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Valorisation of Combustible Wastes to Gasoline; Its Potentials and Hurdles in Nigeria

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ABSTRACT

One of the environmental problems facing developing countries, including Nigeria; is the inadequacy of efficient waste management facilities. Wastes can constitute environmental, social and economic nuisances if the wastes are not properly disposed of. The aim of this study was to evaluate the feasibility for valorisation of combustible wastes to gasoline as a measure to resolve problems associated with the improper disposal of the wastes. The experimental procedure involved heating about 10kg of ground low density polyethylene wastes in a pyrolysis reactor at temperature range of 138 ^{o}C and 358 ^{o}C. About 75 ml of liquid fuel produced was collected and put in a round bottom flask for further separation through fractional distillation process. The volumes of three liquid fractions obtained during the fractional distillation process at 27 ^{o}C, 42 ^{o}C and 75 ^{o}C were 7mL, 20mL and 40 mL, respectively. The liquid fraction obtained at 27 ^{o}C evaporated when left uncovered for about 3 hrs. Analysis of liquid fraction obtained at 75 ^{o}C showed that the fraction had close physicochemical properties with commercial gasoline. This implies its high probability of powering electricity generator and gasoline automobile. The outcome of the research work will definitely contribute to reduction of the amount of wastes in the environment as it would enable the wastes to be used as raw materials for liquid fuel production for use in power generation. Additionally, the findings of this study will contribute to providing alternative source for conventional gasoline.

Keywords : Waste valorisation, Pyrolysis oil, Gasoline, Fractional distillation, Electricity

INTRODUCTION

Most developing nations are confronted with numerous challenges including lacking adequate facilities for efficient treatment of generated wastes [1], as well as, indulging in unsustainable activities of depleting mineral resources without adequate plan for replacement of the depleted minerals. For more than three decades, Nigeria has been dependent on crude oil as a major foreign exchange, revenue and energy sources with consequent depletion of the natural resource [2]. For sustainability, alternative sources for crude oil such as, plastic wastes, should be explored to reduce the impact of fossil fuel depletion. Plastics are polymeric materials that can be classified based on factors such as its chemical structure, synthesis process, density and other properties [3-5]. The various types of plastics include, Polyethylene Terephthalate (PET) used to make household items; High Density Polyethylene (HDPE) used to make storage materials for milk, soap, motor oil, among others; Polyvinylchloride (PVC) used to make plumbing pipes and tiles; Low-Density Polyethylene (LDPE) used to make plastic grocery bags, squeezable bottles, and cling-film; polypropylene (PP) used to make lunch boxes and plastic bottles caps; Polystyrene (PS) used for making disposable coffee cups and plastic cutlery packing foam; as well as, Polycarbonate (PC) and polylactide (PLA) which are difficult to be recycled [3]. Polycarbonates (PC) are used in making compact disc and medical storage containers [6]. The lightweight nature, durability and non-corrosiveness of plastics made it to become one of the commonly used materials in our everyday life. In contrast to these advantages, most of these plastics are non-biodegradable and as a result, plastic waste has become one of the most common garbage problems in the cities all around the world [7]. Plastic thrown into landfills contaminates the soil and groundwater with harmful chemicals and microorganism. The effects of marine pollution caused by plastic are immeasurable; some of these are intestinal injuries, blockage in the gut and eventually death of fish, turtles, marine mammals and amphibians [8-12].

In view of the widespread usage of plastics and the huge amount of non-biodegradable waste generated from the usage; there is urgent need to reduce the amount of the polymeric waste in the environment and adding economic value to the polymeric waste either by reusing or recycling of the materials [7]. LDPE is mostly used in packaging many goods, including packaging of potable water locally known as *Pure Water* in Nigeria. To deal with economic challenges facing Nigeria, water is packaged in low-density polyethylene (LDPE) sachet that can be affordable by the less privileged. This technique for packaging pure water has become popular in almost all the Nigerian communities but unfortunately this technique is associated with environmental pollution since the water sachet is often not properly disposed of but instead thrown away after the water consumption, as it is seen as material of no immediate economic value. Oftentimes, environment is littered with LDPE wastes since LDPE has extremely low degradation rate [3, 7]. Hence, the need for alternative techniques for waste disposal and management is necessary. Different waste management techniques including incineration, pyrolysis, hydrolysis, hydrogenation and gasification, among others, are used in the treatment of wastes. Pyrolysis is a thermal treatment process used for waste treatment in an oxygen free environment at a temperature between 300 ^{o}C and 900 ^{o}C [13] with consequent formation of carbonized char and a volatile fraction that may be separated into condensable hydrocarbon oil and a non-condensable high calorific value gas [5, 14, 15]. The condensable hydrocarbon oil distillate comprising of straight- and branched-chain aliphatic, cyclic aliphatic, and aromatic hydrocarbons; is further separated into liquid fuel products by using fractional distillation process [10, 16]. Various factors affecting pyrolysis process include feedstock nature and composition, process temperature, pressure and residence time [3].

Many researchers have studied the plastic wastes pyrolysis for fuel production; for example, Dayana et al. [17], Bezergini et al. [18], Verma et al. [19], Karad et al. [20] and Chanashetty et al. [21] explored the non-catalytic pyrolysis of plastic waste for liquid fuel production while Mibei, et al. [22], Mileva, et al. [23] and Arunkumar et al. [24] investigated the catalytic pyrolysis of plastic waste to liquid fuel. Moreover, the feasibility of commercial production of fuel from plastic wastes have also been established [25, 26]. However, there are limited studies on the adaptability of the production process of fuel from plastic wastes to the developing countries, particularly, Nigeria. Therefore, the purpose of this study was to examine the potential and hurdles involved in the production of gasoline from plastic wastes in Nigeria**. T**he study evaluated feasibility of converting combustible wastes into gasoline as a solution to the improper disposal of waste. Furthermore, **t**he study addressed the environmental challenges faced by developing countries, particularly Nigeria, due to inadequate waste management systems. It emphasized how improperly disposed waste can lead to environmental, social, and economic issues.

The study detailed the experimental approach where low-density polyethylene was heated in a pyrolysis reactor. The pyrolysis process resulted in the production of liquid fuel, which was then separated through fractional distillation into fraction found to have properties similar to commercial gasoline, suggesting it could be used as fuel for electricity generators and gasoline-powered vehicles. The results underscored the effectiveness of pyrolysis in transforming waste into valuable fuel, thereby contributing to reduction of waste in the environment. The study also provided the potential to create an alternative source of fuel for power generation, which could help mitigate the environmental impact of improper waste disposal. Conversion of plastic wastes to gasoline, a fuel for powering automobiles or generating electricity, adds economic value to plastic wastes. The importance of finding alternative sources for fossil fuels that are continuously being depleted cannot be understated. One alternative source for fossil fuels, especially, the liquid fuels, is plastic waste since the calorific value of plastic wastes is similar to liquid fuels. The activity of converting plastic wastes into gasoline has numerous benefits including job creation, reduction of the amount of polymeric waste

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in the environment, reduction in the pollution caused by polymeric wastes, as well as, making the environment beautiful, aesthetic and healthy [27].

Overall, the study was organized logically from identifying the problem, through experimentation, to the analysis of results and implications, ending with a conclusion about its potential impact.

METHODOLOGY

The experimental procedure involved designing and fabricating of pyrolysis equipment, carrying out the pyrolysis of the combustible wastes, and fractionally distilling of the liquid product of the pyrolysis process. The pyrolysis process took place at Lagos State University, Epe campus, Lagos, Nigeria.

Experimental materials

The instruments employed for this research study were all locally sourced except the digital thermometer that was imported. The digital thermometer with 6Volt 10Amp lead acid rechargeable battery was solar powered. The pyrolysis system comprised of gas-fired furnace, pyrolysis reactor, one heavy oil condenser, one light oil condenser and two scrubbers for removing impurities from the pyrolytic gas (Plate1 and Figure 1). The pyrolysis reactor was a cylindrical steel vessel with thickness, internal diameter and capacity of 12mm, 250mm and

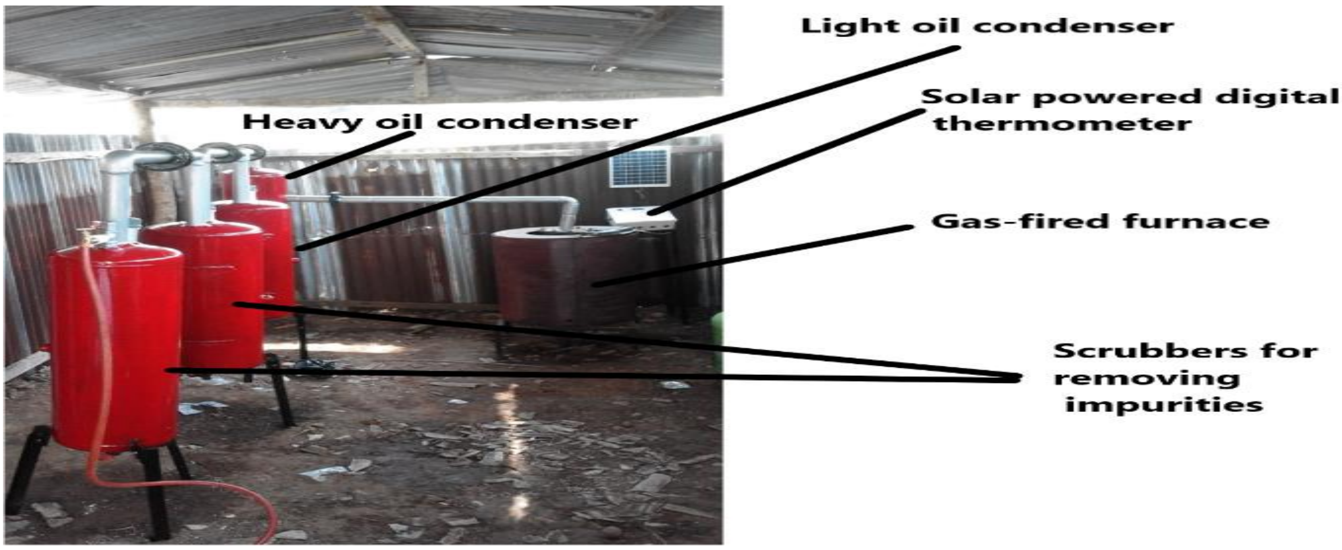

Plate 1. Pyrolysis system Setup

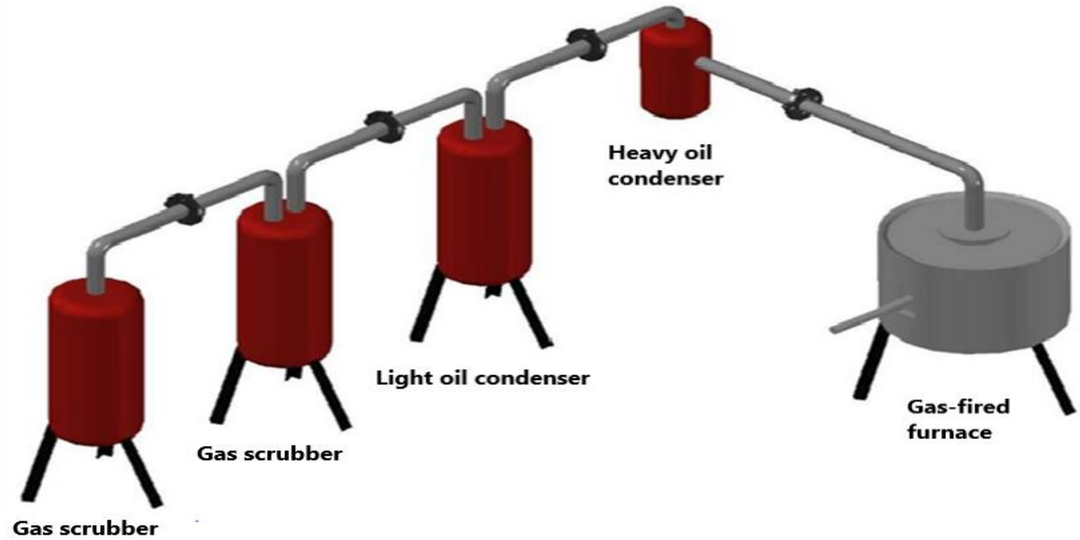

Figure 1. AutoCAD drawing of pyrolysis system Setup

25kg of shredded polymer, respectively. The reactor vessel was closed with two pairs of flanges (top and bottom). There was a hole in the centre of the reactor vessel which served as the gas exit. Solar-power temperature sensor was inserted in the reactor vessel to measure its temperature. The locally fabricated reactor was about 3.357 x 10^{-2} m^3 capacity by volume. It was made of mild steel lagged with laterite sand to reduce heat loss and enhance endothermic reaction. The scrubbers contained water as absorbent medium for toxic gases including hydrogen chloride and hydrogen sulphide, among others. Gaseous and liquid products from the reactor pass through exit pipes to the cyclone and scrubbers before collection. The LPG cylinder supplied the gas used in heating the feedstock in the reactor. Gaseous products from the scrubbers were collected in the gas bag through a rubber tube. The experimental materials used for fractional distillation process included retort stand, round bottom flask, Bunsen burner, mercury-in-glass thermometer, delivery tube, test tubes and beaker. About 50kg of polyethylene terephthalate, PET was sourced from Olusosun dumpsite, Lagos, Nigeria and another 50kg of shredded Low-Density Polyethylene, LDPE, sourced from local shredders at Idimu area of Lagos State.

Experimental procedure

The equipment was initially test run with about 7kg of crushed polyethylene terephthalate (PET) bottle for almost two hours. About 48 hrs. later, the LDPE sample which was obtained from local recyclers in a ground form was used as the main feedstock in the research study. About 10 kg of the LDPE feedstock was weighed and put in a pyrolysis reactor. A digital thermometer was connected to read the initial temperatures of the feedstock before heating. Heavy and light oil condensers along with two scrubbers, were then connected to the gas and liquid outlets of the reactor. The reactor was heated with liquefied petroleum gas (LPG) and temperature of the LDPE began to rise from initial temperature of 35.5 ^{o}C. Temperature readings were being noted and recorded at intervals of ten minutes. Gas production was noticed when the LDPE was heated to a temperature of 345 ^{o}C at about 3 hours from the commencement of the experiment. Liquid production was noticed at temperature of 353 ^{o}C, 45 minutes after the gas production. The volume of the liquid produced was about 400 mL from which 75 mL was taken for further separation through fractional distillation.

The fractional distillation process was carried out using simple laboratory equipment including retort stand, round bottom flask, rubber stopper, mercury-in-glass thermometer, delivery tube, test tubes and Bunsen burner. The liquid product believed to be diesel obtained from pyrolysis of LDPE was put in a round bottom flask, clamped on a retort stand and slowly heated until the liquid boiled. The boiling point at this stage was noted to be 27 ^{o}C. The vapour coming out of the flask passed through the delivery tube to condense in a test tube placed inside cold water bath in a beaker. When the liquid stopped boiling after about 7 minutes, the intensity of the Bunsen burner flame was increased and the liquid started boiling again at temperature of 42 ^{o}C. The liquid vaporized and condensed in another test tube placed inside cold water bath in a beaker. The phenomenon continued for about five minutes before the boiling stopped. The intensity of the Bunsen burner flame remained in this position and the thermometer reading did not exceed 42 ^{o}C for 10 minutes. Then the intensity of the Bunsen burner flame was increased again and the remaining liquid in the flask was boiling. At this time, the thermometer reading was 75 ^{o}C. The vapour coming out of the flask passed through the delivery tube and condensed in another test tube placed in a beaker filled with cold water. The output liquid was found to have the same boiling point with commercial gasoline.

RESULTS AND DISCUSSION

Results presentation

The results obtained from this study on conversion of plastic wastes to gasoline are presented in this study. During test running of the equipment with crushed PET bottles, it was observed that much gas with very little liquid was produced throughout the heating time period which lasted for about two hours. The produced gas was collected in gas bag and tested to power 3.5 KVA gasoline generator with fuel gas adapter. A compact fluorescent lamp rated 20 watts which was connected to the generator lightened up throughout the running period of the generator. During the pyrolysis of LDPE, there was no product formation until the feedstock in the reactor was heated to 345 ^{o}C when gas production started. Further heating of the feedstock to 353 ^{o}C

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produced liquid substance which was assumed to be diesel. Table 1 shows the temperature variation with time during the pyrolysis of PET and LDPE.

Also, during fractional distillation, three different products labeled A, B and C (Plate 2 and Table 2) were obtained at different temperature of 27 °C, 42 °C and 75 °C with liquid yield of 7 mL, 20 mL and 40 mL, respectively. The three products obtained from fractional distillation of liquid oil obtained during pyrolysis of the LDPE waste products, were assumed to be gasoline products since the gasoline fraction of the fractional distillation of petroleum boils at temperature ranges from 25 °C to 75 °C [28].

Table 1. Temperature and Residence Times of PolyethyleneTerephthalate (PET). and Low-Density Polyethylene, (LDPE) during the Pyrolysis Process

S/No	Time (sec)	PET Temperature (°C)	PET Heating Rate (°C/sec)	LDPE Temperature (°C)	LDPE Heating Rate (°C/sec)
1	0 – 600	36.6 – 139	0.17	35.5 – 138	0.17
2	600 – 1200	139 – 247	0.18	138 – 288	0.25
3	1200 – 1800	247 – 348	0.17	288 – 355	0.11
4	1800 – 2400	348 – 408	0.1	355 – 355	0
5	2400 – 3000	408 – 421	0.02	355 – 355	0
6	3000 – 3600	421 – 433	0.02	355 – 361	0.01
7	3600 – 4200	433 – 433	0	361 – 352	-0.02
8	4200 – 4800	433 – 433	0	352 – 345	-0.01
9	4800 – 5200	433 – 488	0.09	345 – 352	0.01
10	5200 – 5800	438 – 435	0	353 – 258	-0.16

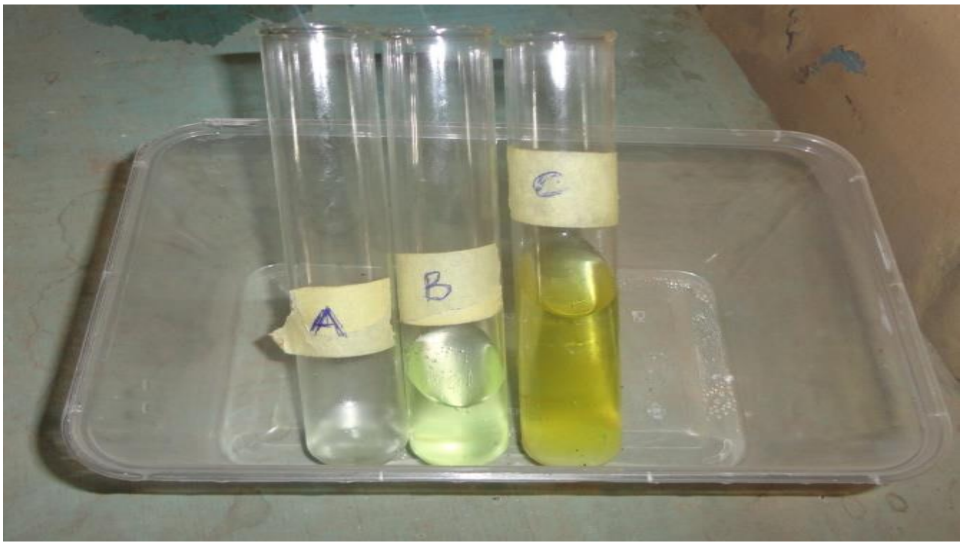

Plate 2. Products from Fractional Distillation.

Table 2. Results during Fractional Distillation Process

S / No	Quantity of Liquid (ml)	Temperature (°C)	Time to Reach Boiling Point (s)	Boiling Period (s)	Volume of Product Obtained (ml)
1	75	27	900	20	7 (Product labeled A)
2	75	42	1320	120	20 (Product labeled B)
3	75	75	1920	300	40 (Product labeled C)

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DISCUSSION OF RESULTS

Table 1 shows the data including heating period, temperature range for the heating period, as well as, the heating rate; obtained from the pyrolysis of PET and LDPE wastes. Regarding PET heating profile, the pyrolysis process began slowly with a heating rate of 0.17°C/s; the heating rate increased slightly to 0.18 °C/s, and then dropped back to 0.17 °C/s as the temperature increased to 348 °C. Later, the heating rate decreased gradually to 0.02 °C/s until there was no increase in temperature, indicating that the pyrolysis of PET had reached its maximum temperature of 433 ° C and was stable. The high amount of gas that was produced during test running of the equipment with crushed PET bottles indicates that the liquids that might have been produced had been further distilled to gaseous products. The little amount of liquid produced during pyrolysis of PET necessitated keen observation during pyrolysis of LDPE which was the major feedstock for the research work. Concerning LDPE, the heating rate increased significantly from 0.17 °C/s to 0.25 °C/s. Later, the heating rate gradually decreased until there was no change in temperature indicating that the pyrolysis process had reached its maximum temperature and was stabled.

During pyrolysis of LDPE, gas production occurred at temperature of 345 ^{o}C. The liquid production occurred 45 minutes after the temperature was reached. Under normal working conditions, the liquid production should not have taken so much time after gas production. This might be due to the inefficient heat energy being supplied due to poor air and gas mixing ratio, which determined the amount of energy and pollutants that would be released [29]. Comparison of the heating profiles of PET and LDPE indicates that PET had a slower heating rate and reached a higher maximum temperature, but its heating rate significantly diminished as time progressed while LPDE was quickly heated with a higher heating rate initially but the peak temperature of LDPE was lower and it was stabilized faster than PET. In the fractional distillation of petroleum; the boiling point, boiling time and volume for sample A were 27 °C, 20 s, and 7 ml, respectively. For sample B; the boiling point, boiling time and volume were 42 °C, 120 s, and 20 ml, respectively, while for sample C; the boiling point, boiling time and volume were 75 °C, 300 s, and 40 ml, respectively. There results obtained showed a direct relationship between temperature, boiling period, and the volume of product obtained indicating that the product volume obtained increased with temperature and boiling point.

The fractional distillation used in this study to separate liquid fuel fractions produced from the pyrolysis of low-density polyethylene (LDPE) waste, is comparable with standard gasoline production methods. While the fractional distillation setup in this study may offer a promising approach for converting plastic waste into usable fuel, it is not as refined or as comprehensive as the standard methods used in the petroleum industry. The study primarily focused on demonstrating the feasibility of converting waste into fuel, while conventional gasoline production involves more sophisticated refining techniques to ensure product quality and environmental compliance. The fractional distillation process in the study was a simplified, laboratory-scale approach to producing a fuel from plastic waste (LDPE). It provided proof of concept that plastic waste can be converted into liquid fuel with properties resembling gasoline.

Potentials and hurdles involved in waste valorisation

Regardless of the potentials that can be derived in valorisation of combustible waste to gasoline, there are challenges that need to be overcome before the process can be sustainable. The major limitation experienced during the research work was unknown ratio of air to fuel that would produce desired burning flame. This consequently led to heat energy loss, very low product output. Additionally, breakdown of the reactor occurred at every experimental run which affected the liquid production. For the successful development of a waste valorisation project in Nigeria, several key strategies must be undertaken. Waste valorisation involves the process of converting waste materials into valuable products, which can help address environmental and economic challenges. In the context of Nigeria, these strategies would need to focus on governmental support, community engagement, infrastructural improvements, and legal frameworks.

Government intervention

Government intervention is crucial for the success of any waste valorisation project. This includes the active involvement of federal, state, and local government bodies in the development and promotion of waste-to-value initiatives.The government should create a legal and regulatory framework that encourages waste valorisation. This could include setting standards for waste management, creating incentives for waste recycling businesses, and enforcing compliance with environmental regulations. Furthermore, the government can provide grants, subsidies, or low-interest loans to businesses and organizations working in waste valorisation. Public-private partnerships can also be encouraged to combine resources and expertise in the sector. Government support is needed to develop the infrastructure required for waste collection, sorting, recycling, and disposal. Government policies should be aligned to promote circular economy principles and waste minimization. Policies encouraging the reduction of waste generation, reuse, and recycling can help facilitate the transition toward a circular economy.

Awareness raising

Raising awareness about the importance and benefits of waste valorisation is essential for gaining public support and participation in waste management systems. Initiating nationwide campaigns to educate the public on the value of recycling, composting, and reducing waste could foster responsible behaviour at the community level. Educational programs targeting students and local communities can create a culture of waste management awareness from an early age. Workshops, seminars, and community events can increase participation in waste valorisation projects. Leveraging traditional media (TV, radio) and digital platforms (social media, blogs) can spread messages about sustainable waste management practices and showcase success stories of waste valorisation.

Capacity Building

Building local capacity is essential for ensuring the sustainability and scalability of waste valorisation projects in Nigeria. Specialized training programs should be developed for individuals, communities, and companies involved in waste management and recycling. This can include technical training on waste sorting, processing technologies, and health and safety procedures. The workforce needs to be equipped with relevant skills in waste management technologies, sustainable business practices, and environmental stewardship. Collaboration with academic institutions can help develop educational curriculums and certifications related to waste valorisation. Developing local expertise and technology solutions is important for reducing dependency on external experts and fostering innovation within the country. Local entrepreneurs can be encouraged to develop technologies that are tailored to Nigeria's unique waste management needs.

Development of physical and technological infrastructure

Investment in facilities like recycling plants and waste-to-energy technologies is crucial. These facilities should be strategically located in areas with high waste generation to maximize efficiency. Implementing modern technologies for waste processing, such as automated sorting systems, will help improve the efficiency and economic viability of waste valorisation. Developing and adapting low-cost, locally suitable technologies is important for affordability and accessibility. The development of economically viable business models around waste valorisation is important. This could include creating market demand for recycled products, developing supply chains for compost and organic waste, and establishing waste-to-energy systems that generate both revenue and power.

Policy formulation

Formulating clear, concise, and supportive policies is a fundamental part of encouraging waste valorisation projects in Nigeria. Government policies can offer financial incentives such as tax rebates, subsidies, and grants for businesses involved in waste valorisation. This would encourage private-sector investment in waste management technologies and services. Policy frameworks like Extended Producer Responsibility can require producers to take responsibility for the entire lifecycle of their products, including the disposal or recycling of packaging materials and other waste. This shifts the responsibility from consumers to producers. Nigeria should develop and implement policies that encourage a shift towards a circular economy, where waste is seen as a resource to be reused, recycled, or converted into valuable products. These policies should address waste reduction, recycling targets, and sustainable production methods.

Regulatory mechanism for waste valorisation

A robust regulatory mechanism is essential to ensure that waste valorisation practices are implemented effectively and that environmental and public health concerns are addressed. The regulatory body should set clear standards for the collection, sorting, processing, and disposal of waste. These standards should align with global best practices and consider Nigeria's specific needs and circumstances. A strong enforcement framework should be put in place to ensure compliance with regulations. This includes monitoring waste management activities and imposing fines or penalties for violations. Regulatory bodies can establish certification programs for businesses and facilities that meet certain standards of waste valorisation. This encourages companies to adhere to high standards of operation and quality control. Furthermore, the regulatory framework should incorporate mechanisms for public participation and transparency in decision-making processes related to waste valorisation. This can include public consultations, community engagement, and feedback mechanisms.

In summary, **f**or Nigeria to develop a successful waste valorisation project, it will require a multi-faceted approach that includes active government intervention, public education, capacity building, technological development, policy formulation, and strong regulatory frameworks. By implementing these strategies, Nigeria can transform its waste management system, reduce environmental pollution, and create economic opportunities in waste valorisation sectors like recycling, and waste-to-energy solutions. These efforts will also help advance sustainability and contribute to global climate goals.

CONCLUSION

The study established the possibility of converting combustible waste, specifically low-density polyethylene, into gasoline through pyrolysis and fractional distillation. The research showed that by heating the waste in a pyrolysis reactor, it is possible to produce liquid fuel fractions that can be separated at different temperatures. Among these, the fraction obtained at 75°C closely resembled commercial gasoline, indicating its potential use in powering electricity generators and gasoline-powered vehicles. The research provides a promising solution to the waste management challenges faced by developing countries, particularly in Nigeria, by reducing environmental waste and offering an alternative source of liquid fuel. Based on a lot of research work on pyrolysis of plastic wastes into fuels, it can be inferred that there are possibilities of using fuels derived from plastic wastes to generate electricity and power automobile. The benefits associated with conversion of plastic wastes to fuel include; reduction in greenhouse gas emission, reduction in other hazardous impact of waste accumulation on the earth, provision of alternative sources of energy, job or wealth creation and economic development. Hence potential development of this process may encourage the clean fuel processing for transport sectors.

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