

# Development and Performance Evaluation of Portable Liquid Soap Making Machine for Small and Medium Scale Industry

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**ABSTRACT:** The project work entails design, fabrication and testing of a 15 litres semi-automatic liquid soap making machine for small and medium scale industry using cold process method. A survey carried out on conventional method (the local method) showed that the conventional method consumes time, energy, has low output and efficiency and is hazardous to health. The fabricated machine consists of four major components which are gear mechanism, four cylindrical chambers, agitators (impellers) and an electric motor. After evaluating its performance, the machine produced had a mixing and time efficiency of 93% and 92.2% respectively as compared to the conventional method which had a mixing and time efficiency of 81.7% and 36.7% respectively. Results obtained from the performance evaluation indicated that the machine saves time and energy, reduces material wastage, reduces hazards and hence; is far more efficient than the conventional method.

**KEYWORDS:** Fabrication, performance, liquid soap, machine, conventional method, efficiency.

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## I. INTRODUCTION

Soap can be regarded as any cleaning agent, manufactured in bars, granules, flakes, or liquid, made from a mixture of mostly sodium or potassium salts of various fatty acids of natural oils and fats (Warra, 2013). Soap has numerous applications in our daily life such as washing dishes, clothes, cars and bath. Ibryamova et al., (2010), stated that soap was invented not only for the purpose of hygiene; rather, it was invented to serve other purposes such as removal of grease from wool in textile industries.

Finished product from chemical and biochemical processes such as suspensions and emulsions must occur in a steady state for the purpose of transportation and use (Ibryamova et al., 2010).

Prior to the 19<sup>th</sup> century; twigs, typically from apple and peach trees, would be bundled together to create a whisk-like implement used for the purpose of mixing (Soap History, 2016). In the line of mixing technology, little work has been done relating to soap mixing technology, thus the invention of soap mixer such as the soap mixing machine was to replace the old method of soap production. The first mixer with electric motor is thought to be the one invented by American Rufus Eastman, which was made of a beater connected to a curved rod contained in a tube which in turn is connected to an electric motor (Rufus, 1885). This was to replace Ralph Collier's hand-held mechanized mixer which consists of a rotating part attached to a whisk and operates using the principle of planetary mixers (Ralph, 1856).

The problem with the hand-held mechanized mixer was that it consumed much energy and could only be used to mix very small volumes of product. Saliu (2005), developed a

mixer that was portable, could be used for small scale production and easy to move but preliminary mixing had to be done manually. Ibryamova et al., (2010) designed a mixer for chemical and biochemical industry which could handle mixtures of different phases: a liquid-liquid, solid-liquid and liquid-gas but the problems with his mixer were found to be as follows; preliminary mixing had to be done manually, it cannot be used for small scale production, it was very large, it was industrially based hence was too expensive for the average citizen (Ibryamova et al., 2010).

An attempt was made by (Ajao et al., 2011) to develop an equipment for making home-made laundry soap to ease the problems of (Ibryamova et al., 2010) but the problems associated with his mixer were found to be as follows; preliminary mixing had to be done manually, the operator had to pedal tirelessly until the mixing process was complete, and it was time consuming (Ajao et al., 2011).

A semi-automatic system using the right mixer at a desired speed can be developed in such a way that all mixing processes are done with the aid of an electric motor and a system of gears and mixers in different chambers, thereby achieving a thorough and even mixture of soap in any of its state.

The conventional (traditional) soap making demands hours of stirring by hand which is energy consuming and the efficiency of this process is merely average. Considering the abundance and industrial potential of liquid soap, the introduction of soap making machine will not only readily make available liquid soap, it will also enhance its method of production, reduce time of production, wastage of raw materials, hazards involved in the making process, create job opportunities, act as a source of income and make this venture

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more profitable to the average citizen. Hence, an improved mixing machine needs to be developed for small and medium scale use. Therefore, the aim of the present work was to design and develop a simple soap making machine which can be maintained at a reduced cost using a 1.5hp motor.

## II. MATERIALS AND METHODS

### A. Machine Description

The semi-automatic soap mixing machine consists of four major components; the gear mechanism, mixing chambers, an electric motor, and a supporting frame Figure 1. The gear mechanism consists of four involute spur gears arranged in the planetary gear configuration with ball bearings, shafts, nuts and a housing cover. The gears are fabricated from cast iron, having a radius of 50 mm and the distance between centers is 100 mm. Over-hanged shafts are attached to the center of each gear, and the shaft is connected to the driver gear supported by two bearings each mounted to the gear case.

Each of the gears have 12 teeth with a width of 7.9 mm and pressure angle of  $14.5^\circ$ , the minor shafts are 10 mm in diameter with a length of 150 mm while the central shaft is 20 mm in diameter and has a length of 300 mm with a key way of 3 mm and is connected to a 1.5hp electric motor mounted overhead and sits on the frame. The minor mixing chambers are made from cylindrical stainless steel of  $\varnothing 100\text{mm} \times 133\text{mm} \times 2.5\text{mm}$ , each having a volume of 1.5 litres. The discharge valves are attached underneath, and the minor mixing chambers are mounted on the central mixing chamber which is also made from cylindrical stainless steel of  $\varnothing 500\text{mm} \times 227\text{mm} \times 2.5\text{mm}$ , with a volume of 16 litres. To achieve a better and even mixture, baffles are inculcated

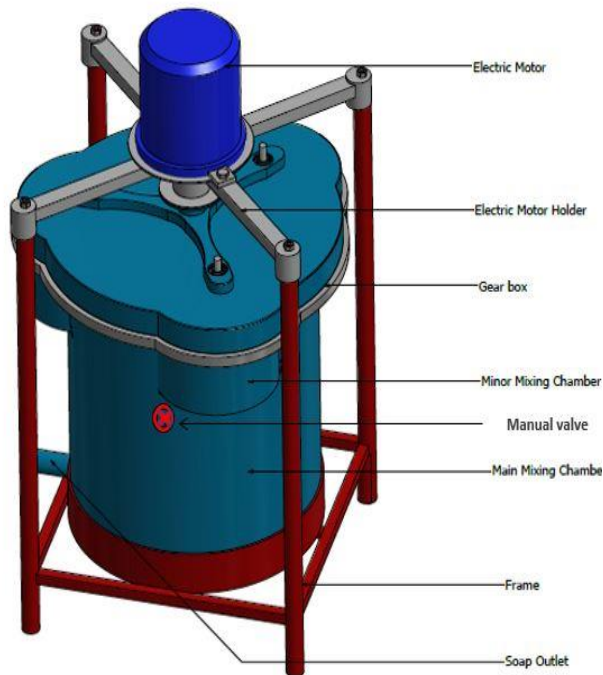


Figure 1: Liquid Soap Machine.

into all the chambers to direct the mixture to the center of the chamber. The supporting frame was made of circular hollow

bar that holds the entire components firmly together. A damper was placed between the frame and the central chamber and it is also placed around the studs to absorb vibration.

### B. Working Principle

The liquid soap making machine operates on the principle of planetary mixers. 1.5hp was transmitted from the electric motor to the shaft which was connected to the gear system. As the central shaft rotates at 1800 rpm, the gears rotate in the opposite direction as the shaft, transmitting torque to the shafts in the minor chambers. Mixing takes place in the chambers as a result of the torque experienced by the shaft and this continues until even mixture was attained. The manual discharge valves are then opened depending on chemicals mixed in each chamber, allowing the mixtures to flow with the aid of gravity to the central chamber where further mixing continues. Once an even mixture was attained in the central chamber, the machine is turned off and the discharge valve in the central chamber was opened allowing the finished product to be collected in a container and stored.

### C. Design Consideration and Computation

In order to develop the various relations necessary for the present design, the following were considered;

*Volume of mixing chamber:*

The volume of the minor mixing chamber,  $V_{minor}$  is given as

$$V_{minor} = \pi r_m^2 h_m \quad (1)$$

where,

$r_m$  = radius of minor mixing chamber,

$h_m$  = height of minor mixing chamber

Volume of central mixing chamber,  $V_{central}$

$$V_{central} = \pi r_c^2 h_c \quad (2)$$



Figure 2: Portable Liquid Soap Making Machine.

where,

$r_c$  = radius of the central mixing chamber,

$h_c$  = height of the central mixing chamber

Also,

$$V_{central} = V_{ni} + V_{mmc} + V_{SS} \quad (3)$$

Where:

$V_{ni}$  = volume of Nitrosol solution

$V_{mmc}$  = volume of mixture from minor chambers

$V_{SS}$  = volume of empty space for safety

Volume of Nitrosol solution ( $V_{ni}$ ) = 10 litres =  $0.01m^3$   
and total volume of mixture in minor chambers ( $V_{mmc}$ ) is three times the volume of mixture from one minor chamber.

Assuming volume of empty space for safety =  $0.003 m^3$   
Therefore, total volume of central chamber =  $0.016 m^3$   
Radius of the central chambers is assumed to be 150 mm, therefore the height,  $h_c$

$$h_c = \frac{volume}{\pi \times r^2} \quad (4)$$

Involute Gears:

Radius of Driver = Driven = 50 mm

Gear ratio = 1:1

Distance between centers ( $D_p$ ) = 100 mm

Using 1.5 horse power motor with 70% efficiency,

The power generated by the electric motor =  $1hp$

Therefore,

Power delivered by the electric motor =  $0.7457 kW$

Power transmitted by the Pinion (P) = Power of the Electric motor =  $0.7457kW = 745.7W$

Speed of Pinion,  $N_p$  = speed of motor = 1800 r.p.m

Minimum number of teeth on pinion ( $T_{pi}$ ) in order to avoid interference as given by Khurmi and Gupta (2005) is

$$T_{pi} = \frac{2A_W}{G \left[ \sqrt{1 + \frac{1}{G}(\frac{1}{G} + 2) \sin^2 \phi} - 1 \right]} \quad (5)$$

Where,  $A_W$  = Fraction by which the standard addendum for the wheel should be multiplied

$G$  = Gear ratio or velocity ratio =  $\frac{T_G}{T_P} = \frac{D_G}{D_P}$

$\phi$  = Pressure angle or angle of obliquity.

Number of teeth on gear ( $T_G$ ) is given as

$$T_G = T_{pi} \times gear\ ratio \quad (6)$$

Pitch circle diameter of pinion ( $D_p$ ) as given by Patre et al., (2014) is

$$D_p = m \times T_{pi}, \quad (7)$$

Actual number of teeth on pinion ( $T_p$ ),

$$T_p = \frac{D_p}{m} \quad (8)$$

The torque acting on the pinion, according to Virendra and Anup (2015) is given as

$$T = \frac{P \times 60}{2\pi N_p} \quad (9)$$

Tangential tooth load ( $W_T$ ) as given by Maitra, (1994) is

$$W_T = \frac{P}{V} \times C_s = \frac{T}{D_p/2} \quad (10)$$

Where,

$P$  = Power transmitted in watts,

$V$  = Pitch line velocity in m/s =  $\frac{\pi N}{60}$

$T$  = Torque (m)

$D_p$  = Pitch circle diameter of the pinion (m),

$C_s$  = Service factor for steady load of 8-10 hours/ day = 1.00 as given by Khurmi and Gupta (2005)

Normal load on the tooth,

$$W_N = \frac{W_T}{\cos \phi} \quad (11)$$

Normal pressure between teeth is 10.3421 N/mm of width, therefore necessary width of the pinion (b) as given by Santosh and Saravanan (2013), is,

$$b = \frac{W_N}{P} \quad (12)$$

Load on bearings of the wheels:

The radial load on bearings ( $W_R$ ) due to the power transmitted,

$$W_R = W_N \times \sin \phi \quad (13)$$

Circular pitch ( $P_c$ ) as given by Errichello, (1978)

$$P_c = \frac{\pi D}{T_p} = \pi m \quad (14)$$

$$D = m \times T_p \quad (15)$$

Thus, the pitch line velocity ( $v$ ) is obtained from the expression in equation 16 as given by Ed Schimed et al., (2015)

$$V = \frac{\pi D N_p}{60} = \frac{\pi m T_p N_p}{60} \quad (16)$$

Where,  $m$  = Module in (m),  $T_p$  = Number of teeth,  $N_p$  = Speed in r.p.m.

For non-enclosed and grease lubricated gears, service factor value is divided by 0.65 as given by Ludwig, (2003).

Therefore,  $C_s = \frac{1.00}{0.65} = 0.5388$

Forces on spur gear teeth:

$$F_n = F_t \tan \theta \text{ and } F_r = \frac{F_t}{\cos \theta} \quad (17)$$

Where,  $F_t$  = transmitted force,  $F_n$  = Normal force or separating force,  $F_r$  = Resultant force,

$\theta$  = Pressure angle

Power transmitted to the shaft (p), is evaluated using equation 18 as given by Karan and Ravi (2015).

$$p = \frac{TN_p}{63000} \quad (18)$$

Therefore, torque transmitted (T) is given as

$$T = \frac{63000 \times P}{N_p} \quad (19)$$

Also,

$$\text{Torque, } T = F_r \times r \quad (20)$$

$$\text{Where, } r = \frac{D_p}{2} \quad (21)$$

$$\text{But, } F_r = \frac{T}{r} \quad (22)$$

Stress on the shaft:

Power transmitted ( $P$ ) =  $1hp = 745.7 W$

Speed of the Motor ( $N$ ) = 1800 RPM

Diameter of gear ( $D$ ) =  $100mm = 0.1m$

Maximum tensile on shaft ( $\sigma_b$ ) =  $56 N/mm^2$

Length of shaft ( $L$ ) =  $100mm = 0.1m$

Normal load on gear ( $W_N$ ) = 81.8 N

Maximum bending moment at the center of gear, as given by Jadon et al., (2008) is

$$M = W_N \times L \quad (23)$$

Maximum shear stress ( $\tau_{max}$ ) as given in eqn (24),

$$\tau_{max} = \frac{1}{2} \sqrt{(\sigma_b)^2 + 4\tau^2} \quad (24)$$

$$\text{where } \tau = \left(\frac{16T}{\pi d^3}\right)^2 \text{ and } \sigma_b = \left(\frac{32M}{\pi d^3}\right)^2 \quad (25)$$

$$\text{Substituting eqns (24) into (23),} \\ \frac{\pi}{16} \times \tau_{max} \times d^3 = \sqrt{M^2 + T^2} \quad (26)$$

$$\text{where, } T_e \text{ (equivalent twisting moment) =} \\ \sqrt{M^2 + T^2}$$

$$\text{Also, } T_e = \frac{\pi}{16} \times \tau_{max} \times d^3 \quad (27)$$

Therefore, the maximum normal stress of the shaft

( $\sigma_{b(max)}$ ) is given as,

$$\sigma_{b(max)} = \frac{1}{2} \sigma_b + \frac{1}{2} \sqrt{(\sigma_b)^2 + 4\tau^2} \quad (28)$$

Substituting equation (25) into (28),

$$\sigma_{b(max)} = \frac{16}{\pi d^3} [(M + \sqrt{M^2 + T^2})] \quad (29)$$

But  $M_e$  (equivalent bending moment) =

$$[(M + \sqrt{M^2 + T^2})] \quad (30)$$

$$\text{Also, } M_e = \frac{\pi}{32} \times \sigma_b \times d^3 \quad (31)$$

$$M_e = \frac{1}{2} [(M + \sqrt{M^2 + T^2})] = \frac{1}{2} (M + T_e) \quad (32)$$

To account for shock and fatigue in rotating shafts with gradually applied loads operating condition,  $K_m = 1.5$  and  $K_t = 1$  as given by Babu, (2009),

Equivalent twisting moment,

$$T_e = \sqrt{(K_t \times M)^2 + (K_t \times T)^2} \quad (33)$$

Also, Equivalent Bending moment,

$$M_e = \frac{1}{2} [K_m \times M + T_e] \quad (34)$$

The diameter of the shaft (d) can be gotten using equation (35)

$$d = \frac{M_e}{\left(\frac{\pi}{32} \times 56\right)} \quad (35)$$

Design for shaft key:

Length of key =  $l$

Shear stress of shaft ( $\tau$ ) = 42 N/mm<sup>2</sup>

$$\text{Width of key (} w \text{)} = \frac{d}{4} \quad (36)$$

$$\text{Thickness of key (} t \text{)} = \frac{2w}{3} = \frac{d}{6} \quad (37)$$

Diameter of the shaft (d) = 20 mm

Shearing strength of the key (torque transmitted) was estimated using equation 39 as given by Bhandar, (2010).

$$T = l \times w \times \tau \times \frac{d}{2} \quad (38)$$

$$\text{Also, Shearing strength (} T \text{)} = \frac{\pi}{16} \times \tau \times d^3 \quad (39)$$

$$l = \frac{T}{2100} \quad (40)$$

#### D. Construction Process

The following parts were fabricated during the construction work; shafts, gears, mixers, shaft key, mixing chambers and support frame. The manufacturing procedures employed for the fabrication of the machine include marking,

cutting, machining, shaping, turning, welding and painting. The procedures are to get the correct dimensions and required shapes of the machine as shown in Figure 2. The machine was assembled after the various components were fabricated. The machine was also evaluated for mixing performance. The details of the production cost were as shown in Table 1.

**Table 1: Bill of Engineering Measurement and Evaluation.**

S/N	Component	Part	Qty	Material	Rate (=N=)	Amount (=N=)
1	Motor		1	Electric motor	20000	20,000
2	Mixing chamber	Central Mixer	1	Stainless steel	10000	10,000
		Small mixers	3	Stainless steel	3000	9,000
3	Gear		4	Stainless steel	2000	8,000
4	Bearing		5	Steel	300	1,500
5	Damper	Damper	1	Latex	1000	1,000
6	Frame		1	Mild steel	3000	3,000
7	Miscellaneous				6000	6,000
	<b>Total</b>					<b>60,000</b>

### III. PERFORMANCE EVALUATION

The Mixing Performance: This was done to determine the amount of soap mixed in percentage. Two set of masses of chemicals sufficient to produce liquid soap of 5, 7, 9, 13 and 15 liters were weighed. The first set was mixed using the conventional method at a merely uniform feed and mixing. The time taken to complete the mixture was recorded and the weight of the product was taken and recorded. The second set was mixed using the liquid soap mixing machine which operates at 1400 rev/min and the time taken for complete mixture was recorded while the weight of the product was taken and recorded.

Machine efficiency estimation was calculated using the relation for amount of:

(i) Time Efficiency:

$$(\eta_T) = \frac{\text{total time saved during production}}{\text{standard time taken for production}} \times 100\% \quad (41)$$

(ii) Mixing Efficiency:

$$(\eta_M) = \frac{\text{mass of chemicals fed} - \text{mass of chemicals lost}}{\text{mass of chemicals fed}} \times 100\% \quad (42)$$

(iii) Mixing Rate:

The mixing rate can be gotten by eqn (43).

$$\text{Mixing rate} = \frac{\text{total mass of product mixed}}{\text{total mixing time}} \quad (43)$$

Foam height: 2 g of the sample was dissolved in 1 L volumetric flask and filled up with tap water to two-third of its volume. 50 mL of the solution was introduced into a measuring cylinder such that it followed the walls of the column to avoid foaming. 200 mL of the solution was taken in a conical flask and poured into a funnel which was already clamped with its outlet closed. The measuring cylinder was then put directly beneath the funnel while the height of the foam generated was read from the cylinder immediately the funnel outlet was opened.

IV. RESULTS AND DISCUSSION

In the production of 5-11 liters of soap using the fabricated machine, material wastage in mass increases with the volume of production compared to the conventional method which gives slight increase of material wastage for 5-11 liters as seen in Figure 3. This was as a result of raw material spillage during mixing and incomplete mixture. The incomplete mixture occurred due to the fact that the volume of soap mixed was below the design specification of the machine. However, beyond 11 liters, the material wastage in conventional method of soap production was greatly higher while in using the machine, the material wastage decreases from volume production of 11-15 liters.

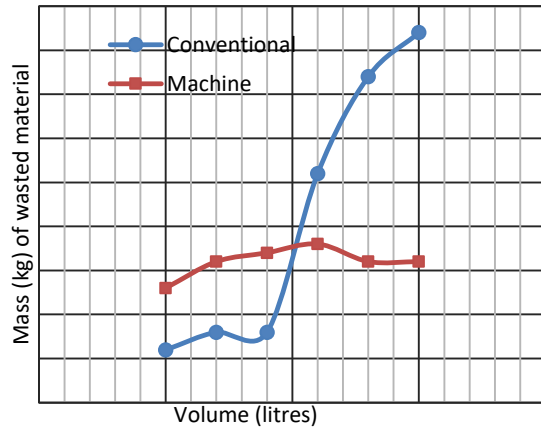


Figure 3: Mass of Material Lost.

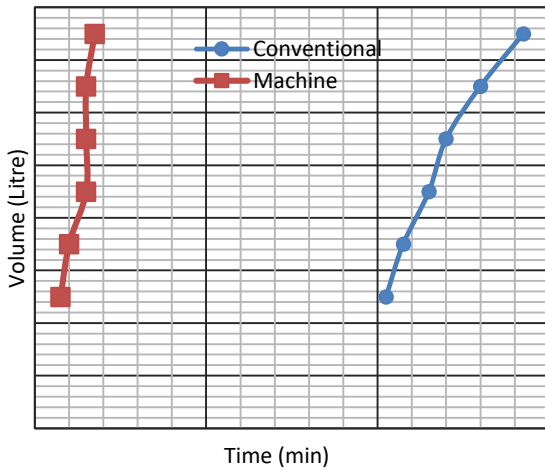


Figure 4: Machine Behavior during Mixing.

In the production of 5 litres and 15 litres of soap, it took 3 minutes and 41 minutes respectively to complete the process using the soap making machine while the conventional process took 41 minutes and 57 minutes for volume of 5 litres and 15 litres respectively as seen in Figure 4. Hence, the mixing rate at every volume of production was higher in the liquid soap making machine as compared with the conventional method of liquid soap mixing. Thus, the mixing process was completed

in far lesser time than the conventional process of soap production. This shows that using the liquid soap making machine for production is more economical.

The efficiency as regards the time taken for production at every volume of product is nearly uniform except for 9 litres of product. This was due to drop in voltage thereby affecting the speed of the mixer (Ajao *et al.*, 2011). At every volume of product, the efficiency of the soap making machine was far higher than the conventional method of soap production, this was due to reliable and uniform mixing rate of the machine as seen in Figure 5. The conventional method of soap production shows an irregular pattern which indicate inconsistent mixing which may be due to physical, psychological and emotional imbalance experienced by the individual carrying out the mixing process hence the conventional method is not reliable.

The mass efficiency of liquid soap making machine increases with increase in volume while in the conventional method of soap production, there was a decrease with increase

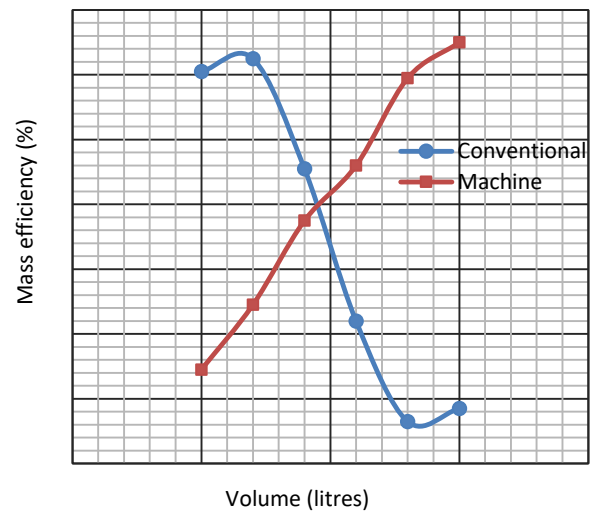


Figure 6: Comparison of Mixing Efficiency of Conventional Method and Developed Machine.

in volume as seen in Figure 6. In 5-9 litres of product, the mass efficiency of the mixing machine was lower than the conventional method. This was because the volume of product mixed was below the working capacity of the machine but at 11-15 litres, the mass efficiency became higher than the conventional method. This was because the volume of soap mixed meets the working capacity of the machine which was influenced by the design of the chambers and mixers.

The viscosity, pH, free acidity, chloride content and foam height of the liquid soap produced was tested and was found to be 0.6 Pa.s, 7.5, 0.07%, 0.3% and 9 mm respectively, which is in line with standards as specified by SANS 238:2008.

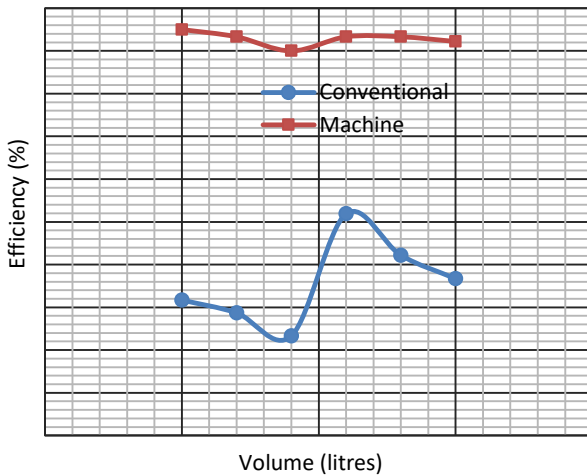


Figure 5: Machine Efficiency relative to Production Volume.

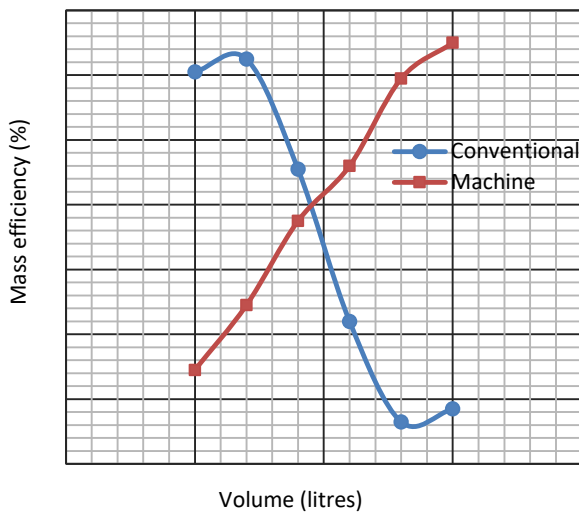


Figure 6: Comparison of Mixing Efficiency of Conventional Method and Developed Machine.

Table 2: Summary of Performance Evaluation of Developed Machine.

Litres (l)	Conventional Method			Developed Machine		
	Time Efficiency (%)	Mixing Efficiency (%)	Mixing Rate (kg/min)	Time Efficiency (%)	Mixing Efficiency (%)	Mixing Rate (kg/min)
5.00	31.70	92.10	0.19	95.00	82.90	2.35
7.00	28.70	92.50	0.25	93.30	84.90	3.47
9.00	23.30	89.10	0.30	90.00	87.50	2.28
11.00	51.90	84.40	0.35	93.30	89.20	2.78
13.00	42.20	81.30	0.40	93.30	91.90	3.30
15.00	36.70	81.70	0.40	92.20	93.00	3.27

V. CONCLUSION

A portable liquid soap making machine that can be used by small and medium scale industry was developed from the available local materials at the cost of sixty thousand naira only (₦60,000). The machine is portable, durable, highly efficient, easy to operate and maintain. The final product of liquid soap produced compares favorably in terms of quality with those produced by the large industry which is readily acceptable. The mixing efficiency for 15 litres soap production was 93 percent

(%) with a process complete time of 7 minutes using the developed machine while the conventional method takes 57 minutes with a relative efficiency of 36.7 percent (%). A liquid soap making machine plant based on this technology can provide employment for average citizens and at the same time provide good quality liquid soap that meets the standard of the regulatory bodies.

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