International Academic Institute for Science and Technology

International Academic Journal of Science and Engineering
Vol. 6, No. 1, 2019, pp. 119-131.
ISSN 2454-3896

International Academic Journal of Science and Engineering

www.iaiest.com

The Design and Fabrication of a used Polyethylene Terephthalate (PET) Bottle Washing and Sterilizing (Recycling) Machine

Oziegbe Joshua Igberaese[a], Ejiroghene Kelly Orhorhoro[b], Chughiefe Lucky[a], Ogiemudia Osasumwen Godswill[a]

[a]*Mechanical Engineering Department, University of Benin, Benin City, Nigeria*

[b]*Cemek Machinery Company, Benin city, Nigeria.*

Abstract

In this paper, the design and fabrication of a Polyethylene Terephthalate (PET) bottle recycling machine was undertaken. It was designed to wash a set of two (2) 75cl used PET bottles in 10 seconds. The washing, rinsing and sterilizing chambers were made of stainless steel. The rotational wash brushes were made of plastic bristles, and the machine runs on a single phase electric motor with a washing speed of 470 rpm. After fabrication and testing, results obtained showed a set of two (2) 75cl used PET bottles were washed effectively in 10 seconds. Further testing results obtained, showed used PET bottles were recycled by simply washing and sterilizing them, using the fabricated prototype machine. This innovation will minimize the virgin reproduction of new PET bottles, save foreign exchange in the importation of virgin resins and alleviate the menace posed by its litter in Nigeria. The machine's efficiency is 81.91% and it's washing capacity is 120 bottles per hour.

Keywords: Waste, Used PET bottles, Reuse, Environment, Cost.

Introduction:

The problem of municipal solid waste (MSW) in sub-Sahara Africa countries is a major concern to government and the society; this waste is worrisome in Nigeria with an increasing population pressure and socio-economic factors (Omole and Alakinde, 2013). Solid wastes are the useless and unwanted products in solid state, discarded by members of the society (Aris et al., 2013). Solid waste can be

DOI:10.9756/IAJSE/V6I1/1910012

Received: 21 March 2019/Revised: 17 April 2019/Accepted: 22 May 2019/Published: 28 June 2019

classified on the basis of their source as: Municipal Solid Waste, Industrial Solid Waste and Agricultural Solid Waste. Most cities in sub-Sahara Africa spend 20-50% of their environmental budget on solid waste management and only 20-80% of the waste is collected (Achankeng, 2003). The standard of waste management in Nigeria is at its lowest with poor documentation of waste generation rates, inefficient storage and collection system, and the under-utilization of disposal sites (Kadafa et al., 2012). Nigeria's urban cities are today struggling to clear heaps of solid waste from its environment (Figure 1).



Figure 1. Used PET bottles littered in drainage at Uselu Lagos road, Edaiken, Benin City.

Strategic place of attraction in Nigeria are now taken over by the messy nature of unattended heaps of solid waste emanating from the society. This menace is beyond the city officials and they appear unable to combat unlawful dumping of house-hold and industrial waste, which is a clear violation of the clean air and health edicts in our environmental sanitation laws and regulations in Nigeria (Momodu et al., 2011).

Plastic waste is a constituent of the solid waste stream of which polyethylene terephthalate (PET) is a part. PET is an acronym for polyethylene terephthalate, which is a long-chain polymer belonging to the generic family of polyesters. PET is a product formed from the intermediates, terephthalic acid (TPA) and ethylene glycol (EG), which are both a derivative of oil feedstock. There are other polyesters based on different intermediates but all are formed by a polymerization reaction between an acid and an alcohol. PET, in its purest form, is an amorphous glass-like material, when under the influence of direct modifying additives develops crystallinity. Moreover, crystallinity can be developed by heat treatment of the polymer melt. Polyethylene terephthalate (PET), is a condensation polymer produced from the monomers ethylene glycol, $HOCH_2CH_2OH$, a dialcohol, and dimethyl terephthalate, $CH_3O_2C–C_6H_4–CO_2CH_3$, a diester. PET is used to produce plastic bottles and several other plastic products (ILSI, 2000). Most bottles produced from PET are transparent in nature with a recycle identification symbol written at the bottom of the container. They are used in packaging water, soft drinks, beer, and vegetable/palm oil etc.

It is observed in Nigeria that most PET bottles produced are not retrieved and recycled by the plastic producers. But, new bottles are produced daily, thus, increasing the litter in the country without

alleviating the menace posed by it. The limited or absence of recycling plants and probably ignorance of recycling technologies in the country has led to the non-recycling of littered waste PET bottles, as compared to other countries in the world. In 2011, 59.6% of plastics were recovered and recycled in Europe (EU-27), while in 2012 this increased to 61.9% (Plastics Europe, 2013). Currently, plastic recycling as observed in Nigeria involves crushing and melting processes that are expensive, energy consuming, environmentally polluting and time dependent among others. Continuous recycling of a plastic material through melting processes reduces the quality of the plastic after several cycles of recycling (Dimitris et al., 2012). An alternative to the recycling of used PET bottles is through reuse. Its recycling process is less expense, less energy/power consuming, less environmentally polluting and less time dependent among others. It's simply to wash and sterilize used PET bottles.

Research methodology

The PET bottle washing and sterilizing machine is designed to process a set of two (2) 75cl used PET bottles in 10 seconds. The machine consists of the following major components: The shaft, pulleys, belt, bearings, and electric motor, wash brushes, pre-wash/washing and rinsing chambers, sterilizing channel, erection reservoirs and the main frame. The wash brushes are designed to fit into a stainless shaft which is connected to an electric motor via a V–belt and pulley system. During the washing operation, the pre-washed PET bottles are fed into the rotational wash brushes. The electric motor transmits power through the V-belt to the shaft. As the shaft rotates, it actuates the wash brushes, which starts washing the fed bottles. The wash brush shafts bear the bigger pulley so as to reduce the speed of the electric motor to a desired washing speed. The operational process of the machine is shown in a flow diagram of Figure 2.

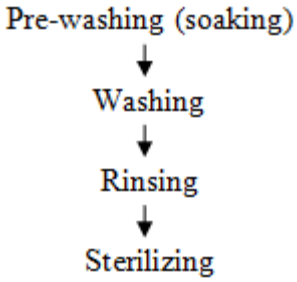

Figure 2. A Flow diagram of the machine operational process for used PET bottles.

The shaft

The shaft made of stainless steel is designed to transmit power to the wash brush to perform the washing operation.

Pulley

The primary function of the pulley is to reduce the original speed of the electric motor to the required speed for washing. The material selected for this pulley is cast iron.

The wash brushes

The rotational wash brushes are two (2) made of plastic bristles weaved around a stainless rod to wash the interior part of a bottle. The static wash brushes are three (3) made of plastics bristles fitted to an adjustable stainless plate to wash the exterior part of a bottle.

The pre-wash/washing and rinsing chambers

The pre-wash chamber is designed with a heater to warm soapy fluids in the chamber for washing. It is made of stainless steel material with a volume of 0.0527 m^3.

The frame

The frame forms the support for the whole component of the machine. It has to be rigid to withstand all the loads acting on it.

Design Considerations

To achieve an efficient prototype machine, the following design considerations were drawn.

Rotational speed required for washing

The wash brush is connected to a shaft attached to a pulley, the wash brush rotational speed, N_2 is

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

N_1= Speed of Electric motor taken as 1400rpm
N_2= Speed of wash brush
D_1= Diameter of motor pulley = 50mm =0.05m
D_2= Diameter of motor pulley = 150mm =0.15m
Thus,
Rotational speed required for washing, N_2 = 470rpm

Washing Force

The washing of the bottles is achieved through the action of a Centripetal Force, F_C

$$F_C = \frac{mv^2}{r} \quad (2)$$

Where,
m = Mass of rotary wash brush =0.07kg =0.7
V = Velocity of rotation
r = Radius of the pre-washed bottle
Therefore,
Velocity of rotation is given as,

$$v = \frac{\pi D_2 N_2}{60} \quad (3)$$

Belt Design

Centre to centre distance, X

x = 450m =0.45m

Length of Open belt

$$L = \frac{\pi}{2}(d_1 + d_2) + 2x + \frac{(d_2 - d_1)^2}{4x}$$ (Source: Khurmi and J.K Gupta, 2005) (4)

Where,

d_1= diameter of motor pulley = 0.05m

d_2 =diameter of drive pulley = 0.15m

x = 450mm = 0.45m

Therefore,

L = 1.2m

Area of Cross-Section of belt

$$\text{Area of trapezium}, A = \frac{1}{2}(a + b)h \quad (5)$$

$$a = 12\ \text{mm} = 0.012\ \text{m}$$

$$b = 6\ \text{mm} = 0.006\ \text{m}$$

h = 10mm = 0.01m

$$A = 9 \times 10^{-5}\ \text{m}^2$$

Mass of the belt per meter length (m)

$$m = \text{Area} \times \text{Length} \times \text{density} \quad (6)$$

$$A = 9 \times 10^{-5}\ \text{m}^2,\ L = 1.0\ \text{m},$$

$$\rho = \text{density of belt material (Double woven Reinforced rubber)} = 1250\text{kg/m}^3$$

Groove angle, 2β, refer to Fig. 3.5

Using the trigonometric ratio

$$\beta = \tan^{-1}\left(\frac{3}{10}\right) = 16.7$$

$$2 \times \beta = 33.4^0$$

Therefore, Groove angle = 33.4^0

Angle of contact between the belt and each pulley, θ

For an open belt drive,

$$\text{Sin}\ \alpha = \frac{d_2 - d_1}{2x} \quad (6)$$

$$\text{Angle of lap on the smaller pulley}, \theta = 180 - 2\alpha \quad (7)$$

Belt Tension

T_C = Centrifugal Tension
T_1 = Tension in the tight side of the belt
T_2 = Tension in the stack side of the belt
T = Maximum allowable tension on the belt
σ = The maximum allowable tension stress of belt (taken as 2.5 mn/m^2) for rubber
Centrifugal Tension, Tc

$$T_C = mv^2 \tag{8}$$

Recalling, mass per meter length of belt, m = 0.1125 kg/m

$$\text{Velocity, } v = \frac{\pi d_1 N_1}{60} \text{ (Source: Khurmi and J.K Gupta, 2005)} \tag{9}$$

d_1 = diameter of motor pulley = 0.05 m
N_1 = motor speed = 1400 rev/min
Maximum allowable tension in the belt, T

$$T = \sigma \times A \tag{10}$$

Where,
$\sigma = 2.5\ MN/m^2$ (Taken)
Tension in the tight side of the belt, T_1

$$T_1 = T - T_C \tag{11}$$

Relationship between T_1 and T_2 for V- belt

$$2.3 \log \left(\frac{T_1}{T_2}\right) = \mu\theta \operatorname{cosec} \beta \tag{12}$$

Where, coefficient of friction for rubber material, μ is 0.2 (Khurmi and Gupta, 2005)

Power transmitted by belt

$$P = (T_1 - T_2)v \tag{13}$$

Number of V – belts required

$$\text{Number of V - Belt} = \frac{\text{Total Power Transmitted}}{\text{Power Transmitted by Belt}} \tag{14}$$

For solid shaft having little or no axial loading the ASME Code equation reduces to;

$$d^3 = \frac{16}{\pi S_s}\sqrt{K_b M_b + K_t T} \tag{15}$$

Where at the section under consideration,

Shock and Fatigue factor for torsion, $K_b = 1.5$
Shock and Fatigue factor for bending, $K_t = 1$
Bending Moment, $M_b = 25.15$ Nm
Torque transmitted by the shaft, $T = (T_1 - T_2) \times \frac{d_2}{2} = 18.863$ Nm

Bearing

A ball bearing was chosen according to SKF standard (S.K.F Catalogue, 2012). The operating characteristics of a rolling-element bearing depend greatly on its diameter and clearance. The internal diameter of the bearing is 20 mm while its external diameter is 72 mm, it basic dynamic load rating is 30700 N and designation 6404.

Main Frame

The main frame of the machine was constructed using 40 x 40 mm low carbon steel angle bar, which provides support for the unit.

The diagram of the manufactured polyethylene terephthalate washing and sterilizing machine is presented in Figure 3 and 4 respectively.



Figure 3. Solid Diagram of the Machine.

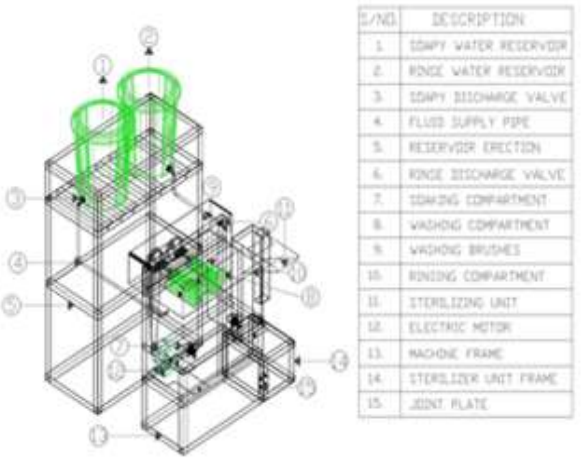

Figure 4. Skeletal Diagram of the Machine

The pictorial view of the fabricated prototype machine is shown in Figure 5.



Figure 5. Pictorial view of the fabricated prototype machine

Test, Results

Preliminary test

A preliminary test was carried out at the conceptual stage of this work. It was to find a suitable soaking temperature for PET bottles. The test results are shown in Table 1.

Soaking temperature

A pre-wash soaking temperature test was carried out to determine the appropriate temperature by which PET bottles can be washed without deforming them. Table 2 shows results of the test carried out and state of the bottles at various temperatures.

Table 1. Soaking temperatures and their effect on PET bottle

1. S/No.	2. Temperature	3. Dip Time	4. Water Status	5. Result
6. 1.	7. 98°C – 90°C	8. 5 Seconds	9. Very Hot	10. Deformed Plastic
11. 2.	12. 89°C – 80°C	13. 5 Seconds	14. Very Hot	15. Deformed Plastic
16. 3.	17. 79°C – 70°C	18. 5 Seconds	19. Hot	20. Deformed Plastic

21. 4.	22. 69°C – 66°C	23. 5 Seconds	24. Hot	25. Deformed Plastic
26. 5.	27. 65°C – 51°C	28. 2 minute	29. Warm	30. No Deformity
31. 6.	32. 50°C – 45°C	33. 2 minute	34. Moderately Warm	35. No Deformity

From the results obtained, 50°C was the pre-wash (soaking) temperature adopted for washing of PET bottles. After testing of the machine, the washed bottles were physical examined to check for proper wash and clarity of bottles. Table 3-Table 5 show results of the test carried out. The results obtained, justifies that used PET bottles can be reused, and the manufactured prototype machine processes used PET bottles through washing and sterilizing for reuse purpose.

Table 3.Test Results Obtained for Washing PET bottles collected from an event.

S/No.	Nos. of Bottles Loaded into the soak chamber	Soak Time	Nos. of bottles fed into the wash brush	Washing period given to fed bottles	Observations
1.	2	2 mins.	2	5 Sec.	Not Clean
2.	2	2 mins.	2	10 Sec.	Clean
3.	2	2 mins.	2	15 Sec.	Clean

Table 4. Test Results Obtained for Washing Dump Site Collected PET bottles.

S/No.	Nos. of Bottles Loaded into the soak chamber	Soak Time	Nos. of bottles fed into the wash brush	Washing period given to fed bottles	Observations
1.	2	2 mins.	2	5 Sec.	Not Clean
2.	2	2 mins.	2	10 Sec.	Not Clean
3.	2	2 mins.	2	15 Sec.	Not Clean
4.	2	2 mins.	2	25 Sec.	Not Clean
5.	2	2 mins.	2	30 Sec.	Not Clean
6.	2	2 mins.	2	35 Sec.	Clean
7.	2	2 mins.	2	40 Sec.	Clean

Table 5. Test Results Obtained for Washing Drainage System Collected PET bottles.

S/No.	Nos. of Bottles Loaded into the soak chamber	Soak Time	Nos. of bottles fed into the wash brush	Washing period given to fed bottles	Observations
1.	2	2 mins.	2	5 Sec.	Not Clean
2.	2	2 mins.	2	10 Sec.	Not Clean
3.	2	2 mins.	2	15 Sec.	Not Clean
4.	2	2 mins.	2	25 Sec.	Not Clean
5.	2	2 mins.	2	30 Sec.	Not Clean

6.	2	2 mins.	2	35 Sec.	Not Clean
7.	2	2 mins.	2	40 Sec.	Not Clean
8.	2	2 mins.	2	45 Sec.	Not Clean
9.	2	2 mins.	2	50 Sec.	Not Clean
10.	2	2 mins.	2	55 Sec.	Clean
11.	2	2 mins.	2	60 Sec.	Clean

Figure 5 – 10 shows the products obtained after testing of the machine



Figure5. Unwashed Event collected PET bottles.



Figure 6.Washed Event collected PET bottles.



Figure7. Unwashed Dump site collected PET bottles.



Figure8. Washed Dump site collected PET bottles.



Figure 9. Unwashed Drainage collected PET bottles.



Figure 10. Washed Drainage collected PET bottles.

Machine Efficiency

The Efficiency of the machine was derived using equation 16

$$\text{Efficiency}, \eta = \frac{\text{No. of Product Obtained}}{\text{No. of Product Fed}} \times \frac{100}{1} \tag{16}$$

The Efficiency of the machine in respect to event collected (91.6%), Dumpsite collected (83.3%) and drainage collected PET bottles (70.83%), washed and sterilized. An average was taken and found to be;

$$\eta = \frac{91.6 + 83.3 + 70.83}{3}$$

$$\eta = 81.91\ \%$$

Thus, the efficiency of the machine is **81.91 %**

Washing Capacity of the machine

Washing time for a set of two (2) bottles = 10 Seconds
Downtime in-between each washing set of two (2) bottles = 50seconds
Washing time for a set of two (2) bottles and downtime in-between each set = 60 seconds
Wash time for a batch of 24 bottles of a pair of 12 bottles = 60seconds x 12 = 720 seconds

$$\frac{3600\ \text{secs.}}{720\ \text{secs.}} = 5$$

$$\text{A pair of 12 bottles} \times 5 = 60\ \text{pairs of bottles}$$

Therefore,

60 pairs of bottles $\times 2 = 120$ bottles

Thus, the washing capacity of the machine is 120 bottles per hour

Discussion

In view of the need to reduce the waste generation of used PET bottles, a machine was designed and fabricated for the purpose of washing and sterilizing reusable PET bottles for reuse. During the course of fabrication a brick wall was encountered involving the rotational wash brushes. The desired design for the wash brushes could not be sourced and so it had to be improvised, using locally available materials. After fabrication and assembling the machine was prepared for testing, the soak and rinse chambers were properly washed and the surrounding environment was cleared of all unsafe objects. The prototype machine was tested and was found to wash event site collected bottles of a set of two (2) in 10 seconds, Dump site collected bottles of a set of two (2) in 35 seconds and drainage system collected bottles of a set of two (2) in 55 seconds.

The fabricated prototype soaking chamber was designed for a batch of twenty four (24) bottles. The chambers were made of stainless steel and the rotating wash brushes were made of plastic bristles wrapped around a stainless steel rod of 5 mm thick. The machine runs on a single phase 0.5 hp electric motor at a speed of 1440 rpm, the speed was further stepped down by pulleys to a wash speed of 470 rpm. The efficiency of the machine is 81.91 % and it washing capacity is 120 bottles per hour.

Conclusion

Post-consumed PET bottles are non-biodegradable waste; they constitute a nuisance in our environment, and they are found littered in all nooks and crannies within our cities in Nigeria. A PET bottle washing and sterilizing machine was therefore designed and fabricated using locally available materials. It was done to recycle used PET bottles at source and reduce it litter in the country. Test results of the prototype machine, showed that used PET bottles can be recycled by simply washing and sterilizing them. The fabricated prototype washes a set of two (2) 75cl used PET bottles in 10 seconds, with an efficiency of 81.91 %. It washing capacity is 120 bottles per hour. This new development reduces the virgin reproduction of PET bottles. Thus, alleviating the menace posed by its litter in the country. Furthermore, it will provide formal and informal economic activity in the collection, sorting, washing, sterilizing and the re-use of PET bottles in Nigeria.

Acknowledgement

I wish to acknowledge the support of Patrick O.B Ebunilo (PhD) of the Department of Mechanical Engineering, University of Benin, Benin-City, Edo State.

Reference

Achankeng, E. (2003). "Globalization, Urbanization and Municipal Solid Waste Management in Africa". African Studies Association of Australasia and the Pacific 2003 Conference Proceedings - African on a Global Stage. University of Adelaide. p.7. [Online] Available from: http://libvolume7.xyz/politicalscience/ba/semester5/theafricanexperiencepolityandeconomy/situatingafricapanafricanismandthethirdworld/situatingafricapanafricanismandthethirdworldtutorial2.pdf. [Accessed: 12th August 2015].

Aris, A.Z. (eds) (2013). "From Sources to Solution". Proceedings of the International Conference on Environment Forensics. DOI 10.1007/978-981-4560-70-2, p. 348. Singapore: Springer Science and Business Media. [Online] Google E-Books, Available from: https://books.google.com.ng/books?id=ilpFAwAAQBAJ&printsec=frontcover#v=onepage&q&f=false. [Accessed: 13th August 2015].

Data".p.25. [Online] Available from: http://www.plasticseurope.org/documents/document/20131014095824-final_plastics_the_facts_2013_published_october2013.pdf. [Accessed: 13th August 2015].

Dimitris S.A (ed), Lefteris A., Ioannis A.K, Dimitra A.L, Nikolaos P.N, Panoraia S., Ioannis T. and Georgia T. (2012). "Recent Advances in the Chemical Recycling of Polymers (PP, PS, LDPE, HDPE, PVC, PC, Nylon, PMMA)". Material Recycling - Trends and Perspectives. Laboratory of Organic Chemical Technology, Department of Chemistry, Aristotle University of Thessaloniki, Thessaloniki Greece. p.3-4, ISBN: 978-953-51-0327-1.

International Life Sciences Institute Europe (ILSI) (2000). "Report on Packaging Materials: 1. Polyethylene Terephthalate (PET) for Food Packaging Applications". ISBN: 1-57881-092-2, p.5. Brussels: Belgium. [Online] Available from: http://www.ilsi.org/europe/publications/r2000pac_mat1.pdf. [Accessed: 13th August 2015].

Kadafa, A., Latifah, A.M, Abdullah, H.S, and Wan nur A.(2012). "A Review on Municipal Solid Waste Management in Nigeria". Journal of American Science 8(12) p.975-982. ISSN 1545-1003. Department of Environmental Management, Faculty of Environmental Studies, University Putra Malaysia.

Kadafa, A.A, Latifah, A.M., Abdullah, H.S., Wan N. A., (2012). "A Review on Municipal Solid Waste Management in Nigeria". Journal of American Science. Department of Environmental Management, Faculty of Environmental Studies, University Putra Malaysia.

Khurmi, R.S. and Gupta, J.K. (2005). "Textbook: Machine Design", Fourteenth Edition. Ram Nagar: Eurasia Publishing House (Pvt.) Ltd, New Delhi-110 055. p.470-557, 600-623, 727-758.

Momodu S.N., Dimuna K.O., and Dimuna J. E. (2011). "Mitigating the impact of Solid Wastes in Urban Centres in Nigeria". J Hum Ecol, 34(2): 125-133. [online] Available from: http://www.krepublishers.com/02-Journals/JHE/JHE-34-0-000-11-Web/JHE-34-2-000-11-Abst-PDF/JHE-34-2-125-11-1687-Momodu-N-S/JHE-34-2-125-11-1687-Momodu-N-S-Tt.pdf. [Accessed: 13th August 2015].

Omole, F.K. and Alakinde, M.K. (2013). "Managing the Unwanted Materials: The Agony of Solid Waste Management in Ibadan Metropolis, Nigeria". International Journal of Education and Research 1(4): p.1.

Plasticseurope (2013). "An Analysis of European latest Plastics Production, Demand and Waste

SKF (Svenska Kullagerfabriken AB) (2012). "Bearings Catalogue". 905535 Intech., p.354, PUB BU/P1 10000 EN.