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Valorization Potential of Soiled Disposable Infant Diapers into Pyrolytic Liquid Fuel

J. G. Akinbomi[*], L. Salami[*], J. A. Ututu[*], S.O. Odoziaku[*], A. Ajao[**], and O. Oladeji [**]

[*4]Department of Chemical Engineering,
Lagos State University, Epe Campus, Epe, Lagos State, Nigeria

[**]Amsol Bio Company, Lagos, Nigeria

Corresponding author:
Email: julius.akinbomi@lasu.edu.ng

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Abstract:

The non-existence of efficient waste management system for soiled disposable diapers in most developing countries has resulted in indiscriminate littering, unsanitary landfilling, burning and ocean dumping of the used diapers with consequent environmental and health impacts, including air pollution, global warming, and waterborne diseases, among others. Therefore, the objective of this study was to develop an environmental friendly pyrolysis system for the conversion of soiled diapers into liquid oil that could be used as alternate fuel for diesel engine. During the research, 5kg of disposable soiled diapers was pyrolysed at 500□C into liquid oil and the obtained oil was characterized to determine its potential as an alternate fuel for diesel engine. The physicochemical analysis conducted on the oil indicated that the diaper oil properties were favourably compared with that of the diesel oil only that the quality of the diaper oil would need some upgrading to improve its quality. The p-value, of 0.47 which showed the non-significant difference between the properties of the diaper oil and the disel oil corroborated the suitability of the diaper oil for usage as an alternative to diesel oil in diesel engines

***Keywords*:** disposable diapers, soiled material, pyrolysis, diesel oil, waste management,

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I. INTRODUCTION

The ease and convenience associated with the usage of infant disposable diapers, as well as the diapers superabsorbent ability have made the diapers unavoidable and indispensable for parents [1] . Diaper is a piece of absorbent material used to absorb and retain urine and faeces in a way to keep the wearer dry and comfortable without soiling their

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clothes or surroundings. Besides disposable diapers, there are other diapers including cloth and biodegradable diapers. Unlike disposable diapers that have high absorption quality and are discarded after one-time usage; cloth diapers are designed to be washed, dried and reused after being soiled. The usage of cloth diaper is limited by its low absorption quality which necessitates the need to frequently change and wash the diapers with scarce water resource. Biodegradable diapers, on the other hand, are designed to be easily degraded by biological agents when landfilled. The high cost of biodegradable diapers when compared to other diapers, has limited their usage. Consequently, disposable diapers are still the mostly used diapers among the three types of diapers.

According to a study [1], an average of 4 to 5 disposable diapers are used for a baby in a day with the average unused diaper weight being 0.21 kg. The diaper weight after usage is estimated to be approximately 0.4kg with the disposable soiled diaper composition consisting of 88% of human excreta and 12% of diapers material [2]. The average composition of baby disposable diapers includes cellulose pulp (35%), superabsorbent polymer (33%), polypropylene (17%), polystyrene (6%), adhesives (4%), elastics (1%) and others (4%) which could be harmful substances such as dioxins, phthalates, tributyltin and volatile organic compounds like toluene, xylene, ethylbenzene, and dipentene [3-10]. The design of disposable diaper is such that there is an absorbent pad, made of a hydrophilic polymer and a fibrous material (cellulose) that is placed between two sheets of permeable and impermeable non-woven fabric.

Huge amount of soiled disposable diapers generated on a daily basis due to increase in consumption rate has unavoidably resulted in indiscriminate open dumping, burning, unsanitary landfilling and ocean dumping of soiled diapers, which are common disposal methods in most developing countries where efficient waste management systems are often non-existent Unfortunately these common disposal methods for diapers have consequent environmental (land degradation, air and water pollution) and health hazards. For example, indiscriminate dumping of diapers soiled with urine and faeces could contaminate nearby water sources through leaching process causing water borne diseases [11]. Since disposable diapers are non-biodegradable in nature, landfilling disposable soiled diapers will make the urine and faeces in the diapers to stay for a long period without degradation. This could cause breed pathogenic organisms that could spread diseases. Burning of diapers openly could result in the emission of hazardous pollutants including dioxins, furans, carbon monoxide hydrogen chloride, hydrogen fluoride, among others. Ocean dumping of diapers can cause flooding, eutrophication and biodiversity loss. Over the years, various techniques have been developed for the disposal of non-biodegradable

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wastes like diapers, among which are incineration, gasification, pyrolysis and microbial biodegradation. Application of pyrolysis for the disposal of soiled diapers has many benefits, including effective disposal of the diapers with minimal environmental pollution, as well as, converting the diapers into valuable products such as gas and liquid fuels, petrochemicals and activated carbon, among others [12-14].

There are few case studies on safe management and conversion of used diapers using various technologies including landfilling, biodegradation by microorganisms [15], pyrolysis[16] and composting, incineration and recycling[17-19]. Oh and Shinogi [20] studied the pyrolysis process of used diapers at a temperature ranging from 300 to 900□C and observed that up to 62 wt% yield of solid product could be produced by this process. As the pyrolytic temperature increased the diapers were transformed into bio-char containing coarse and heterogeneous pores. The porous structure of the bio-char enabled it to function as an adsorbent for removal of soil contaminants. According to Matsakas et al. [21] the pyrolytic liquid from the condensation of the volatiles can be developed into a fuel, referred to as pyro-oil, after upgrading and/or as an intermediate for the synthesis of fine chemicals. Consequently, this implies that as a supplemental advantage, volatile matter can be extracted from disposable diapers after use. The high volatile matter and total carbon contents of diapers indicates the diapers suitability for energy and material recovery through pyrolysis, as well as, the diapers potential danger for toxic pollutant emissions if dumped in unsanitary landfills [22-25].

The proximate and ultimate analyses conducted on seven most common disposable diaper brands including Best Baby, Huggies, My Kids, Pampers, SR7, Sun Face and Sweet Baby; showed that the proximate analysis for the average contents of volatile matter, fixed carbon and ash for the interior part of the diapers were 68.07, 11.14 and 9.70, respectively, while the average volatile matter, fixed carbon and ash contents for the exterior part of the diapers were 85.90, 7.12 and 6.08, respectively. Regarding the ultimate analysis, the results showed that the average contents of total carbon and hydrogen for the interior part of the diapers were 39.92 and 5.77, respectively, while for the average contents of total carbon and hydrogen for the exterior part of the diapers were70.79 and 10.56, respectively.[22]. The results indicated that diapers have high volatile matter and total carbon which could be converted to energy through pyrolysis or gasification process. On the other hand, if soiled diapers are indiscriminately land filled, the high volatile content of the diapers could be easily leached to the nearby water sources causing environmental and health challenges. Furthermore, among the seven diapers studied, Pampers disposable diaper brand has the highest carbon percentage of 54.12 and 78.29% for both interior

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and exterior fractions, respectively. It was also observed that Pampers disposable diaper brand has the highest volatile matter of 94.57 wt. %.

This pointed to the fact that Pampers disposable diapers have the potential to be converted to fuel for industrial and household applications. The nature and composition of Pampers disposable diapers make pyrolysis one of the effective technologies that could be used in the disposal and recovery of resources including fuel oil from soiled diapers,

As a consequence of the above findings coupled with the fact that Pampers disposable diaper brand is the most common diaper in Nigeria but there is scarcely any effective pilot scale pyrolysis plant dedicated for the conversion of used diapers into fuel oil in Nigeria; this study therefore examined the potential for the conversion of soiled Pampers disposable diapers into alternate fuel for diesel engine using a pilot scale pyrolysis plant with the goal of commercializing the process in the future. The scope of the study was limited to the setting up of the gas fired pyrolysis plant, collection of the disposable soiled infant diapers, pyrolysis of the diapers into fuel oil, as well as, the measurement and analysis of the physicochemical parameters of the fuel oil to determine its potential as substitute for diesel oil Commercialisation of this research study has the potential of contributing to environmental sustainability, besides the valourization of the soiled diapers into diesel oil .

2. MATERIALS AND METHODS

The research was aimed at investigating the potential of using pyrolytic liquid oil from soiled diapers as alternate fuel for diesel engine. The pyrolytic liquid oil obtained from 5kg of soiled diapers was characterized and its physicochemical qualtues were compared with liquid oils obtained from separate pyrolysis of discarded rubber tyres, pure water nylon sachet wastes (low density polyethylene), and plastic bottle wastes obtained under the same design and operating conditions that were used for diapers pyrolysis.

2.1. Experimental Materials

The pyrolysis system (Figure 1) comprised of gas-fired furnace, pyrolysis reactor, heavy oil condenser, two cyclones for light oil condensation, scrubber for gas cleaning, and gas storage bag. The pyrolysis reactor was a cylindrical steel vessel with thickness, internal diameter and capacity of 12 mm, 250 mm, and 25 kg of shredded polymer, respectively. The reactor vessel was closed with two pairs of flanges (top and bottom). There was a hole at the center of the reactor vessel which served as the gas exit. The gas-fired furnace was made in such a way that it would provide uniform heat to the pyrolysis reactor. Solar-power temperature sensor (Figure 2) was inserted in the reactor vessel to measure the temperature in the pyrolysis reactor. Regarding the feedstock, soiled children diapers were the only raw material used for the pyrolysis process during the

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research work. The soiled diapers were collected from different households in Sagamu local government area of Ogun State, Nigeria.. Chemical balance, measuring cylinder, and stop clock were also used during the pyrolysis experiment for measuring feedstock weight, cooling water volume, and progressing reaction time, respectively. Empty containers were also prepared for the collection of condensed liquid oil and char.

1.2. Experimental Procedure

The main reactor containing 5 kg of soiled children diapers was placed inside liquefied petroleum (LPG) gas-fired furnace for batch pyrolysis process. Before starting the pyrolysis process, Between 20 and 30 litres of clean water were measured into each of the two cyclones used for light oil condensation. The soiled diapers was pyrolyzed at a temperature range of 500 □C and the non-condensable gas collected was stored in a gas storage bag (Figure 3) while the condensable liquid oil which was 2 litres was collected in a separate container. The collected oil was sent for physicochemical analysis at a company (Master Control Service Ltd., Dopemu, Agege, Lagos State). At the end of the pyrolysis experiment, the furnace was left to cool down to room temperature (25 □C) before the char left in the reactor vessel was removed.

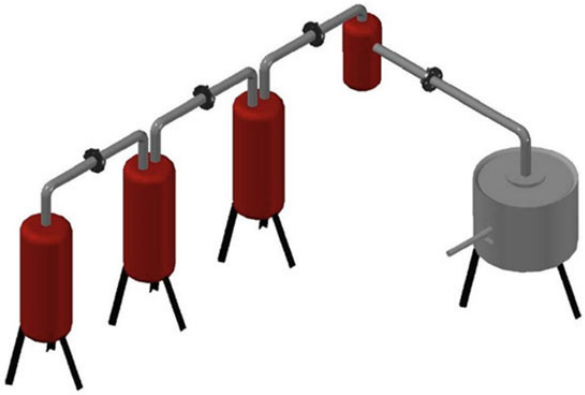

Figure 1: Pyrolysis system setup

Figure 2: Gas-fired furnace with attached solar-powered temperature sensor

Figure 3 A gas storage bag filled with non-condensable pyrolysis gas

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3. RESULTS AND DISCUSSION

The properties of the pyrolytic diaper oil obtained from the physicochemical analysis were compared with the standard diesel oil from crude oil, as well as, pyrolytic oils from other polymeric wastes including rubber tyre, plastic and pure water sachet wastes (Table 1). The same pyrolysis system used for producing liquid oil from soiled diapers was used for producing liquid oils from the polymeric wastes. Table 1 showed that the liquid oil produced from the soiled diapers had higher values of density, kinematic viscosity, sulfur content, centane number and pour point; than the respective values of the standard diesel oil. Only flash point and gross calorific values of the diaper oil were lower than the respective values of the standard diesel oil. The higher density of the diaper oil implies that more mass of the diaper oil will be required for the same volume of the standard diesel oil if used for a diesel engine. For the kinematic viscosity of the diaper oil which is a little bit higher than the standard diesel oil, there is tendency for the diaper oil to result in a heavier mist of fuel that can cause hard starting and smoke issues. The sulphur content of the diaper oil is also higher than that of the standard diesel oil indicating that there will be tendency for increased wear on engine components including pistons, valves and rings, among others;; when diaper oil is used in diesel engine. The high sulphur content of the diaper oil could reduce the catalytic conversion capacity of a diesel engine that could cause the emission of gaseous pollutants. Regarding the higher centane number of the diaper oil when compared with standard diesel oil; it indicates that the ignition quality of the diaper oil is higher and that it has shorter lag time than that of the diesel oil. The diaper oil also has a pour point higher than that of the standard diesel oil which indicates that during cold weather, the diaper oil will cease to flow at a higher temperature than the temperature at which the standard diesel oil will cease to flow. Consequently, the diaper oil may not be suitable for very low temperature applications.

The flash point value of the diaper oil is lower than the standard diesel oil which indicates that the risk of explosion is higher when diaper oil used as an alternative to standard diesel oil. The low flash point of diaper oil shows that there are highly volatile substances in the diaper oil and that adequate safety measures must be put in place when handling diaper oil. Table 1 also shows that gross calorific value of the diaper oil is less than the standard diesel oil indicating that more fuel will be consumed using diaper oil than standard diesel oil to do the same amount of work. The results of the physicochemical analysis of the diaper oils show that the diaper oil needs to be upgraded to improve on some of the diaper oil properties such as the density, sulphur content, gross calorific value, pour point and possibly

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kinematic viscosity. The upgrading of the diaper oil will make it suitable as an alternative to diesel oil for usage in diesel engines. The potential for the diaper oil to be used as an alternative to diesel oil is corroborated by the obtained p-value (0.47) of the difference between the properties of the standard diesel oil and the diaper oil. The p-value, which was obtained using the Minitab 17 paired t-test, showed that there was no statistical significant difference between the properties of the diaper oil and the standard diesel oil since the p-value was greater than the α-level = 0.05. The quality of the diaper oil only needs slight improvement to make it suitable for usage in diesel engines. For other pyrolyic oils obtained from rubber tyre, water nylon sachet and plastic bottle wastes, using the same pyrolysis system; their p-values also indicate that there were no significant differences between their properties and that of diesel oil except that the qualities of the oils obtained need to be upgraded to make them suitable as alternatives to diesel oil. in general, the properties of the diaper oil compared favourably with that of the diesel oil.

4. CONCLUSION

The study has demonstrated the potential for conversion of soiled disposable diapers into pyrolytic liquid oil that can be used as substitute for diesel oil. The results of the physicochemical analysis showed that the quality of pyrolytic diaper oil would need some upgrading for it to be suitable for usage as an alternative to diesel oil. The statistical analysis on the properties of the diaper oil in comparison to that of the diesel oil confirmed the suitability of the diaper oil as an alternative to diesel oil since there was no significant difference between their properties. Hence, pyrolysis of soiled disposable diaper is a waste management technique that has twin benefits of effective disposal of diaper wastes, as well as, converting the diaper wastes into valuable product such as an alternative oil for diesel engines.

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Table 1: Properties of pyrolitic liquid oil from soiled diapers in comparison with standard disel oil, as well as, pyrolytic liquid oils from plastic bottle, rubber tyre and pure water nylon sachet wastes

S/N	Liquid oil properties	Unit	Diesel oil from crude oil [26-31] (Standard Limits)	Pyrolytic oil from soiled diapers (this study)	Pyrolytic oil from rubber tyre waste [32]	Pyrolytic oil from pure water nylon sachet wastes (on-going project)	Pyrolytic oil from plastic bottle wastes (on-going project)
1	Density at 20□C	Kg/m^3	806 – 855	925	936	787	785
2	Kinematic viscosity at 40□C	nm^2/sec	1.6 – 5.5	5.63	3.6	1.98	5.76
3	Flash point	□C	≥ 55 □C	34	52	15	43
4	Sulfur content	%	≤ 0.05	0.714	0.904	0.238	0.026
5	Gross calorific value	MJ/kg	≥ 45.15	36.43	43.22	41.23	37.46
6	Centane number		≥ 40.0	43	45	-	47
7	Pour point	□C	- 13	-6	-	-13	-5
8	P-value in comparison to standard diesel oil			0.47	0.36	0.14	0.37

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