DESIGN AND DEVELOPMENT OF A SOAP STAMPING AND TABLETING MACHINE FOR SMALL SCALE SOAP MANUFACTURING

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Abstract

A soap stamping and tableting machine comprising a printing die/pattern inscriptioner, cutting blade, conveyor belt, and two electric motors was developed and tested. Performance test analysis conducted showed that the machine operated with an optimal stamping/tableting capacity of 10205 soap tablets per hour with an efficiency of 98.8% when its conveying and stamping/tableting units were powered with 2HP and 4HP electric motors respectively. All materials used in the fabrication of this machine were sourced locally, and the estimated cost for producing one unit of the machine is ninety five thousand six hundred and fifty naira (N95,650). The machine reduced drudgery and tedium in small scale soap making and also enhanced mass production and profit.

Keywords: small scale soap making, portable, stamping, tableting, machine

1. Introduction

Soap is a salt of a fatty acid used in textile spinning, lubricants production and mainly as surfactant in conjunction with water for washing, bathing and cleaning [1, 2, 3]. Thus, it is a vital product for good hygiene of man and his environment. Soaps for cleansing are usually obtained by treating vegetable or animal oils and fats such as palm oil, coconut oil, olive oil and laurel oil with strong alkaline solution [4, 5]. Wikepedia [6], attributed the cleaning action of soap/water mixture to the action of micelles, tiny spheres coated on the outside with polar hydrophilic (water loving) groups, encasing a lipophilic (fat loving) pocket that can surround the grease particles, causing them to disperse in water. In other words, whereas normally oil and water do not mix, the addition of soap allows oils to disperse in water and be rinsed away [6]. According to refs [7], [8], [9] and [10], soap production is a lucrative business which every business-minded person can invest on because the raw materials for the production are readily available in all part of Nigeria. Zillion [7], further said that the amount of soap consumed daily in Nigeria is staggering and the huge market presents a golden opportunity for investors and opportunity seekers who may decide to go into soap making. LEAP [11], also indicated that the simplicity of soap making process has led to its worldwide practice as a small business

operation. Soap making falls into two distinct scales;- small and industrial production [6]. The industrial production of soap involves a continuous process that requires constant addition of fat and removal of products. Smaller scale production involves the traditional batch processes with three major variations: the cold-process, wherein the reaction takes place substantially at room temperature, the semi-boiled or hot-process, wherein the reaction takes place at near-boiling point, and the fully boiled process, wherein the reactants are boiled at least once and the glycerol recovered [2]. The cold and hot processes (semi-boiled bath process) are the simplest and typically used by small scale soap producers, artisans and hobbyists [6]. The sequential steps involved in use of these two processes for soap production by these categories of producers as described in [2], [6] and [7] are shown in Figure 1.

Soaps are produced in different shapes, sizes, colours and qualities/grades depending on their specific uses and manufacturer. However, soaps produced by different manufacturers may have identical shapes and sizes especially when the shape is not part of the manufacturers trade mark. Hence, it is always difficult to differentiate soaps of the same features produced by different manufacturers. Oluka et al [12], said that trademark is made on products by manufacturers to distinguish the products from that of
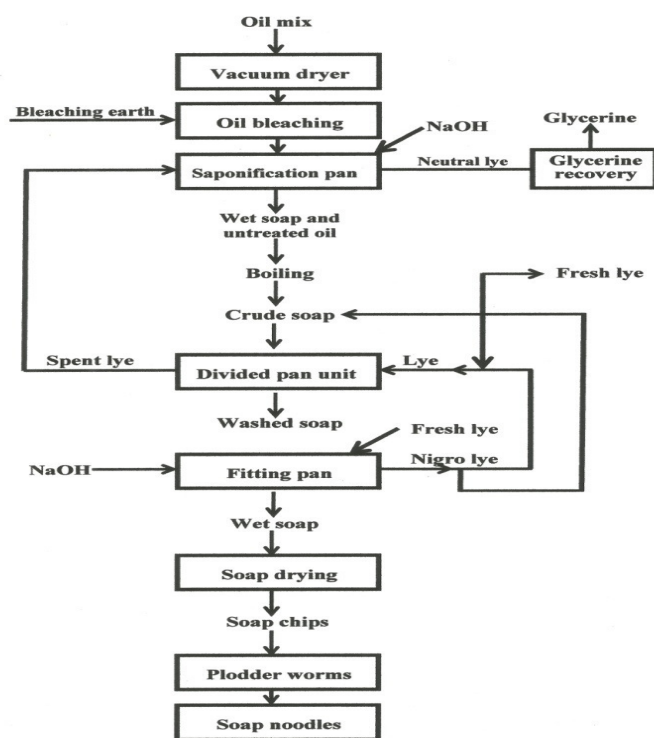
Figure 1: Flow diagram of soap production by bath process.

others and that it is useful to companies producing high quality goods since consumers usually patronize their products even without testing. Registration of trademark prevents another manufacturer from using it. As a result of the problem of product identification, large scale soap manufacturers registers some unique shape of their products as trademark and also print their logo in the body of the products to enable its identification even when it is not packaged or covered with the companys label. Stamping (printing of identification marks) and tableting (shaping and sizing) of manufactured soaps are done in industrial scale using automated manufacturing systems while most small and some medium scale soap producers use hand stamps and mould/cutting devices (Knifes) for these two operations. The manual cutting of manufactured soap into bars after insulation and printing of identification marks on the bars using these manual devices is prone to accident and also tedious, energy sapping, time consuming, resulting to inconsistency in the shape and identification (marks) printed on soaps produced by small scale manufacturers due to human error. Thus, consumers find it difficult to differentiate the original products of this group of soap makers from the fake ones. Hence, consumers view the products of small scale soap producers as inferior even though some of their products are of higher quality than some industrially produced ones.

In addition, the tedium and drudgery associated with the use of manual devices for soap tableting and stamping by small scale producers make production of soap at this level uneconomical and unattractive to youths, despite the huge market prospect of this sector in Nigeria. Tableting of soap into different sizes is very important in small scale production since it is these producers that make most of the laundry soaps used by rural dwellers whose bulk purchasing power are very small. For these reasons it makes economic sense to ensure consistency in the size, shape and identification marks on soaps produced by our small scale producers to enhance customers' confidence in their products by introducing a labour saving machine which will tablet and stamp soaps simultaneously. As a result of this desire for soap tableting and stamping machines by small scale soap producers, Eze [13] developed a manually operated soap tableting and stamping machine for these categories of soap producers. However, the manually operated machine still retain some tedious nature of the mould and hand stamp due to the manual effort required to operate it, thus, the need for a motorized model of this machine to reduce human intervention in this process. Ajoa et al [14] answered this call by developing a set of shop floor size pedal-powered soap mixer, mould, cutting and stamping machines for making homemade laundry soap.

Although, the soap cutting and stamping machine in the set of equipment developed by [14] makes the act of cutting and stamping easy, faster and neater than using ordinary knife and manual stamping machine, the cutting and stamping operations were done at different regions, thus a soap tablet is cut and stamped at different times and regions in the same machine unlike the manual tableting and stamping machine produced by [13] that cuts and stamps a soap tablet at the same time/region. The later process of simultaneous soap cutting and stamping process (at the same time and region) reduces inconsistence in the output and also enhanced the portability of the machine. Furthermore, the set of equipment developed by [14] is of shop size even though there were made for local soap production and therefore not portable for use by all categories of small scale soap producer such as the artisans that may not afford the space required. Thus, the need for a more portable electric motor driven soap tableting and stamping machine that can cut and stamp soap tablet simultaneously. This will enable the products of small scale soap manufacturers compete favourably with those of the major soap producers as well as enhance efficiency, reduce cost of production and increase profit of small scale producer. Hence, the objectives of this present work are to design, develop and test the performance of a portable soap stamping and tableting machine for all categories of small scale soap producers.

2. Materials/Methods of Study

2.1. Description of the developed soap stamping and tableting machine

The major components of the developed soap stamping and tableting machine shown in Figure 2 are frame, conveying unit, stamping/tableting unit, crank assembly, bearing housings, 2HP and 4HP electric motors.

The frame is the main supporting structure upon which other components of this machine were mounted. The frame is a welded section fabricated from 2.5mm thick angle iron and 1.5mm thick mild steel plate. The conveying unit of this machine comprised of a 2HP single phase electric motor, conveyor shaft and rollers, conveyor belt, a V-belt and two pulleys. The electric motor installed on a base made from 2.5mm thick angle iron drives the conveyor shaft via a v-belt/pulley mechanism. The conveyor shaft is a 25mm diameter mild steel rod with a length of 465mm and is supported at both ends using ball bearings. The soap conveying belt was installed on the surface of the machine using two rollers with one mounted on the conveyor shaft and the other at a distance of 80mm in the opposite end of the machine surface.

The stamping and tableting unit comprised a 4HP single phase electric motor, a crank shaft, crank link mechanism with slider, printing die and tableting blade. The motor installed on the same base with that of the conveying unit, operates the crank assembly which converts the rotary motion of the motor to reciprocating motion of the slider and piston. The crank shaft and piston were made from 20mm diameter mild steel rods each while the link is a 5mm thick mild steel flat bar with a length of 670mm. The length of the shaft and piston are 350mm and 555mm respectively. The bearing housings were fabricated using mild steel pipe of 3mm thickness. The printing die and cutting blade are detachable so that they can be changed easily when different shapes and inscriptions are desired.

The developed soap stamping and tableting machine requires the service of one operator. When the electric motors are powered, the conveyor belt which carries the soap placed on it to the tableting and stamping section where it will be stamped and tableted simultaneously as the piston of the tableting and stamping unit reciprocates with the tableting blade and printing die attached to it. The motion of the soap conveyor and piston was synchronized by an automatic relay timer such that as the soap gets to the tableting and stamping section of the machine, the conveyor motor automatically switches off to enable proper stamping and cutting of the soap. The motor switches on again automatically after the stamping and cutting to convey the stamped soap out of the section and feed another to the section simultaneously.

2.2. Design analysis of the machine

2.2.1. Design considerations

In accordance with Cornish [15] guides for design and selection of component of engineering systems, the design, material selection and fabrication of the soap stamping and tableting machine was based on the following considerations:

1. The availability of materials locally to reduce cost of production and maintenance.

2. The criteria for selecting materials for the various components of this machine were based on the type of force that will be acting on them, the work they are expected to perform and the environmental condition in which they will function.

3. It is desired that there should be consistence in the size, shape, and inscription on the soap tablet produced by the machine; therefore pulleys were carefully designed/selected to meet the required synchronized speeds of the feeding conveyor and stamping/tableting units.

2.2.2. Selection of pulleys, belts and determination of their speeds

The machine requires four pulleys with one each mounted on both the conveyor shaft and the crank shaft. The remaining two pulleys were keyed to each of the electric motor shafts. Due to its availability, cost and performance, mild steel pulleys with groove angle of 380 each were selected. The speed ratios of the driver to the driven pulleys for the motor/conveyor shaft and motor/crank shaft drives were approximately 2.68:1 and 41:1 respectively. The rated speeds of the primary drivers (motor) for both the conveyor and crank shaft are 2400rpm and 1600rpm respectively. Thus, the speeds of the driven conveyor shaft and crank shaft pulleys were determined as 896rpm and 38.96rpm ($\simeq$ 39rpm) respectively using the following relation [16] ;

$$\frac{N_1}{N_2} = \frac{D_1}{D_2} \qquad (1)$$

Where: N_1 is driving pulleys speed, rpm ; N_2 is driven pulleys speed, rpm; D_1 is diameter of driving pulley = 56mm for the motor/conveyor drive and 61mm for the motor/crank shaft drive; D_2 is diameter of driven pulley = 150mm for motor/conveyor drive and 305mm for motor/crank shaft drive.

The centre distances, C between the adjacent pulleys for both drives were determined as 159mm and 244mm for the motor/conveyor and motor/crank shaft drives respectively using Equation (2) [17];
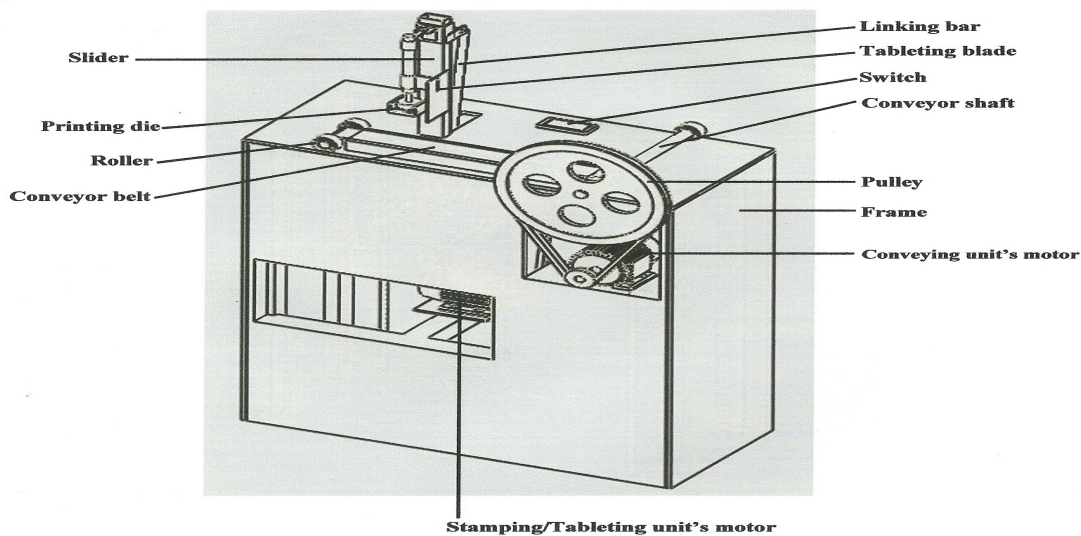
$$C = \frac{1.5D_2}{VR^{1/3}} \qquad (2)$$

Figure 2: Diagram of the developed soap stamping and tableting machine.

Where VR is velocity ratio.

Thus, lengths l of the belt required were computed as 655.31mm and 1123.62mm for the motor/conveyor shaft and motor/crank shaft drives respectively from Equation (3) [16, 17]:

$$l = 2C + 1.57(D_1 + D_2) + \frac{D_2 - D_1}{4C} \qquad (3)$$

Since each of the drives transmits less than 3.75kW each, type "A" V-belt was selected for each of the drives. Therefore, based on IS: 2494-1974 [18], belts of standard pitch lengths of 696mm and 1128mm were selected for the motor/conveyor shaft and motor/crank shaft drives respectively. Consequently, the exact centre distances between the adjacent pulleys used in the fabrication of the machine were also determined using Equation (3) as 202mm and 325mm for the motor/conveyor shaft and motor/crank shaft drives respectively. Thus, the angles of lap, θ of the drives' small pulleys were respectively computed as 164.790 (2.877 rad.) and 165.950 (2.896 rad.) for the motor/conveyor shaft and the motor/crank shaft drives using the following relationship [16];

$$\theta = 180 - \left[\arcsin \left(\frac{D_2 - D_1}{2C} \right) \right] \qquad (4)$$

The belt speed for the drives were determined as 18.85m/s and 25.55 m/s for the motor/conveyor shaft and the motor/crank shaft drives respectively using the following relation given as.

$$v = \frac{\pi N_2 D_2}{60} \qquad (5)$$

2.2.3. Determination of belts tensions and shaft diameters

The mass per unit length, of the selected belts were obtained from standard table as 0.173kg/m and 0.237kg/m for the A-696mm and A-1128mm belts respectively [16, 17]. The coefficient of friction, μ between the pulleys and the belts, maximum safe stress, δ and cross sectional area, a of the belts were also obtained from standard tables as 0.3, 2.1N/mm^2 and 81mm^2 respectively [17]. The tensions on the tight side, T_i of the belts for each drive is given as [16];

$$T_i = T_{max} - T_c \qquad (6)$$

Where:

$$T_{max} = \delta a \qquad (7)$$

$$T_c = mv^2 \qquad (8)$$

T_{max} = Maximum tension of the belts T_c = Centrifugal tension Thus, T_i was computed as 194.14N and 241.67N for the motor/conveyor shaft and the motor/crank shaft drives respectively. Consequently, the slack side belt tensions T_j were determined as 131.66N and 162.71N for the motor/conveyor shaft and motor/crank shaft drives respectively using Equation (9).

$$2.3 \log \frac{T_i}{T_j} = \mu \theta \csc \beta \qquad (9)$$

The diameters, d of the conveyor and crank shafts of the soap stamping and tableting machine were determined using maximum stress relations given by [16, 17] as;

$$d = \left[\frac{16}{\pi \tau} \sqrt{(k_b M_b)^2 + (k_t M_t)^2} \right]^{1/3} \qquad (10)$$

where; τ = Allowable shear stress for steel shaft with provision for key ways = 42N/mm^2; M_t = Maximum twisting moment on the shafts, N-mm; M_b = Maximum bending moment on the shaft, N-mm; k_b = Combined shock and fatigue for bending; k_t = Combined shock and fatigue factor for twisting.

The maximum twisting moments on conveyor shaft and crank shaft were determined as 13536N-mm and 34306.4N-mm respectively using Equation (11) by [16, 17].

$$M_t = (T_i - T_j)\frac{D_2}{2} \qquad (11)$$

Bending moments occur on the shafts as a result of applied loads and belt tension, thus the maximum bending moment on the shafts were determined as follows;

Conveyor shaft:

The applied loads and belt tensions on the conveyor shaft are shown in Figure 2.

Where; W_C = weight of the conveyor shaft = 15.70N, W_{CP} = weight of the conveyor shaft pulley = 11N, T_i = Tension on the tight side of conveyor shaft drive belt = 194.14N, T_j = Tension on the slack side of the conveyor shaft drive belt = 131.66N.

Thus; Total force at point

$$A = W_{CP} + T_i + T_j = 218.8N$$

The reactions of bearings, R_B and R_D were determined by taking moment about B

$$\sum M_A = 0; \quad R_D(360) = 218.8(75) + 15.70(180)$$

R_D = 53.43N. Also

$$\sum F_Y = 0; 15.70 + 218.8 = 53.43 + R_B$$

R_B = 181.07

Taking downward forces to be negative (-) and upward forces positive (+), the shear forces acting on this shaft were computed as follows;

$$F_{A-B} = -218.8N$$

$$F_{B-C} = -218.8 + 181.07 = -37.73$$

$$F_{C-D} = -218.8 + 181.0715.70 = -53.43$$

$$F_{D-E} = -218.8 + 181.0715.70 + 53.43 = 0N$$

Thus, the bending moments on this shaft are as follows; M_A = 0N-mm; M_B = -16410N-mm; M_C = 23201.4N-mm; M_D = 21992.8N-mm; M_E = 0. Therefore, the maximum bending moment on the conveyor shaft is 23201.4N-mm. The conveying of the soap by the conveyor is gradual and steady, hence, k_b = 1.5 and k_t = 1.0 [16]. The diameter of this conveyor shaft was determined as 23.7mm using Equation (10). Thus, a standard 25mm diameter solid mild steel shaft was selected for conveyor shaft.

Crank shaft:

The crank shaft and the forces acting on it are as shown in Figure 3.

where; W_L= weight of the link mechanism = 10.30N, W_{CP} = weight of the crank shaft pulley = 13.734N, T_i = Tension on the tight side of the crank shaft drive belt = 241.67N, T_j = Tension on the slack side of the crank shaft drive belt = 162.71N, W_{CS} = weight of the crank shaft = 6.867N. Thus, total force at points C and A are 17.167N and 272.114N respectively.

The reactions of the bearings, RB and RD were determined by taking moment about D;

$$\sum M_D = 0; \quad R_B(200) = 17.167(95) + 272.114(360)$$

R_B = 497.96N. Also

$$\sum F_Y = 0; \quad R_A + 497.96 = 17.167 + 272.114$$

R_A = 208.68N.

Taking downward forces to be negative (-) and upward forces positive (+), the shear forces acting on the crank shaft were computed as follows. F_{A-B} = -272.114N; F_{B-C} = -272.114 + 497.96 = 225.85N; F_{C-D} = 208.68N; F_D = 0N.

Following the same sign convention, the bending moments on this cake breaker shaft were computed as follows. M_A = 0N-mm; M_B = -43538.24N-mm; M_C = 23658.32N-mm; M_D = 0N-mm.

Thus, the maximum bending moment on the crank shaft is 23658.32N-mm. The crank shaft is subjected to fairly sudden impact, hence, K_b = 1.5 and K_t = 1.5 [16]. The diameter of this shaft was determined as 19.27mm using Equation 10; thus, a standard 20mm diameter solid mild steel shaft was selected for crank shaft.

2.2.4. Selection of electric motors

The power, P required for driving the conveying and stamping/tableting units of this machine were determined as 1.1589kW and 2.226kW respectively using Equation (12) given by [16, 17].

$$P = (T_i - T_j)v \qquad (12)$$

Taking care of 10% possible power loss due to drives friction, the power required to drive the conveying and stamping/tableting units were computed as 1.27479kW (1.71HP) and 2.448kW (3.28HP). Therefore, a standard 2HP and 4HP electric motors were selected to drive the conveyor and stamping/tableting units of this machine respectively.

2.3. Performance testing procedure

The stamping/ tableting capacity, C and efficiency of this soap stamping and tableting were evaluated using ten (10) experimental runs. Each test involved operating the machine at a constant tableting/stamping
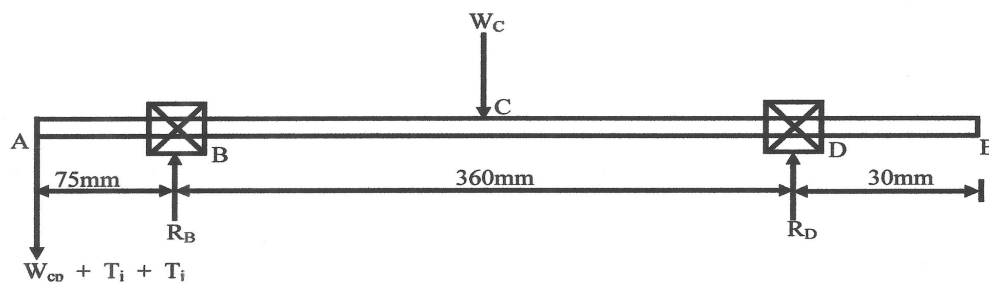
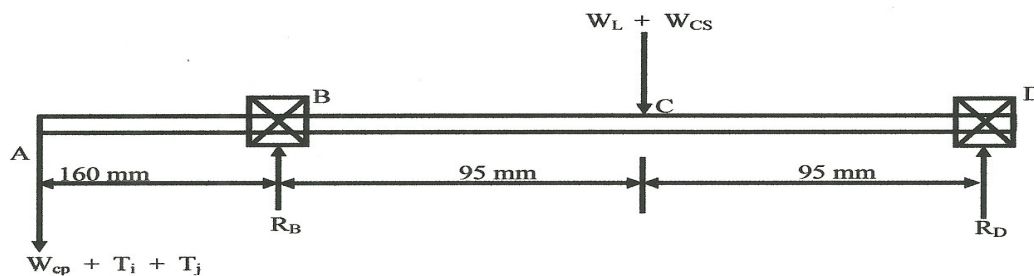Figure 3: The conveyor shaft showing forces acting on it.

Figure 4: The crank shaft showing forces acting on it.

design speed of 39rpm for five (5) minutes while the conveyor speed was varied among the experimental runs in ascending order of 50rpm step. The number of soaps tableted and stamped during each test was recorded. The numbers of well stamped and tableted soap, and scraps were also recorded. Soaps with imprint depth of 3mm and well cut to dimension were taken as well stamped and tableted (good ones) while the scraps includes soaps with improper cuts or with more or less than 3mm imprint depth. The imprint depth was measured with depth gauge. Thereafter, the capacity and efficiency of the machine were computed in each case using the following relations:

$$\eta(\%) = \frac{N_g}{N_T} \times \frac{100}{1} \qquad (13)$$

$$C(\text{Tablets/h}) = \frac{N_g}{t} \qquad (14)$$

Where t = Time of the operation = 5 minutes, N_g = Number of well stamped and tableted soaps, N_T = Total number of soaps stamped and tableted.

3. Results and Discussion

The result of the performance testing of the developed soap stamping and tableting machine is shown in Table 1. It is clear from this table that the capacity of this machine increased proportionally with the conveying speed, however, its efficiency increases progressively from 61.4% at a conveying speed of 50rpm

to a peak or optimal of 98.80% at 320rpm and then decreased (efficiency) progressively as the speed increased after 320 rpm. Thus, the machines performance is optimal at the conveying speed of 320 rpm with a capacity and efficiency of 10205 soaps tablets per hour and 98.80% respectively. The machine is affordable because all the materials used for its construction were sourced in the local market and its low price of ninety-five thousand, six hundred and fifty naira (N95, 650.00).

4. Conclusions and Recommendations

A portable soap stamping and tableting machine was designed, fabricated and tested at Michael Okpara University of Agriculture, Umudike for all categories of small scale soap producers. This machine which cuts and stamps soap tablets simultaneously, reduced drudgery and risks involved in small scale soap production and also affordable due to its low cost of production because it was fabricated with locally sourced materials. The performance of this machine was quite appreciable at a conveying speed of 320rpm during which it performed with maximum throughput and efficiency of 10205 soaps tablets per hour and 98.80% respectively. It is therefore, recommended that manufacturers should mass produce this machine in order to further reduce its cost through bulk purchase of raw materials. Also, government and other agencies

Table 1: Result of the Performance Evaluation of the soap stamping and tableting machine.

S/No.	Conveying Speed (rpm)	Total number of Soap tablets produced	Total number of well tableted and stamped soaps	Total number of soaps not tableted or stamped well	Efficiency (%)	Capacity (Tablets/h)
1.	50.00	26	16	10	61.54	3120.00
2.	100.00	34	22	12	64.70	4082.00
3.	150.00	39	27	12	69.23	4688.00
4.	200.00	53	38	15	71.70	6365.00
5.	250.00	65	47	18	72.30	7807.00
6.	300.00	73	66	7	90.41	8760.00
7.	320.00	85	84	1	98.80	10205.00
8.	340.00	97	65	32	67.01	11641.00
9.	360.00	101	63	38	62.38	12123.00
10.	380.00	108	63	45	58.33	12961.00

should encourage small scale soap producers by granting interest free credits to them to enable them adopt this machine. This will enhance production/profit in this sector as well as help in achieving vision 20:20:20 of the Federal Government and MDG goals in the areas of employment and effective raw materials utilization.

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