Design and Characterization of a Model Polythene Recycling Machine for Economic Development and Pollution Control in Nigeria

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Abstract **– Consequent on the environmental degradation caused by the littering of polythene materials in our cities, a polythene-recycling machine was designed and constructed. The machine melts washed polythene products of various sizes and shapes, and pelletized them for industrial use. The machine was designed to convey polythene materials used as satchels, bags or sheets, feed through a hopper and transferred to the hot zone through a screw conveyor chamber. The screw conveyor was driven by an electric motor that turns or rotates at a predetermined speed. The hot zone was heated with a resistance heating element and the heat being controlled or regulated by a thermocouple. When the polythene material gets to the hot zone which was maintained at 200°c (within the temp range of 150 -300°c) Khanna, O.P. (2005,) it is melted or softened. The resulting soft material-was extruded through the orifice or die at the end of the chamber. The out-feed product was collected as raw materials for the plastic industry.**

Keywords: **Machine design, Polythene Recycling, Heat, Palletized, Environmental degradation.**

I. INTRODUCTION

The twentieth century has witnessed a tremendous advancement in the polythene manufacturing industries and products. Babajide (2004) stressed that on the introduction of structural Adjustment Programme (SAP) by the Babangida administration, many Nigerians looked inwards for opportunities of self employment and wealth generation. On the heels of this self-reliance,, government spearheaded in the lead by setting up a number of agencies to either provide the platform for the actualization of individual self-employment programme or provide basic infrastructure in that direction. Chief among such agencies were the National Directorate of Employment (NDE) and the Directorate of Foods, Roads and Rural Infrastructure (DFRRl).

Nigerians responded quickly and embraced these government policies. One area that was found fertile in entrepreneurship was the manufacturing of polythene, especially those used for the packaging of goods. In no distance future much success was recorded to the extent that food items such as eba, moi-moi, pounded yam, etc which were wrapped in leaves, were now wrapped in "plastic".

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Again, cold water business for the thirsty transit passengers developed. This gave rise to iced water which was first wrapped in transparent plastic bags for sale. Later on the enterprise went several rungs up the ladder, and the "pure water" industry emerged.

The business became completely stabilized with the National Agency for Food and Drug Administration and Control (NAFDAC) endorsement. Alongside the transparent polythene are the black polythene shopping bags generally known as "poly bags", made in various sizes and thickness. The resulting effect of these polythenes put into use is that virtually all our villages, towns and cities are littered with both used and unused polythene bags.

Okonkwo and Eboatu (1999) however emphasized that the concern here is about the nature of these polythene products, which science has proved to be non-biodegradable. That means that these plastic bags and wrappers remain where they are dropped, choking our soil, and suffocating our environment. The implication is that ground water which gets to the surface by capillary action is blocked by the plastic product which has serious implication on agricultural activities. Furthermore, our poor refuse disposal habits gave room for “pure water” bags and other plastic products to be dumped just anywhere. This accounts for much of the blockage in gutters in the cities which in turn causes flooding that wash away our roads, pull down structures and cause other environmental problems.

II. THE ECONOMIC IMPORTANCE OF POLYTHENE MATERIALS

The different manufacturing processes have improved drastically and technologically, just as the hardware or physical machineries have also gone high in development. Today, polythene, a polymer (i.e consists of large chain like molecules containing carbon) and a starting material has been put to different uses as containers, utensils, tables and chairs, slippers and shoes, bags and packages, toys and wrappers. Onibukun and Kumuyi (1981) believed that because of the extensive use of the polythene materials in almost every facet of Nigerian life and economy the sachets, wrappers, containers etc are littered in almost every nook and cranny of our roads, markets, streets and other non designated places. This greatly has negative impacts on our environment. These materials are non biodegradable and may not go extinct unless they are recycled. Nikolaou (2002) added that recycling as an industrial process is gradually increasing in both developed and under developed countries. In a developing country like Nigeria, the need is highly indispensable so as to reduce the volume of polythene waste generated and also to serve as a means of solving environmental pollution/degradation which is currently eating deep into the fabric of our environment. Our environment is faced with the problem of pollution, be it air, water or land. The pollutant could either be waste gasses from industries, effluent water, refuse comprising various materials ranging from plant cellulose to plastics, which is non-biodegradable. These pollutants are introduced into the environment and are left as nuisance. The non-biodegradable materials which include plastics: polythene, polyvinyl chloride (PVC) etc are emphasized here. Because of their non-biodegradable nature, they terribly constitute the major environmental pollutants. It is in a bid to salvage our environment from this menace, and at the same time subject the ecosystem to an equilibrium that gave rise to recycling as an industrial, chemical and economic process which is targeted towards economic empowerment. Recycling does not only get environment rid of pollutants but also produces new products from waste.

III. THE ORIGIN OF PLASTICS (POLYTHENE MATERIALS), ITS REVOLUTION AND POLLUTION

The use of raw materials is an essential factor in manufacturing industries. Plastics are broadly integrated into today's lifestyle and make a major, irreplaceable contribution to virtually all product areas. One can go as far back as the Old Testament to find reference about natural materials used as fillers, adhesive, coatings and the like. These materials were the precursors of modern plastic materials. The history of the rubber industry has a bearing on plastics. The origins of commonly used plastics are (1) the natural gas (2) the crude oil distillation and (3) the natural cellulose.

The period 1930-1940 saw the initial commercial development of today's major thermoplastics, namely: polyvinyl chloride, low density polyethylene, polystyrene, and polymethyl methacrylate. The advent of World War II in 1939 brought plastics into great demand, largely as substitute for materials in short supply such as natural rubber. The first decade after World War II saw the development of polypropylene and high density polyethylene. Linear low density polyethylene was introduced in 1978, and this introduction made it possible to produce polyethylenes with densities ranging from 0.90 to 0.96. The raw materials (polyethylenes) began to compete with the older plastics and even with the more traditional materials such as wood, paper, metal, glass, and leather. The demand for plastics has increased steadily. Plastics are now accepted by designers and engineers as basic materials along with the more traditional materials. The automotive industry, for example relies on plastics to reduce weight and thus increase energy efficiency.

Genssner (1981) stated that polyethylene is not compressible, and when deformed, it tends to stay out of shape undergoing permanent or plastic deformation. A substance that behaves like this is called plastic. Plastics generally are high polymers (i.e. elements consisting of large chain like molecules containing carbon), which are formed either during or after their transition from a low molecular weight chemical to a high molecular weight solid material. The higher molecular weight of the solid materials is as a result of additives or ingredients such as fillers, plasticizers etc.

Plastic materials, though cheap, available and serve society's needs, are not very durable compared to metals. They are easily damaged. This means that they constitute menace to the environment. Pollution of this form is not suitable for a clean and healthy environment. Plastic as a solid waste can take the form of damaged washing bowls, jerry cans, food storage containers, foot wears, buckets, plates, seats etc. the disadvantages caused by the massive use of plastics are invidious. These plastics being synthetic rather than natural are frequently not broken down by micro-organisms in the way that natural polymers are. That is they are not biodegradable.

Evans and Williams (2003) suggested that the menace of plastic pollutions can be controlled by the new technological breakthrough called recycling. This is important because plastic pollution has really become almost an intractable problem. Everywhere in cities and towns, one sees litters of discarded plastic items. They come in whole or parts. The most striking menace is the packaging plastics, especially the polythene sheets that are used for packaging water (pure water), foods and confectioneries. They stay out there and accumulate continuously. This plastic wastes belong to the general class of solid wastes. Brandrup (1996) observed that these modern plastics tend to defy disposal activities. They are generally non biodegradable, therefore not good material for composting and sanitary fills. Incineration is not a very attractive option for we end up spewing into the atmosphere obnoxious gases and particles. Recycling has been tried, and it has shown a reasonable degree of success for thermoplastics such as polyethylene and polypropylene. For sure recycling is not applicable to thermoset plastics.

IV. DISPOSAL AND ENVIRONMENTAL POLLUTION OF POLYTHENE MATERIALS.

The Association of Plastic Manufacturers in Europe (AMPE) 1998 describe that the development activities carry with them the seeds of environmental damage, assisted and abetted by both needs and greed of man. Activities such as manufacturing, processing, transportation and consumption not only deplete the stock of natural resources, but also add stress to the environmental system by accumulating stock of waste.

Before going into the aspects of environmental pollution it is better to understand the concepts of environment and ecology. Environment refers to the places and situations in which plants, animals and people live. It is a matrix of living and non-living organisms, whereas ecology is the relationship between living things and their environment. Pollution degrades the environment which in turn leads to the depletion of the earth's ozone layer. The pollution of water, air and environment are the byproducts of economic development particularly industrialization and urbanization. Environmental pollution results from careless disposal of non-biodegradable waste experienced by many ecologically sensitive ecosystems.

A cleaning campaign carried out by the Eco Friendly Volunteers with the participation of the Sri Lanka Army saw a load of polythene and plastic weighing more than 3 tons being collected in just a day. This was along a single trail to the Sir Pada Peak and had been carelessly disposed by heartless and thoughtless pilgrim tourists.

Accumulated polythene and plastic results to soil degradation, blocks springs, and a huge threat to wild animals. Polythene and plastics are popular wrapping and packaging materials due to many reasons. They are light, has water proofing nature, easy to manipulate and cheap. However, it is not really the use of polythene that has

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disastrous consequences, but its careless disposal. Polythene and plastic should not be dumped, not even in a landfill because they are non-biodegradable stuff. They contain hydrocarbons that when burnt release many toxic materials or matters into the atmosphere. The gases released are also highly carcinogenic. So if burning is to be done, it should be carried out in a sophisticated incineration plant. But this is extremely costly and highly unmanageable in a developing country like Nigeria. There are three processes we can use to control polythene environmental pollution.

1 Reduction of the usage: Plastic and polythene should be used only when there is no alternative.

2. Re-use: This may help to reduce the production of environmental pollutant. Polythene materials should be used several times before disposal.

3. Re-cycle: Polythene and plastics should be separated from other garbage so that they could be handed over to be re-cycled. There are several factories that recycle both plastic and polythene. Identify and sort out the products that are recyclable.

V. PREVIOUS POLYTHENE RECYCLING MACHINES

In recycling, especially for primary recycling, the machine used is generally designed to accommodate reprocessing by injection moulding method, blow moulding method or extrusion method, to manufacture plastic products similar to those of the original parts.

Polythene or plastic scraps can be reprocessed alone, but more often are blended with fresh (virgin) materials at various ratios. Both post-industrial and post-consumer scraps can undergo primary recycling as long as the plastics can be separated (by colour as well as type).

Primary recycling machine is always incorporated with elevated temperatures for processing which results to the changes in polymer structure, and therefore the physical properties. Such changes are due to material degradation from repeated processing, and results in a loss of properties such as appearance, chemical resistance, and other properties. Polythene recycling machine is used to provide crushing of materials into smaller particles mechanically and thermally, thereby providing for melting and conversion.

A recycling machine that has the capability of recycling polythene films, sachets and packages was designed. The recycled products are used as raw materials for the production of fresh polythene products like cups, hangers, toys etc. Polythene films and used sachets are fed into the machine through the hopper. The material is conveyed mechanically through a screw barrel system to the heat zone. The heat is provided with the help of a heating element, and a thermocouple is provided for regulation of the heat.

When the materials get to the heated zone, maintained at a temperature of about 200°c, they melt and are extruded through the orifice at the end of the barrel. The extruded materials come out and are collected in lumps as raw materials for the plastic industry that finally produce plastic wares.

Odior et al, 2012 developed a polythene recycling machine from locally sourced materials from Nigeria which uses designed fixed and rotary blades for slitting the loaded wastes. The rotary blades are rotated by a single phase, high speed electric motor and the friction generated provides the heat required to soften the waste charges. The recycling machine produces an average of 35kg of small flakes of recycled waste per hour at a machine speed of 2880 rpm. But the friction effects generated in the system is considered inappropriate as this would cause frequent changes of the friction parts involved.

Ugoamadi et al, 2011 optimized the development of a plastic recycling machine that minimizes the limitations of the already existing (imported) ones to a great extent and at the same time ensuring effective waste management. The results presented show that for every used plastic fed into the hopper, about temperature of 200^0C is required to melt it. The machine employs the principle of conveying and heating to effect shredding and melting of the materials fed through the hopper, and requires only two persons to operate. But the use of chain drive from the electric motor is a disadvantage as a direct coupling system adopted in this design gives effective power and significant mechanical advantage.

VI. DESIGN OF THE POLYTHENE RECYCLING MACHINE

In the design of the recycling machine in this report, many things were considered when analyzing the system:

Parts Design and Materials Selection

The factors which influenced the choice of materials selected for this design include materials suitability, strength, local availability and cost effectiveness.

The mechanical parts in this system are the barrel, the screw conveyor, gears, coupling and keys. The electrical components include the heating elements, switches, thermocouple, cables or wires and geared electric motor.

The screw was made with a pitch of 50mm which means that for every revolution the polythene materials move a distance of 50mm. The material moves until it gets to the end of the screw. The screw was housed in a barrel with holes at the end. When the molten polythene materials get to the end of the barrel, it discharges through the holes.

The heater or heating element was wrapped round the barrel half way of the length. It is to provide heat to the barrel, the screw and the polythene material in them. The heater is preset at a temperature of 220°C. At this temperature the polythene material melts and form paste. The paste is conveyed to the holes at the end of the barrel and discharges as raw material for various plastic ware productions. The thermocouple is used to regulate the heating of the barrel and screw within the range of 180°-220°C.

The screw inside the barrel is rotated by the geared electric motor. As the screw rotates, it conveys the polythene material through to the heated zone of the barrel. From there it moves out from the orifices provided at the end of the barrel. Water is provided at the end of the barrel where the molten material run into and be cooled.

Fig 1: The Designed Polythene recycling machine

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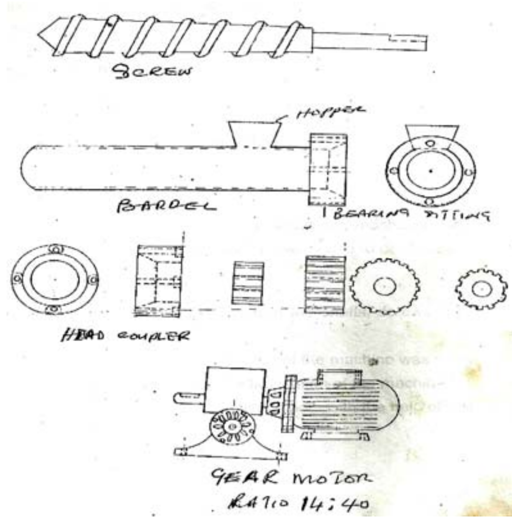


Fig 2: Hand sketch of the component parts

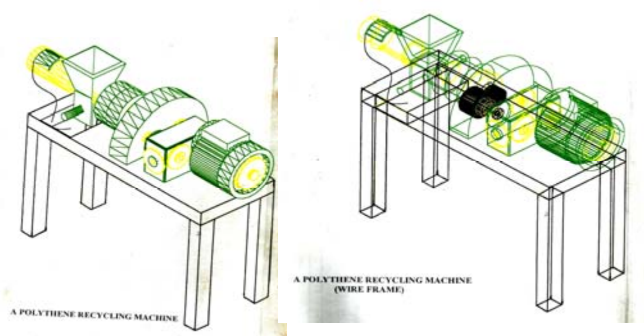
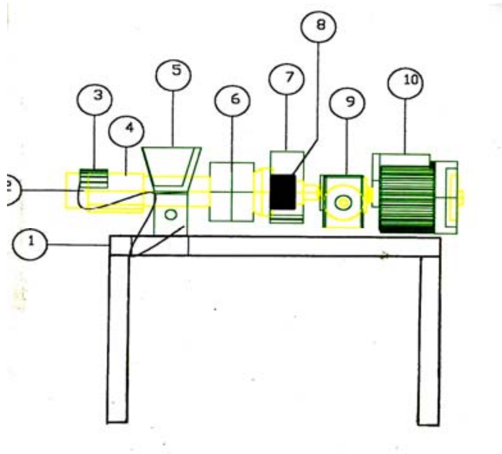


Fig 3: The front technical views of the machine



Items	Descriptions	Items	Descriptions
1	Stand	2	Nozzle
3	Element	4	Heater
5	Hopper	6	Coupling
7	Gear cover	8	Spur gear
9	Gear box	10	Motor

Fig 4: Assembly view of the recycling machine

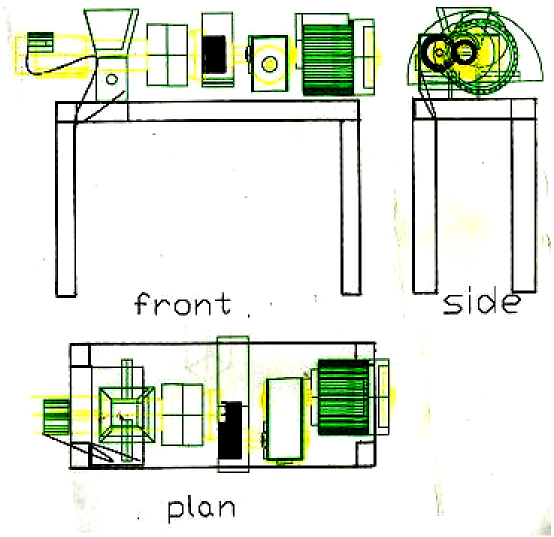


Fig 5: Different technical views of the machine.

Parts Design Analysis

The Barrel:
The barrel made with mild steel houses the screw conveyor. The fed polythene materials pass through the barrel from the hopper to the orifice at the exit. It is equally where the heating and melting of the materials take place.

The Screw Conveyor:
The screw conveyor is rotated by the geared electric motor. As the screw rotates, it conveys the polythene material through to the heated zone of the barrel band to the exit.
To determine the pitch of the screw conveyor, we considered that the *pitch* is the distance between adjacent thread forms measured parallel to the thread axis. The pitch in U.S. units is the reciprocal of the number of thread forms per inch *N*.

The driving power of the loaded screw conveyor is given by:

$$P = P_H + P_N + P_{st} \qquad (1)$$

Where,
P_H = Power necessary for the progress of the material
P_N = Driving power of the screw conveyor at no load
P_{st} = Power requirement for the inclination of the conveyor

Power necessary for the progress of the material, P_H:
For a length L of the screw conveyor (feeder), the power, P_H in kilowatts is the product of the mass flow rate of the material, the length L and an artificial friction coefficient λ, also called the progress resistance coefficient.

$$P_H = M_f.L.\ \lambda.g / 3600 \text{ (kilowatt)}$$
$$= M_f.L.\ \lambda / 367 \text{ (kilowatt)} \qquad (2)$$

Where,
M_f = Mass flow rate in t/hr
λ = Progress resistance coefficient

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Each material has its own coefficient λ. It is generally of the order of 2 to 4. For materials like rock salt etc, the mean value of λ is 2.5. For gypsum, lumpy or dry fine clay, foundry sand, cement, ash, lime, large grain ordinary sand, even plastics, the mean value of λ is 4.0.

In this connection it should be noted that the sliding of the material particles against each other gives rise to internal friction. Other resistance due to grading or shape of the output discharge pattern contributes to the resistance factor. That is why the parameter λ is always higher than that due to pure friction.

Drive power of the screw conveyor at no load, P_N:
This power requirement is very low and is proportional to the nominal diameter and length of the screw.

$$P_N = D.L / 20 \text{ (Kilowatt)} \quad (3)$$

Where,
D = Nominal diameter of screw in meter
L = Length of screw conveyor in meter

Power due to inclination, P_{st}
This power requirement will be the product of the mass flow rate, the height H and the acceleration due to gravity g.

$$Pst = M_f.H.g / 3600 = M_f.H / 367 \quad (4)$$

H should be taken positive for ascending screws and will be negative for descending screws.

Total power requirement:
The total power requirement is the sum total of the above items

$$P = (M_f (\lambda.L + H) / 367) + (D.L /20) \text{ (kW)} \quad (5)$$

Gears:

The power rating of the gear is calculated from

$$P = \frac{W_t \times \pi d n}{60000} \text{ (kW)} \quad (6)$$

where

W_t = transmitted load, kN

d = gear diameter, mm

n = speed, rev/min

For Metallic Spur Gears:

$$W = SFY.\ 600 / (P.\ [600 + V]) \quad (7)$$

where
W = Tooth Load, kN
S = Safe Material Stress (static) N/m^2
F = Face Width, m.
Y = Tooth Form Factor
P = Diametral Pitch
D = Pitch Diameter
V = Pitch Line Velocity, mm/s.
= 0.262.PD.n

For Non-Metallic Gears

$$W = S.F.Y.\ \{(150 /[200 + V]) + 0.25\} / P \quad (8)$$

To calculate Design Power,

Design Power, P_d = P x Service Load factor (9)

Gear/pinion with power capacity equal to or more than Design Power was thus selected.

VII. TESTING AND RESULT

The fabricated recycling machine was tested to evaluate its performance.

First and foremost, polythene materials of various types, sizes and shapes were collected, sliced and washed. But before that, they were sorted out according to their types (i.e. sachets and sheets). The machine was prepared for the recycling operation by first switching on the heater (i.e. the heating element). The heating lasted for 1hr 45 minutes to enable the barrel reach the heating temperature of 200°c. The hot zone of the barrel was maintained at this temperature.

Then, the sorted sliced polythene materials were fed into the machine through the hopper, as the electric motor was simultaneously switched on. The feed material was conveyed through the barrel by means of the screw positioned inside it. The material eventually got softened, and came out of the die's orifice at the end of the chamber. The material came out in droplets or palletized form and dropped into a bucket of water kept in place. The water medium helped to cool the resulted material fast. On subsequent testing period, it was discovered that the remnant of the softened polythene inside the heating chamber had caked on cooling thereby ceasing the screw from rotating. The chamber was heated to soften the remaining material before resuming operation but much progress was not made.

VIII. CONCLUSION

The study shows that used polythene materials of various types, sizes and shapes can be gathered, washed, melted and pelleted for various industrial uses. In the operation of the machine the heater was first switched on for 1hr 45m minutes. This is for the barrel to be hot to enable the left over plastic inside the barrel to melt, and to allow free flow of the materials heated when the electric motor is switched on. The European Union directive on packaging and packaging waste is in favour of setting up recycling scheme when feasible. The recycling rate of plastic film in the country is poor. The potential to increase plastic recycling in general is large.

From the research carried out it is obvious that we can get rid of polythene wastes all over the place because the practice has long been proved to be a reality in developed countries of the world. A polythene recycling machine was therefore designed and manufactured using locally sourced and available materials. The manufactured recycling machine was found to be very useful in absorbing the huge waste materials in our country. The performance test shows that the machine has a capacity of recycling polythene/nylon wastes that has good quality for reuse in various homes and industrial applications. The various levels of the government Federal, State and Local Government, and even

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nongovernmental organizations (NGOs) are hereby called upon to develop a control policy towards the manufacture and use of polythene products, its disposal and recycling.

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