Arid Zone Journal of Engineering, Technology and Environment, August, 2017; Vol. 13(4):458-466
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Print ISSN: 1596-2490, Electronic ISSN: 2545-5818, www.azojete.com.ng

EXPERIMENTING WITH SOLID CONE NOZZLE FOR DISH WASHING OPERATIONS

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Abstract
This study is a preliminary effort to build a local reproducible dish washing machine. Hygiene is a nontrivial issue to many people especially in a developing country like Nigeria. All elements of sophistication and automation are deliberately left out and only the main dish washing components (the solid cone nozzle) mounted on a rigare herein presented. The experiment was carried out by spraying pressurized hot water at 55°C on dishes soiled with one of the stickiest local food, specifically *Eba* or *Garri*. (The nozzle wash by impinging on the soiled dishes the jet of hot water). The washing operation was completed in 90s. The condition at which very good performance was obtained was found to be 25 psi (172kpa) pressure and temperature of 55°C. At this condition, the water jet had the highest kinetic energy (130.49 J) as indicated by the pressure gauge. The nozzles were set at a distance of 30cm from the dish edge andwerefound to be adequate enough to cover the dish (10cm in diameter) at that distance.

Keywords: Dish, washer, nozzle, kitchen, Solid cone, Hygiene, Automation, Mechatronics

1. Introduction

Hygiene, the absence of germs and harmful micro-organisms in a given environment or human body, is usually undertaken by human beings to achieve good health. Certain equipment and amenities have been designed and constructed over the years to achieve hygiene as well as improve its efficiency at an affordable cost and at the same time save energy and time. Examples of such equipment are dish washing machine, cloth washing machine, vacuum cleaners and floor cleaners. Some are even autonomous in their operations such as Roomba vacuum cleaner robot and GoogleNext thermostat (Song, 2017; Bjor, 2005; www.irobot.com/index and https://nest.com/thermostat)

The dish washer aids in cleaning and washing dishes. It is time and energy saver in terms of not stressing the operator and increasing labour cost. It can be referred to as the cherished asset of most housewives and is in use by large catering companies. The dish washer is made up of components which include the pump, nozzles, racks, thermostats, water treatment device and some form of automations and (child) safety mechanism (Sharp, 2016).

The aim of this study is to design a bare bone dish washer using solid cone nozzle. Other objectives include finding the condition for good performance, jet height, impact time period that will give the best cleaning experience of different plates sizes, material and soiling states.

2. Description and Operation of Nozzles

Spraying technology is not a new field but the atomization methodology and how to increase the kinetic energy of the outlet fluid is a growing field (Lefebvre, 1989, Vijay *et al.*, 2015). The atomization process follows some form of modification to the basic nozzle design, for example, some authors like Mairorova *et al.* (2011), had to make a multi-outlet and inline nozzle just to be able to atomize several form of fluid. Some had to adjust universally known equations in order to reduce droplet size (Yule and Chinn, 1994; Sandeep *et al.*, 1999; Khavkin, 2001), or to get some form of spray pattern. Statistical tools such as ANOVA

(Mandal, 2011) and numerical tools like Lagrangian Methods (Ashgriz, 2011) were used. Chien-Pei *et al*. (1991), and Chen *et al*. (1991), subscribed to both analytical tools and experimental procedure in an effort to optimize swirl plate design of a solid cone nozzle.
Nozzles are selected based on the target applications. Solid cone nozzles are selected for high impact on the surface they impinge. This is the basis for its selection in this study.
On the swirl plate design, Chien-Pei *et al*. (1991), analyzed the pressure swirl and pure air blast atomization process. Experiments were conducted by using a high-magnification 4 × 5 camera and an Aerometrics Phase/Doppler particle analyzer to evaluate the spray characteristics and atomizer performance. The primary parameters of interest are liquid film break up length, spray angle, drop size, and trajectory. Observation of wave formation and propagation along the sheet surface was made to provide guidance in formulating mathematical models. Effects of air flow and nozzle design on atomization were examined for a wide range of flow conditions. Computational analysis also was used to predict the sheet break up and subsequent drop behavior. They concluded that their prediction and the experiments correlated well. Moreira and Moita (2011) in their work on droplet-wall interaction were able to present spray disintegration mechanisms as it hit solid surface. Chandra (2011) was able to classify the splashing and fragmentation into corona splashes and freezing induced splashing experimentally.
The nozzle's actual goal is to increase the kinetic energy of the water jet (the usual cleaning liquid with dissolved detergent and rinsing agent) as it impacts on the material being cleaned. Nozzles achieve this goal by following Bernoulli's flow equation shown in equation 1.

$$P_1 + ½\rho V_1^2 + Z_1 = P_2 + ½\rho V_2^2 + Z_2 \quad (1)$$

From which it can be rewritten in terms of flow rate as

$$q = V_1 A_1 = V_2 A_2 \quad (2)$$

where: P= pressure (mmHg), V=Velocity of fluid (m/s), ρ=liquid density (kg/m^3), q=flow rate (m^3/s), A=Area of the flow (m^2), Z= the horizontal height of the inlet/outlet hole
Subscripts 1 and 2 stand for parameters before and after the device in consideration.
Equation (2) is referred to as continuity equation. Thus the nozzle will cause an increase in the velocity of the fluid exiting from its orifice in other to satisfy equation (2).
The kinetic energy of the fluid coming out is given as;

$$\text{K.E} = \frac{1}{2} m V^2 \quad (3)$$

where: m = mass of the fluid (kg) and V= velocity of the fluid (m/s)

3 Materials and Method

3.1 Materials and Equipment

The following equipment was used for the experiment:

(a) A solid cone nozzle (1mm exit hole), 40° cone angle,
(b) Patternator – 5cm pitch
(c) Jet energy tester
(d) Dish holding rig – made from rigid PVC plastic
(e) 0.5hp (372W) Pump
(f) Pressure gauge
(g) 1000W Water heater
(h) Dishes made from different materials – average diameter of 25cm

The solid cone nozzle (Figure 1) was attached to the pump using a flexible hose (8.0mm internal diameter). The pressure gauge was attached to monitor the pressure supplied. The patternator (Figure 2) is a fluid collector with a corrugated surface. The corrugation forces the liquid landing on it to go straight into the collectors (usually measuring cylinders). Two similar solid cone nozzles were used and attached to vertically adjustable boom as shown in Figure 3. Furthermore, a water heating container was attached so that heated water can be used for the washing operations. Hot water is well known for easily dislodging dried food residue on plates. The water temperature was maintained at 55°C.

The jet energy tester (Figure 4) is for testing the kinetic energy of the water coming out of the nozzle. It is a pendulum made from flat wooden panel with a 0.023kg weight attached at the tip. The device converts the kinetic energy of the water impinging on the plate to potential energy (PE). The potential energy was estimated using equation 4.

$$KE = PE = mgh \tag{4}$$

where m = mass of the object (kg) = mass of the attached body (Figure 4),
g = acceleration due to the earth gravity (m/s^2),
h = height the object is displaced (m)

From Figure 4, h is calculated as $h = x(1 - \cos\theta)$ (5)
using the angle of displacement.
where: x is the length of the pendulum

Equation (4) assumes the followings;

(a) no loss due to air drag
(b) all the water exiting the nozzle actually touches the tester plate
(c) the water is steady as it comes out of the nozzle
(d) the plate centroid is the only point receiving the impact (that is the resultant force acts at the centroid of the plate).
(e) The tester plate's deformity due to the jet impact is minimal.

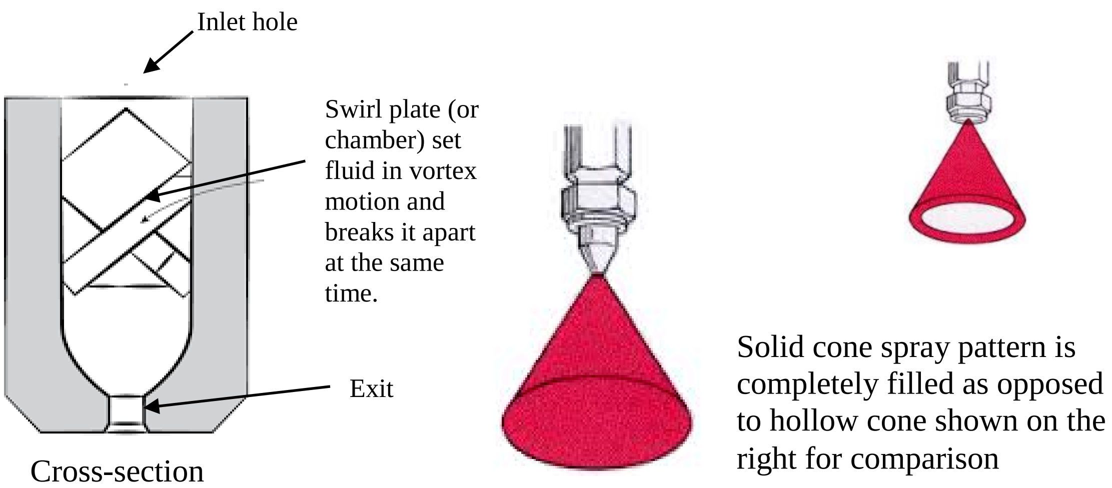

Figure 1: Solid cone nozzle (Available online at www.bete.co.uk)

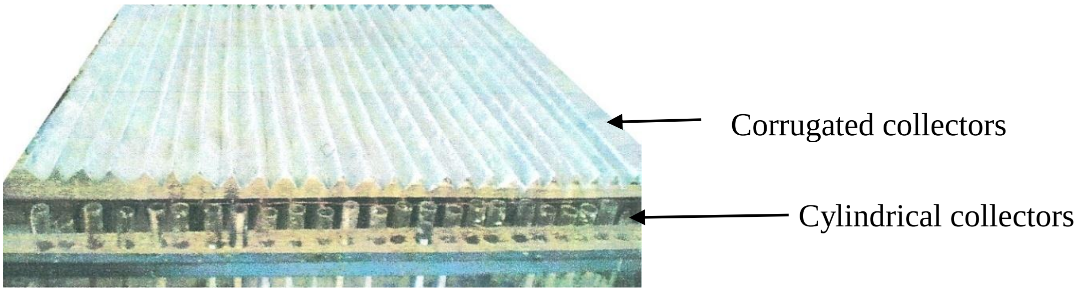

Figure 2: The design of the patternator used

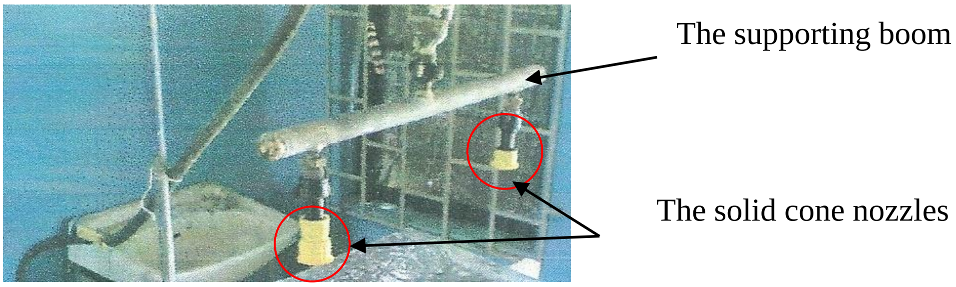

Figure 3: The solid nozzles supported on the boom

(a) **(b)** **(c)**

Figure 4: (a)Jet energy tester, (b) The jet energy tester in use, (c) The critical components of the energy tester

3.2 Methodology

The following experiments were conducted in order to evaluate the experimental dish washing machine:

(a) Nozzle pressure and flow pattern distribution at 10, 15, 20 and 25s interval at height of 30cm and at pump pressures of 20, 25 and 30 psi using the patternator.

(b) The kinetic energy of the water coming out of the nozzles at pump pressures of 20psi (138kPa), 25psi (172kPa) and 30psi (207kPa).

(c) The speed and effectiveness of an actual washing operation using ceramic, glass, stainless and plastic plates soiled with cooked *garri* (*eba* in Yoruba language) and stew. This combination is selected as it is the commonest and universal food in Nigeria.The plate's average diameter was 10cm and the temperature was fixed at 55^{o}C.

Nozzle water pressure and flow pattern distribution experiments were conducted by fixing the nozzles support at height of 30cm above the patternator surface and letting the water run for 10, 15, 20 and 25s, at 30cm, the jet adequately cover the dish being washed. The pump pressure was set to 20psi (138kPa), 25psi (172kPa) and 30psi (207kPa) using a fly screw and ensuring the reading was correctly indicated by the pressure gauge. The kinetic energy was determined by measuring the angle of deflection of the energy tester plate atnozzle inlet pressure of 20psi (138kPa), 25psi (172kPa) and 30psi (207kPa) respectively. Equations (4) and (5) were then used to translate the measurements values into the kinetic energy of the jet coming out of the nozzle. The speed and effectiveness of an actual washing operation was determined by setting up the plates as shown in Figure 5 and heating the water to an initial temperature of 60^oC (excessive heating may not be safe for the soap and end users; it may alter the chemistry of the soap) in a bowl to which the pump is connected. The water was allowed to cool down and stabilize at 55^oC. The pump is then primed and switched on. The time taken from the moment the water jet startshitting the plates to the time it was observed to be clean was measured, for different plates and different soiling. The plates were soiled with plain stew and "Eba" (cassava pudding). The nozzle height was fixed at 30cm to the plates edges so that the water jet can cover it adequately. The plates were set at 45^o angle to the horizontal to allow the water to flow down freely.

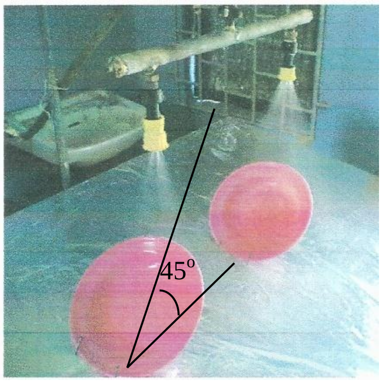

Figure 5: The plates arrangement for washing operation (setting at 45^o to the horizontal)

4. Results and Discussion

The nozzle pressure and flow pattern distribution experiment results are indicated in Figures 6-8 for 20psi (138kPa), 25psi (172kPa) and 30psi (207kPa) inlet pressure respectively. The 10s plots were shaded to show the spread of the jet at the minimum time. The longer the time, the more the total volume as expected. However, the spread of the jet is expected to increase with pressure, but the plot showed a contrary result at 25psi (172kPa).It shrank instead, starting from tube 5and is irrespective of how long the test was carried out. Furthermore, the flow rate showed an outlier result for the 25psi (172kPa) at 10s. This anomaly is likely due to the swirl plate design used inside the cone. The turbulence effect of the swirl plates was found to be consistently abnormal at 25psi (172kPa) inlet pressure even with the raw data.

Another observation from the result presented in Figures 6,7 and 8 is that the nozzles are obviously not responding the same way, the left nozzle is giving out less amount of water. The boom line supply is at the middle, meaning, the pressure drop towards both end must be approximately the same. This we attribute to manufacturers error or carelessness.

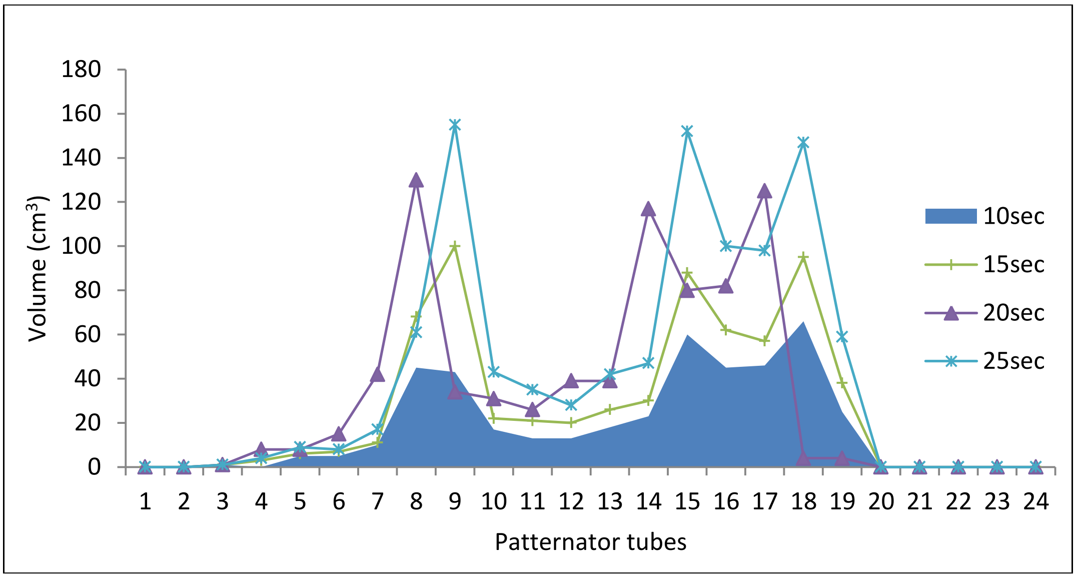

Figure6: The flow pattern for 10s, 15s, 20s and 25s duration of time at pressure head of20psi (138kPa)

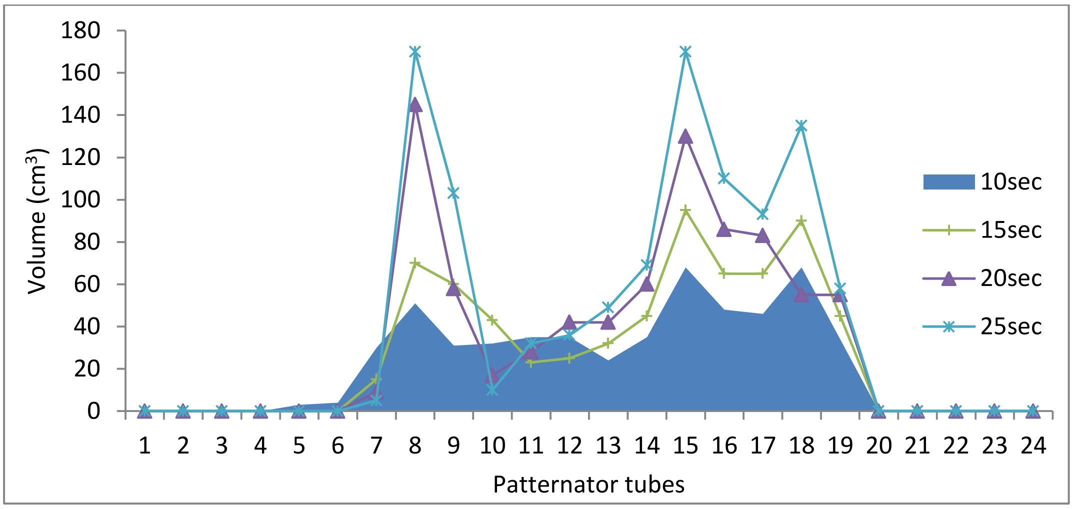

Figure 7: The flow pattern for 10s, 15s, 20s and 25s duration of time at pressure head of25psi (172kPa)

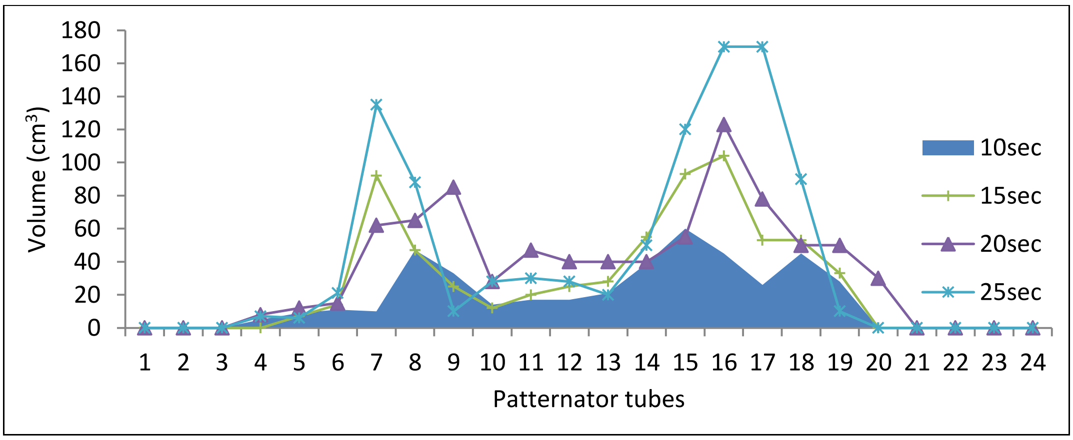

Figure 8: The flow pattern for 10s, 15s, 20s and 25s duration of time at pressure head of 30psi (207kPa)

The kinetic energy (KE) of the outlet water pressure (Figure 9) shows that the nozzles used for the experiment generally has more energy output at 25psi (172kpa) than the other tested pressure values. It simply means that this pressure is the best for the washing operation for this particular nozzle design. The flow rate at this best washing pressure of 25psi (172kPa) is 45.3 ml/s.

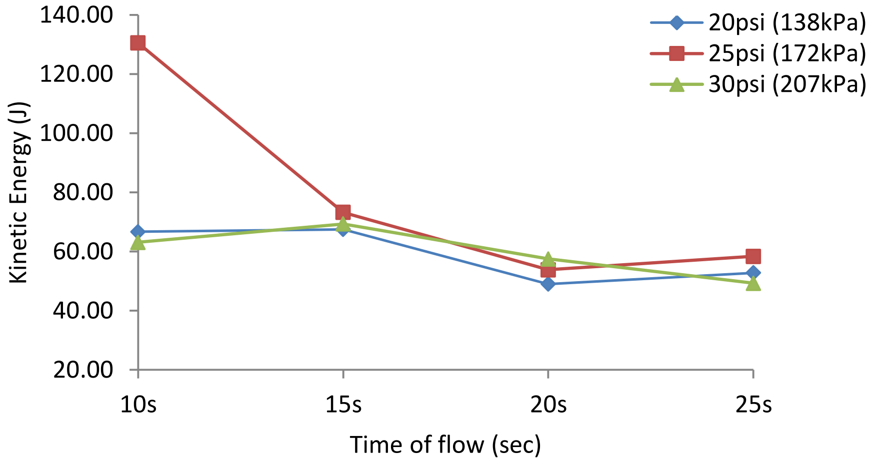

Figure 9: Kinetic Energy of the outlet jet

The result of an actual washing operation is presented in Table 1. The water consumed by each washing operation is also indicated with the minimum being 4.1 liter. The plastic soiled with *eba* (*garri* pudding) took longest time (120s) to dislodge. That is not surprising because, *garri* is a very starchy food made from cassava. It is a common starter for many glue products. It can be used as glue and binder. Also the stew soiled plastic plate took longest time to clear up – see table 1. This is becauseplate made from plastic materialsare the least polished among the four plates materials tested. Glass and ceramics are both fired and polished. During manufacturing, stainless steel platesare formed by drawing it (as in stamping operation). The plate will be in tensile mode during theforming process. This removes or reduces poreson the surface of the plates – because of the stretching. Pores increase contact areas. This is the reason why the washing time for plates made with the stainless steel is the least followed by the washing time for theplates made with glass material (glass blowing is also a stretching operation during manufacturing).

For comparison purposes, a typical commercial dish washer (Sharp Incorporation QW-V834Z) uses rectangular spray nozzles (Figure 10) that are set at 20cm interval on a rotating boom

Table 1: Time taken to wash different types of plates

Type of plates	Time (s)			
	Eba (*Garri*) Soiled	Stew soiled	Time difference	*Quantity of water used (Liter)
Glass	90	50	40	4.1
Stainless steel	102	69	33	4.6
Ceramic	120	55	65	5.4
Plastic	138	80	58	6.3

*Flow rate at 25 psi (175 Kpa) is 45.3 ml/s

Figure 10: Sharp Incorporation QW-V843Z dish washer spray boom and several rectangular nozzles.

5. Conclusions

The solid cone nozzle was able to clean dishes in a reasonable time. The best pressure to operate this very design of solid cone is 25 psi (172kpa) as it was at this pressure the highest kinetic energy (130.49 J) was realized. The distance of 25cm between the nozzles and the tip of the dish is adequate enough to cover the dish diameter. Noticeable also is the fact that the dish washing times are not the same, however, the longer the washing process, the cleaner the dish becomes.

However, it is recommended that the dish washing operation be built with some element of automation else it will be a drudgery operating it. For commercial purpose, prewashing (so as to soak and remove heavy soiling) should be standard, hand scraping before loading machine is tantamount to manual operation also. The degree of roughness of the surfaces of the washed dish was not put into consideration in this work, it is recommended that further experiment be conducted on this parameter as it influence the washing efficiency.

This work is essential as most dishwashers available in Nigeria (for commercial and domestic uses) are imported. At the current and rising exchange rate, it is highly discouraging for people to acquire one, thus half washed/ cleaned plates are still used by many households. Also, disassembling the imported dishwasher to their fundamental functioning parts will encourage even the artisan to do some justices into fabricate local one. This was what happened to yam pounder, many are now fabricating different designs locally.

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