Monothetic Analysis and Optimization of Improved Soap Stamping and Tableting Machine

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Abstract—This study involves performance characterization and optimization of an improved soap stamping and tabulating machine using monothetic analysis method foster its improvement for economic viability. The parameters evaluated include conveying and stamping/tabulating speeds as factors while throughput, efficiency and specific energy constitute the performance indicators (responses) of this machine. Results revealed 320rpm and 38rpm as optimal settings of the conveying and stamping/tableting speeds respectively. It also showed that the machine operates with an efficiency, throughput and specific energy of 100%, 1020 soap tablets/h and 19.74kJ/soap tablet respectively at these optimal speed settings. This analysis further revealed that modification and operation of this machine with a single 5Hp motor will reduce its energy consumption rate by 16.67%. Thus, operation of this improved soap stamping and tableting machine with single prime mover of 5Hp and optimal conveying and stamping/tableting speeds of 320rpm and 38rpm respectively is recommended for its techno-economic viability.

Index Terms— Bar soap, dirts/germs removal, modification, optimal parameters, stamping-tabulating machine, techno-economic viability

1. INTRODUCTION

Soap is a compound of oil fats and caustic alkali used for removing/washing of dirts, germs and other contaminants [1], [2]. It is indispensable for promoting save and hygienic daily lives because it keep us clean and refreshed with positive odors and help in fighting germs in our homes, schools, hospitals and offices/business places [3]. Soaps come in two variant forms, liquid and solid. It is usually refers as bar soap when shaped as a bar in its solid form such that one can actually hold it easily. Both liquid and bar soap are effective against bacteria and viruses, the friction created by rubbing bar soap against your hands can be more effective at removing visible debris/dirts [3]. This caused intensive application of bar soap in bathing, washing of clothes and kitchen utensils, thereby making both small and industrial scale bar soap production lucrative over the years [4]. Although, industrial bar soap production is fully mechanized/automated for to match the ever increasing daily demand for this item in Nigeria, [5] revealed small scale sector as the major source of most laundry soaps used by rural dwellers which constitutes over 70% of Nigeria population. Eze [5] also indicated unsuccessful development of suitable stamping and tabulating machine for this small scale soap producers as major constraint to economic viability of this business sub-sector despite high demand for bar soap in this country. Suitable soap stamping and tabulating machines for small holders in this sector is vital to ensure consistency in the size, shape and identification marks on their products thereby enhancing easy identification by customers. The works [5] and [6] indicated that enhancing these two finishing operations will reduce drudgery and improve product quality/aesthesis, production rate and profit/favourable competition in this small scale sub-sector.

The quest for suitable mechanized stamping and tabulating system for small scale soap producers led to a cranked machine developed by [5] for simultaneous soap stamping and tabulating operation and shop floor size pedal-powered soap mixer, mould, cutting and stamping machine by [6] for making homemade laundry soap. However, these two machines still retain some tedious nature of the mould and hand stamp due to the manual effort required to operate them. Thus, the continuous need for drudgery reduction in this process which prompted motorization of a cranked machine by [7] as shown in Fig. 1.

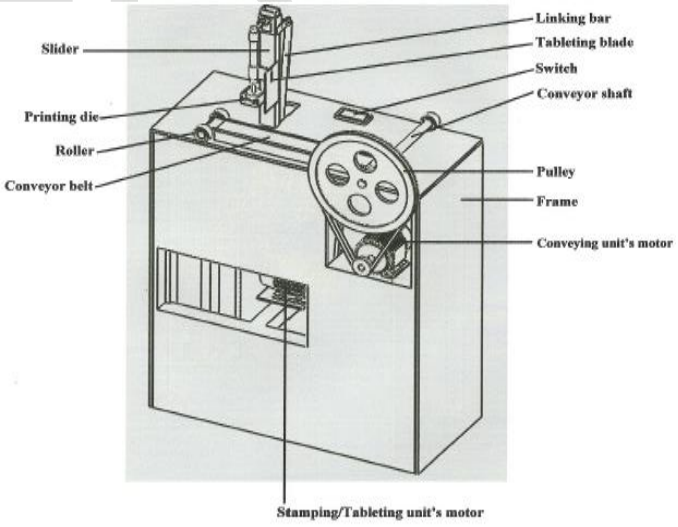

Fig. 1. Improved-motorized soap stamping and tabulating machine [7]

Although the motorized soap stamping and tabulating machine addressed the need for these process automation as desired for small scale soap production, the effect of stamping/tabulating speed on the responses of this machine and its energy consumption profile were not assessed. Existing performance records of this machine showed that its throughput increased proportionally with the conveying speed while its

efficiency increases progressively from 61.4% at a conveying speed of 50rpm to a peak of 98.80% at 320rpm and then decreased progressively as the speed increased after 320 rpm [7]. The unavailable record of interactions of stamping/tabulating speed with the responses of this machine indicates possibility of its suboptimal operation in accord with [8] which uneconomical. In addition, it is desired that this machine operates with minimum energy consumption rate and maximum efficiency and throughput possible because its economic application is only tenable if its specific energy is minimized. Specific energy of a machine refers to the energy consumed per a unit mass of its output [9]. Investigation of systems' specific energy profiles remained outstanding tasks of researchers and designers over the years because of its role in production cost reduction and overall system improvement as evident in the works of [9], [10], [11] and [12]. Thus, the monothetic performance evaluation and optimization of this innovative motorized soap stamping and tabulating machine for small stakeholders.

2. MATERIALS AND METHODS

The study involved evaluation the effects of stamping/tableting speed of the improved soap stamping and tabulating machine on its throughput, efficiency and specific energy consumption using the same monothetic experimental procedure applied in [7]. Each test involved operating the machine for five 5 minutes (300s) with optimal conveying speed of 320rpm and a varied tableting/stamping speed before measuring imprint depth on each of the processed soap tablet with depth gauge. This is followed by counting and recording of the total number of soap tablets processed (N), well stamped and tableted soap (Ng) and defected ones. Soap tablets with imprint depth of 3mm and well cut to dimension were taken as well processed tablets (good ones) while defects are those with improper cuts or imprint depth of less than 3mm. Thereafter, the throughput (TP), efficiency (η) and specific energy (SE) of the machine were computed in each case using (1), (2) and (3) respectively derived based on 6Hp-total power ratings of the machine's electric motors

$$TP = 12N \quad (1)$$

$$\eta = \frac{N_g}{N} \quad (2)$$

$$SE = \frac{20133.9}{TP} \quad (3)$$

In addition, the specific energy consumption rates of this machine were computed as per each conveying speed-performance interaction test data contained in [7] before tabulating the entire results for effective survey of the variation trends of its three functional responses with the operational speeds.

3. RESULTS AND DISCUSSION

The performance analysis of the improved soap stamping and tableting machine revealed that it's conveying speed influences all the three responses of this machine significantly while the stamping and tableting speed affects its efficiency only (Table 1 and 2).

TABLE 1
EFFECTS OF CONVEYOR SPEED ON THE IMPROVED SOAP MACHINE PERFORMANCE

S/No	Conveying speed (rpm)	Number of soaps processed	Number of well processed soaps	Number of Defects	TP (Tablets/h)	η (%)	SE (kJ/Tablet)
1	50.00	26.00	16.00	10.00	312.00	61.54	64.53
2	100.00	34.00	22.00	12.00	408.00	64.70	49.35
3	150.00	39.00	27.00	12.00	468.00	69.23	43.02
4	200.00	53.00	38.00	15.00	636.00	71.70	31.66
5	250.00	65.00	47.00	18.00	780.00	72.30	25.81
6	300.00	73.00	66.00	7.00	876.00	90.41	22.98
7	320.00	85.00	84.00	1.00	1020.00	98.80	19.74
8	340.00	97.00	65.00	32.00	1164.00	67.01	17.30
9	360.00	101.00	63.00	38.00	1212.00	62.38	16.61
10	380.00	108.00	63.00	45.00	1296.00	58.33	15.54

TABLE 2
EFFECTS OF STAMPING/TABLETING SPEED ON THE IMPROVED SOAP MACHINE PERFORMANCE

S/No	Stamp/tableting speed (rpm)	Number of soaps processed	Number of well processed soaps	Number of Defects	TP (Tablets/h)	η (%)	SE (KJ/Tablet)
1	20.00	85.00	85.00	17.00	1020.00	80.00	19.74
2	30.00	85.00	85.00	6.00	1020.00	92.94	19.74
3	35.00	85.00	85.00	3.00	1008.00	96.47	19.74
4	36.00	85.00	85.00	1.00	1020.00	98.82	19.74
5	37.00	85.00	85.00	1.00	1020.00	98.82	19.74
6	37.50	85.00	85.00	1.00	1020.00	98.82	19.74
7	37.60	85.00	85.00	1.00	1020.00	98.82	19.74
8	37.70	85.00	85.00	1.00	1020.00	98.82	19.74
9	37.80	85.00	85.00	1.00	1020.00	98.82	19.74
10	37.90	85.00	85.00	1.00	1020.00	98.82	19.74
11	38.00	85.00	85.00	0.00	1020.00	100.00	19.74
12	38.10	85.00	85.00	1.00	1020.00	98.82	19.74
13	38.20	85.00	85.00	1.00	1020.00	98.82	19.74
14	38.50	85.00	85.00	1.00	1020.00	98.82	19.74
15	39.00	85.00	85.00	1.00	1020.00	98.82	19.74

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Table 1 showed that the conveying speed increase improves both the throughput and specific energy of this machine as desired because the throughput increases with this speed while specific energy reduces with it. The conveying speed increases the efficiency to a peak of 98.80% at 320rpm but this response decreasing progressively as it increases above 320rpm, thereby affirming the record of [7] which showed 320rpm as optimal conveying speed of this machine. Experimental evaluation of this machine's operation at this optimal conveying speed shown in table 2 revealed 38rpm as its optimal stamping/tableting speed. This table indicated zero defect index when this machine operates with conveying and stamping/tableting speeds of 320rpm and 38rpm respectively. It also obvious from both table 1 and 2 that this soap stamping and tableting machine operates with a throughput and specific energy of 1020 soap tablets/h and 19.74kJ/soap tablet at these optimal speed settings. Further analysis of energy consumption profile of this machine with respect to its design record of 27479kW (1.71Hp) and 2.448kW (3.28Hp) as the power required to drive its conveying and stamping/tableting units by [7] revealed possible reduction of its specific energy if it is modified to operate with single prime mover. Presently, this machine operates with two electric motors rated 2Hp and 4Hp for its conveyor and stamping/tableting units respectively amounting to a total of 6Hp while the precise total power required by both units is 4.99Hp (1.71Hp + 3.28Hp). It is therefore of economic sense if a single standard 5Hp motor is used for both units' drives by introducing an intermediate shaft that will both units while the motor drives it. This will reduce the specific energy of this machine from 19.74kJ/soap tablet to 16.45 kJ/soap tablet which amount to 16.67% reduction in energy consumption rating.

4. CONCLUSION

This study revealed that the conveying speed of an improved soap stamping and tableting machine influences its three functional responses while its stamping and tableting speed affects the efficiency only. It also showed 320rpm and 38rpm as optimal settings of the conveying and stamping/tableting speeds respectively. This machine operates with an efficiency, throughput and specific energy of 100%, 1020 soap tablets/h and 19.74kJ/soap tablet respectively at these optimal speed settings. In addition, this raised the need for modification and operation of this machine with a single 5Hp motor to reduce its energy consumption rate by 16.67% in order to ensure its techno-economic viability.

ACKNOWLEDGMENT

Tertiary Education Trust Fund, Abuja is acknowledged for funding this study through Institutional based Research fund for Enugu State University of Science and Technology, Enugu.

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