.96 rpm (1.65 Hz) and extruder efficiency of 64%. Barrel temperature varied directly with extrusion time in a polynomial trend while actual extruder screw speed and efficiency varied inversely with extrusion time and it is best fitted with a polynomial trend.

Keywords: Design, Extrusion, Extruder efficiency, Cassava, Fabrication.

1. Introduction

The development of machines and systems for optimized production in agricultural industries has been the concern of engineers over the years. Also, production of cassava and other cereals like maize and millet is highly favoured by the climatic conditions in Nigeria but a lot of post-harvest losses and glut of

Nomenclatures

c	Factor of inclination to horizontal (Equation 5)
C	Temperature, ^oC
$D^1{}_c$	Outer diameter of cylinder, m
D_t	Duration of sampling, min.
H	Average screw channel length over the active volume, m
L	Length, m
L_d	Length of die, m
K_d	Die constant, a function of geometry
M	Moisture fraction of the feed, %
m	Mass flow rate, kg/s
N	Screw speed, Hz
N	Number of revolutions per sec, Hz
P	Pressure, Pa
P_c	Designed pressure in extruder, Pa
P_d	Pressure drop across the die, Pa
Q	Volumetric flow rate, m^3/s
S	Screw pitch, m
T	Torque, Nm
U_o	Apparent viscosity of the feed material, Pa.s
V_1	Volume of extruder worm's first pitch, m^3
V_2	Volume of extruder worm's last pitch, m^3
v	Screw speed, m/s
W	Power requirement for the extruder screw, kW
W_o	Material factor

Greek Symbols

β	Angle of inclination of screw shaft to horizontal, deg.
γ	Shear rate, s^{-1}
μ	Viscosity of the feed material, Pa.s
η	Extruder's efficiency
η'	Efficiency of gear reducer
π	pi
ρ	Density of feed material, kg/m^3
σ	The tangential stress perpendicular to the axis of the barrel, Pa
τ	Die shear stress, Pa
ψ	Loading efficiency for the conveyor

Abbreviations

CR	Compression ratio
L/D	Length to diameter ratio
TMS	Tropical Manioc Selection

the commodities are usually experienced [1, 2]. Most processed foods being consumed in Nigeria are made using imported machines. Yet, efficient and increased processing could be achieved by developing an indigenous machine.

Extrusion is a food processing operation that can increase the usefulness of starchy crops by producing a range of products with different shapes, nutrients, texture, colours, sizes, flavour etc., thereby increasing the varieties of food products in the diet [3]. With this expansion of the alternative processing options for starch crops, sustainable production would be ensured and post-harvest loses minimized. Cassava and maize have high potentials for production of extruded foods. Extrusion Technology is a process that has gained popularity in the developed nations and it comes in a variety of sizes, shapes and methods of operation [3].

However, getting the type that suits the local condition in terms of technological know-how and availability of spare parts for easy maintenance required detailed study and design to suit local conditions, thus preventing high initial costs and poor adaptation. Single screw extruders are known for their simplicity of design when compared to twin screw extruders [4]. Records of local development of food extruders in developing countries have been sparse. Therefore, the objective of this study is to design, fabricate and carry out a preliminary test of locally developed equipment for screw extrusion of starchy crops.

2. Design Considerations

A dry type extruder was considered because of its simplicity of design. Also, since the machine is being developed for food processing, it should be devoid of contaminants. Therefore, all parts in contact with the feed material were made of stainless steel to prevent contamination and to withstand frictional wear. The heat for gelatinization of starch will be provided through viscous dissipation. Therefore, compression was achieved by back pressure created in the die using a tapering shaft diameter and decreasing screw pitch [4] and by increasing the die length. Also, since the extruder is being considered for highly viscous starch, a die pressure approaching to 17000×10^3 Pa was used [3].

A major factor that determines the retention times of materials in extruder is the length of the extruder barrel. According to Van Zuilichem et al. [5], L/D of biopolymer extruder should be shorter than that of chemical polymer so as to control chemical reactions such as burning of starches and denaturation of proteins: For food products, L/D ratios of 6 to 15 are required. Therefore, a L/D ratio of 12 was selected. The relationship between the length of screw, number of flights, common difference in pitch and the first pitch was estimated by arithmetic progression. Fellows [3] suggested typical screw speeds of between 150 and 600 rpm for food extruders. Therefore, a screw speed of 300 rpm (5 Hz) was selected.

Selection of bearings was based on axial load in one direction of the extruder, the back pressure created by the die and for combined radial and axial loads on the drive shafts. This arrangement helps in reducing the noise level of the machine. As a test rig, allowance was given for varying the screw configuration, feed rate, screw speed, die configuration and nozzle. Every part of the machine was constructed with materials which could be obtained locally, except for the electric motors, bearings and gear box which were purchased in a local market. Finally, materials were selected based on availability and their ease of being fabricated.

3. Design Features of the Extruder

The major components of the extruder are the compression screw, the barrel, the feeding conveyor, die, shafts and transmission system. Components were designed using conventional engineering principles and standard equations as discussed in this section.

3.1. Design of the extruder worm and barrel

The design principle of a square threaded power screw was applied in the design of this worm. The major parameters defining the specifications of the extruder worm were determined in the following subsections.

3.1.1. The compression ratio

CR was calculated according to Van Zuilichem and Stolp [6] in Eq. (1) to be 4.44:1.

$$\mathrm{CR} = \frac{V_1}{V_2} \tag{1}$$

3.1.2. Extruder's capacity

The volume of starch Q, extruded in 1 hour was calculated as follows: Assuming a helix land 10 mm and a helix height 13 mm, barrel inner diameter 63 mm, minimum shaft diameter 35 mm, pitch 45 mm and screw speed 300 rpm. The volume of starch to be extruded in one hour is 1, 370, 368, 260 mm^3/s = 1.371 m^3/s. Since average weight of starch is 7.853×10^{-6} N/mm^3 [7]. M = 107.615 ton/hr = 27.12 kg/s.

3.1.3. The power requirement for the extruder screw

The power requirement for the extruder screw was calculated using Eq. (2) [8].

$$W = QL\frac{W_o \pm \sin\beta}{367}\frac{1}{\eta'} \tag{2}$$

The power requirement of the extruder was calculated to be 4.402 kW. However, a 5.5 kW electric motor was selected to cater for other fluctuations during operation. The torque required to drive the screw was calculated to be 152.15 Nm using Eq. (3) [9].

$$T = \frac{60W}{2\pi N} \tag{3}$$

The pressure generated in the extruder was calculated from Power/Capacity to be 115.642 Pa.

3.2. The design of the barrel

The barrel (cylinder) was designed based on internal pressure according to Sivakumaran and Goodman [10]. The tangential stress, σ, perpendicular to the axis of the cylinder is given in Eq. (4).

$$\sigma = \frac{2P_c D_c{}^2}{(D^1{}_c)^2 - (D_c)^2} \tag{4}$$

Allowable tangential stress is assumed to be 140×10^6 Pa and the designed pressure in extruder is 115.642 Pa. Outer diameter of cylinder was calculated to be 130 mm.

3.3. Design of the feeding conveyor

The feeding conveyor was designed using Eq. (5) according to PSGTECH Design Data [8].

$$Q = 15\pi D^2 SN\psi\rho c \tag{5}$$

The density of starch was taken to be 790×10^{-3} ton/m^3 (716.7 kg/m^3) [8]. To prevent overfeeding or blockage of the extruder, the feeding conveyor was starve-fed [11]. Power required for driving the screw = 0.14 kW while the diameter of the outlet orifice was calculated to be 0.023 m. The designed conveyor speed is 92 rpm and the torque acting on the shaft 1.62 Nm.

3.4. Power transmission system

The design analysis of power transmission system was carried out following the procedure of PSG TECH [8]. Also, a reducing speed gear box of ratio10: 1 was incorporated into the design. The resultant bending moment and torsional moment of the extruder were determined to be 277.70 Nm and 53.93 Nm respectively. The required diameter for a solid shaft with little or no axial loading but having combined bending and torsional loads, were obtained from ASME code equation. The diameter of the extruder shaft was calculated to be 37.65 mm. The resultant bending moment and torsional moment of the feeding conveyor were determined to be 45.02 Nm and 53.93 Nm respectively.

The diameter of the conveyor shaft was calculated to be 0.0226 m. The V-belt parameters were designed according to PSG TECH [8]. The outer and inner sides of the extruder shaft driving belts are subjected to a tension of 450.68 N and 67.60 N respectively while the corresponding values for the feeder shaft are 275 N and 43.8 N. Two belts were designed for the extruder worm while one was designed for the feeding conveyor.

3.5. Design of extruder die

From Frame [11], for a die of circular cross section, the volumetric flow rate is expressed as Eq. (6).

$$Q = K_d \frac{P_d}{\mu} \tag{6}$$

K_d for cylindrical die is calculated according to Eq. (7)

$$K_d = \frac{\pi R^4}{8L_d} \quad (7)$$

The pressure drop across the die is estimated as shown in Eq. (8)

$$P_d = \frac{2\tau L_d}{R} \quad (8)$$

The shear stress was estimated from the relationship in Eq. (9) [12].

$$\tau = U_o v \quad (9)$$

Apparent viscosity was calculated in Eq. (10) according to Alvarez-Martinez et al. [13]

$$U_o = 78.5\gamma^{-0.49} e^{\frac{2500}{C}} e^{-7.9m} \quad (10)$$

$$\gamma = \frac{\pi D n}{H} \quad (11)$$

A die length of 0.01 m was calculated. However, a die length of 0.02 m was selected to improve on the operating die pressure, according to Sohkey et al. [14].

4. Fabrication of the Extruder.

The components were fabricated and assembled at the Agricultural Engineering Workshop of the Federal University of Technology Akure and the Mechanical Engineering Workshop of the Rufus Giwa Polytechnic, Owo, Nigeria. The extruder shaft was taper turned using taper turning attachment on a central lathe and by manipulation of the alignment of tail stock. Flights were formed and welded on the tapered shaft using the following procedure:

Firstly, 0.065 m diameter solid rod was cut into 0.015 m length pieces with a power saw. Each piece was turned and surfaced to a consistent 0.0625 m × 0.01 m thickness. A stencil of the screw was cut and used to indicate the various points of the flights on the shaft. Then, each disc (flight) was center-drilled with 0.035 m drilling bit on a turret heavy duty drilling machine and bored to the required corresponding size of the hole of the flight on the tapered shaft.

The disc was cut through to the bored hole and drawn out with chain block. Thereafter each piece was placed in its corresponding position on the shaft beginning with the biggest end of the shaft. The flights were then tacked into place and full welding was done. Then the driver end of the shaft was step turned and a key way provided with a milling machine. Threading of the screw conveyor cap for locking purpose was done on the lathe. The thread was cut counter clockwise. The cap serves to prevent overloading or clogging of the extruder-feeding chute.

Thereafter, the extruder conveyor was positioned on a lathe machine to align any distortion, wobbling and the screw flight diameter reduced to 0.0615 m. Also, the die was step turned to reduce its weight and the end of the die nozzle was threaded. A prime mover of 1400 rpm (23.33 Hz) was selected. The electric motor rotates clock wisely.

A and B-belts tensioning was achieved using screw adjuster by lifting the drive train (electric motor + gear box) vertically, either up or down as applicable. The bearings were well lubricated with grease. Also, K type thermocouples were installed with acyanoacrylate adhesive towards the outlet end of the barrel to measure the highest barrel temperature attained. A digital tachometer was set in place to measure the actual screw speed of the extruder.

The isometric view, orthographic and the exploded drawings of the extruder are shown in Figs. 1, 2 and 3, all drawn from scratch with AUTOCAD 2007 software.

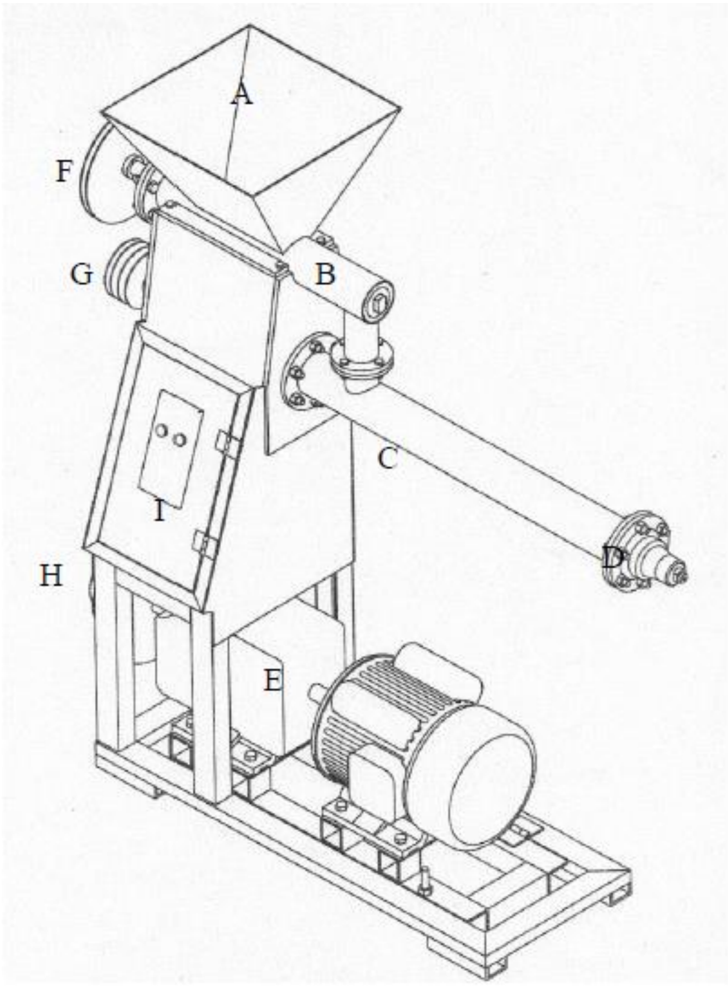

Fig. 1. Isometric drawing of the extruder (LEGEND: A- Hopper, B- Feeding Conveyor, C- Extruder worm, D- Die Unit, E- Power train, F- Conveyor pulley, G- Extruder pulley, H- Extruder Housing, I- Control switch).

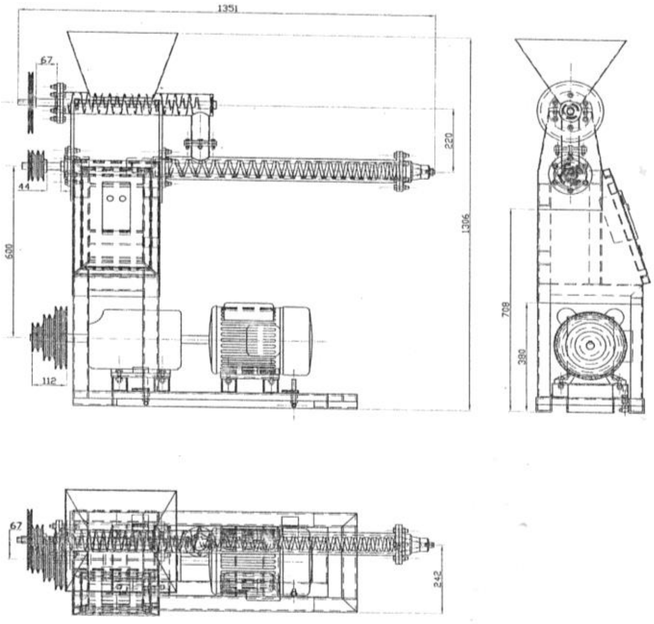

Fig. 2. Third angle orthographic drawing of the extruder.

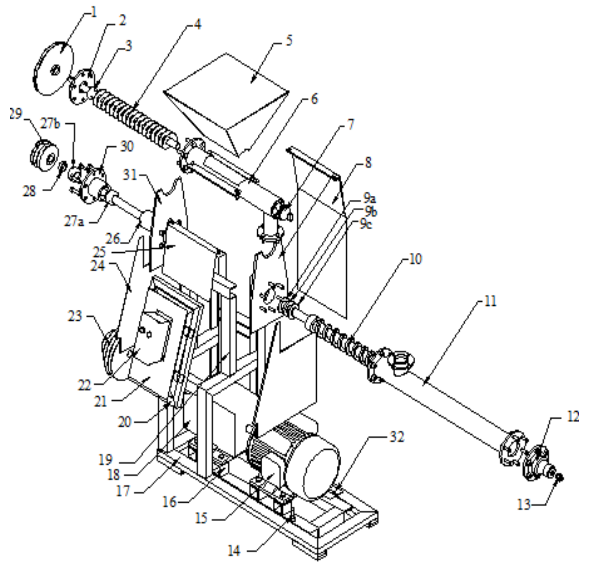

Fig. 3. The exploded drawing of the extruder (LEGEND: 1 -Conveyor pulley, 2- Flange, 3-Bearing, 4- Conveyor, 5- Hopper,6-Conveyor Housing, 7-Housing Plug, 8- Rear Cover Sheet, 9-Thrust bearing, 10-Extruder worm, 12-Die, 13-Nozzle,14-Belt Adjuster,15-Electric Motor,16- Gear Sea, 17-Base Frame,18-Gear Box,19-Main Frame, 20-Panel Frame, 21-Panel Cover Sheet, 22- Control Switch, 23-Driver Pulley, 24-Side Cover Sheet, 25-Front Cover Sheet, 26-Shaft with Cup, 27-Taper Roller Bearing, 28- Lock Nut, 29-Extruder Pulley, 30-Hub, 31-Hub Support Plate, 32-Hinge).

5. Preliminary Testing of the Extruder

5.1. Test parameters

The steps and parameters which are very necessary during preliminary testing of extruders were investigated in the following sub sections:

5.1.1. Sample preparation

Cassava tubers (*Manihot esculenta Crantz*) TMS 30572, were sourced from experimental plots at the Federal College of Agriculture, Akure and processed into flour according to International Starch Institute standards [15] using a wet sieving machine developed by Fayose [16].

5.1.2. Barrel and product temperature

Barrel and product temperatures were determined as described by Chessari and Sellahewa [17] with K type copper- constantan thermocouple inserted into the barrel immediately before entry of the mass into the die and with Portec CAI 001 thermometer probe (Portec instrumental, Milton Keynes, UK) inserted into the melt immediately before passage of the mass out of the die. The result was read from a read out digital meter.

5.1.3. Extruder efficiency

The extruder efficiency (η) was determined as described by Liang et al. [18]. Extruder efficiency is considered as the theoretical power required divided by the actual power consumed.

5.2. Experimental procedure

Samples were fed into the extruder at a feed rate 10 kg/h (0.0027kg/s) and the feeding section of the extruder maintained at room temperature. The extruder was operated for 30 minutes for each set of conditions. Steady state extrusion conditions is assumed to have been reached where there is no visible drifts in products temperature and torques required to turn the screw and by a steady extrusion rate [19]. Temperature, both of the barrel and product were varied by continuous running of the machine, thereby building up the temperature. A major reason why heat is better generated through viscous dissipation than that added or removed through the barrel walls is that heat generated by drive unit (through viscous dissipation) is more dominant and cost efficient [18].

The temperature was controlled by removing and dipping the barrel and screw in a bath of cold water each time the extruder is to be loaded with samples. Moisture content values from 15 to 60% (d.b.) was tried for cassava flour to see which moisture content will allow for easy flow of the samples through the extruder. Moisture contents of samples and their extrudates were determined on a dry basis by an oven method using the AOAC (1995) method [20]. Screw speeds of operation of machine ranging from 80 to 200 rpm were also tested. Data were read simultaneously by two observers, each person taking specified instruments simultaneously. The sizes of die (6 – 12 mm) that would allow for easy passage of materials were also tested.

6. Results and Discussion

6.1. Description of the extruder

The extruder is made up of three (3) main units namely the feeding unit, the compression and melting unit and the die unit all fabricated using locally available materials. The extruder was developed as a test rig. A detailed report of the extruder is contained in Fayose [21]. The feeding unit and the compression/melting unit are operated by one electric motor through a gear reducer and belt and pulley transmission system. As a test rig, allowance was given for varying the screw configuration, feed rate, screw speed, die configuration and nozzle. Speed regulation was done by varying the pulley ratios.

All parts through which the feed material will pass were made of stainless steel to prevent food contamination and to withstand frictional wear. The screw is of single flight, increasing diameter and tapering/decreasing pitch with a compression ratio of 4.5:1. The diameter of the final portion of the screw is reduced to a cone. This aid in pressure built up, easy conveyance of materials through the die and in reducing wear rate. The length to diameter ratio is 12:1. An electric motor drives the screw through a gear reducer, and the backward thrust of the screw is absorbed by a thrust bearing. The barrel and the screw/die configuration is typical of alimentary food production equipment.

The extrudates were extruded as ribbons and later cut into sizes manually. A unit of the machine costs N 470, 390.00.00 as at April 2013. This cost was based on an estimate by Aderoba et al [22] but reviewed upwards to the prevalent existing exchange rate at the time this study was conducted.

The cost comprised of the cost of bought out components, e.g., electric motor, cost of the materials used for fabricating the various component parts of the machine, cost of machining and non-machining jobs. The cost of machining and non-machining jobs were determined by multiplying the time spent on each job/ hour (e.g., boring or turning on a lathe), the labour cost for each of the jobs/hour and the equipment cost/hr. This cost is different from the selling price since the purpose of this study is not for commercialization. Hence no profit cost has been added to it.

6.2. Result of preliminary tests

The result of preliminary testing of the extruder is presented in Table 1. This table shows the outcome of the trials on the range of moisture level of cassava to be selected for further investigation. Feed moisture $\leq$ 20 % blocked the rotation of the screw as there was no transition from the original floury nature to a melted state typical of most extrusion processing.

This may be because the moisture content was not sufficient to solvate the starch polymers and allow them to move freely in the mass, hence there was resistance to deformation. The minimum moisture necessary to obtain steady flow of extrudate on this extruder was 25%. This result is in contrast with observation on previous studies on extrusion of cassava flour, e.g., Hashimoto and Grossmann [23] where the minimum moisture content required was 10 % d.b.

Table 1. Result of preliminary running of machine.

***m* %**	**D_t sec**	**Size of Die, mm**	**Observation**	**Remark**
15	2	6-12	sample got stocked	Not selected
25	30	12	formed but no expansion	Not selected
		6	well-formed	Selected
30	2	12	formed but no expansion	Not selected
	30	6	well-formed	Selected
40	2	12	formed but no expansion	Not selected
	30	6	well-formed	Selected
50	2	6-12	sample adhere to the surface of container	Not selected

This observation in the present study with the variety of cassava flour used, TMS 30572, may be because efforts to improve cassava have being focused on increasing yield, dry matter content, nutritional and protein content to contribute to a sustainable and cost effective solution to malnutrition [24]. This problem of getting stocked at lower moisture levels can be overcome by improving the torque. Low-moisture materials require more mechanical energy to cause to flow.

Also, from Eq. (3), speed is inversely proportional to torque. It can be deduced that to develop higher torque, the pulley on the extruder shaft must be bigger than that of the driver pulley to increase its torque force. It is therefore advisable to select high speed prime mover and attempt to step down its speed on the extruder shaft by using a bigger pulley. This will improve the propelling force.

Figures 4 and 5 show the variation of highest barrel temperature and actual extruder screw speed respectively with extrusion time at moisture contents 25, 30 and 40 % (d.b). Figure 4 shows that barrel temperature varies directly with extrusion time in a polynomial trend. The barrel temperature increased positively as the extrusion time increased. A maximum temperature of 114°C was attained in 30 minutes through viscous dissipation at 25% moisture content. Steady state condition was attained within 25 minutes for moisture content 25% while it took longer periods for those of 30% and 40% moisture contents to attain steady state.

From Fig. 5, actual extruder screw speed varies inversely with extrusion time and it is best fitted with a polynomial trend. The actual extruder screw speed decreased as the extrusion time increased. The reason for the difference between the actual screw speed and the rated screw speed was because as the extrusion time increased, the temperature of the sample increased with a consequent increase in viscosity thereby increasing the resistance of the material to flow.

The extruder's efficiency against duration of sampling at screw speed 100 rpm and 30 % moisture content is shown in Fig. 6. Efficiency decreased with duration of sampling and it is highly correlated with actual screw speed. However, the extruder's efficiency strongly depends on the material being processed. From a detailed study, this extruder's efficiency was observed to increase with duration of sampling for cereal products (maize and wheat) while it decreased with duration of sampling for cassava products [21]. Also, an extruder cannot be expected to run at 100% efficiency, since the extruder is not completely adiabatic and the system itself consumes power, plus the external energy consumption.

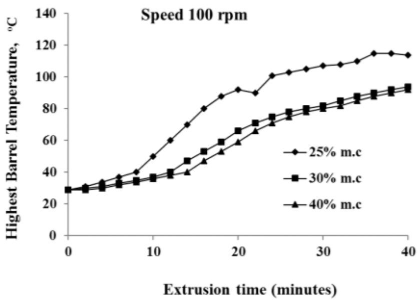

Fig. 4. Variation of highest barrel temperature with extrusion time at different moisture content.

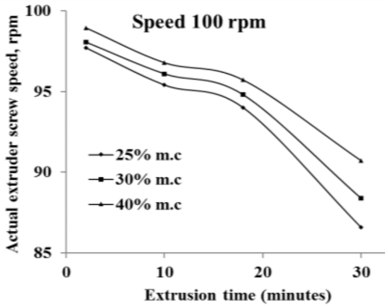

Fig. 5. Variation of actual extruder screw speed with extrusion time at different moisture content.

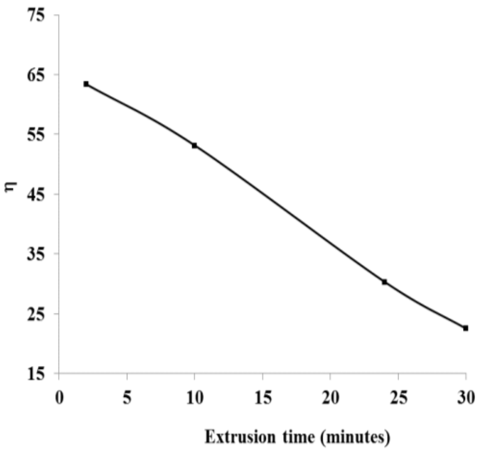

Fig. 6. Variation of extruder's efficiency with extrusion time at screw speed 100 rpm and 30 % moisture content.

7. Conclusions

A single screw starch extruder has been designed and tested using locally available materials as a means of arresting post-harvest losses of starch based crops in Nigeria. The extruder is the dry type and it has a capacity of 107.615 ton/hr (27.12 kg/s), approximately 4.5: 1 compression ratio and is powered by a 5.5 kW electric motor. Some concluding observations from the investigation are given below.

- When used to process cassava flour, a maximum temperature of 114 °C was attained through viscous dissipation, up to an actual screw speed of 98.96 rpm and extruder's efficiency of 64%.
- Barrel temperature varied directly with extrusion time in a polynomial trend while actual extruder screw speed and efficiency varied inversely with duration of sampling and it is best fitted with a polynomial trend.
- The extruder's efficiency was higher at low extrusion time (64%) than at high extrusion time (22%).
- A unit cost of production of the machine was ₦ 470, 390.00.00 as at April 2015.
- The study showed some variations from previous studies on effect of moisture levels on cassava flour.
- The study will facilitate the development of an indigenous starch extruder adaptable to local conditions. Data base on food extrusion which of benefit in food processing has been provided.
- Suggestions on further works to be done to improve the performance of the extruder were discussed.

References

1. Mogirya, P.W. (2012). You can become a millionaire from cassava farming, *East Africa Agribusiness*, 9-11. Retrieved October 14, 2013, from https://issuu.com/mugenipeter/docs/east_africa_agribusiness_01/11.
2. Mulegeta, T. (2011). Industrial use of maize grains in Ethopia: A review, in. Worku, M.; Twumasi Afriyie, S.; Wolde, L.; Tadesse, B.; Demisie, G.; Bogale, G.; Wegary, D.; and Prasanna, B.M. (eds.). *Proceedings of the National Maize Workshop of Ethiopia, 3*; Addis Ababa, Ethiopia, 286-271.
3. Fellows, P.J. (2003). *Food processing technology: principles and practice.* England: Woodhead Publishers Limited.
4. Aruna, K.Y. (2012). *Theory of extrusion technology, theory study material.* Acharya N. G. Ranga Agricultural University. Retrieved May 13, 2014, from http://www.angrau.ac.in/media.
5. Van Zuilichem, D.J.; Bruin, S.; Janssen, L.P.B.M.; and Stolp, W. (1980). Single-screw extrusion of starch – and protein- rich materials, in Linko P.; Malkki Y.; and Olkku J. (1980). *Food Processing Engineering*, Vol. 1 Food Processing Systems, England: Applied Science Publishers Ltd.
6. Van Zuilichem, D.J.; and Stolp, W. (1987). Survey of the present extrusion cooking techniques in the food and confectionery industry, In Connor, O.C. (1987) *Extrusion Technology for the Food Industry*, London: Elsevier Applied Science Publishers.
7. Perry, R.H.; Green, D.W.; and Maloney, J.O. (1986). *Handbook of Chemical Engineers* (6th ed.) New York: John Wiley and Sons Inc.
8. PSG TECH Design Data (1982). Compiled by Faculty of Mechanical Engineering, PSG College of Technology, Coimbatore, India.
9. Khurmi, R.S. (2006). *Strength of materials (Mechanics of Solids)* S.I. Units. New Delhi: S. Chand and Company Ltd.

10. Sivakumaran, K.; and Goodman, J.W. (1986). Influence of internal pressure on performance of a small screw expeller. *Trans. of ASAE,* 28(1), 2801.
11. Frame, N.D. (1994). *The technology of extrusion cooking*. New York: Blackie Academic and Professional.
12. Govindasamy, S.; Campanella, O.H.; and Oates, C.G. (1996). High moisture twin-screw extrusion of sago starch: influence on granule morphology and structure. *Carbohydrate Polymers*, 30, 275-286.
13. Alvarez-Martinez, L.; Kondury, K.P.; and Harper, J.M. (1988). A general model for expansion of extruded products. *Journal of Food Science*, 53, 609-615.
14. Sokhey, A.S.; Ali, Y.; and Hanna, M.A. (1997). Effects of die dimensions on extruder performance. *Journal of Food Engineering*, 31(2), 251-261.
15. International Starch (2005). Memorandum on tapioca (cassava) starch, International Starch Institute, Science Park Aarhus, Denmark, Retrieved August 8, 2008, from http:// http://www.starch.dk/isi/starch/cassavastarch.asp
16. Fayose, F.T. (2008). Development of multipurpose sieving machine for wet agricultural products, *Agricultural Engineering International* 10, 1-9.
17. Chessari, C.J.; and Sellahewa, J.N. (2001). Effective process control in Guy, R. (ed.), *Extrusion Cooking Technologies and Applications*. Cambridge: Wood Head Publishing Limited and CRC Press LLC.
18. Liang, M.; Huff, H.E.; and Hsieh, F.H. (2002). Evaluating energy consumption and efficiency of a twin – screw extruder. *Journal of Food Science*, 67(5), 1803-1807.
19. Alves, R.M.L; Grossmann, M.V.E; and Silva, R.S.S.F. (1999). Gelling properties of extruded yam (Dioscorea Alata) Starch. *Food Chemistry*, 67, 123-127.
20. AOAC (1995). Official Methods of Analysis of the Association of Official Analytical Chemists, Washington D. C. pp.710.
21. Fayose, F.T. (2009). *Development and performance evaluation of a single-screw starch extruder* Ph.D. Thesis, School of Engineering and Engineering Technology, Federal University of Technology Akure, Nigeria.
22. Aderoba, A.A.; Badu, J.Y.; Olufayo, A.A.; and Adesina, A.A. (1987). *A final report of reinvestment analysis for effective commercialization of FUTA machine shop.* Workshop Report 1, Federal University of Technology Akure Nigeria.
23. Hashimoto, J.M.; and Grossmann, M.V.E. (2003). Effects of extrusion conditions on quality of cassava bran/cassava starch extrudates, *International Journal of Food Science and Technology,* 38, 511-517.
24. Dixon, A.G.O.; Ssemakula, G.; Maziya- Dixon, B.; Caballos, H.; and Fregene, M. (2007). *Genetic enhancement of protein content in cassava storage roots.* Cassava Utilization Programme, IITA. Retrieved February 2, 2009, from www.slideshare.net/IITA-CO/genetic-enhancement-of-betacarotene-in.