

Conversion of End-of-Life Latex Gloves as Chemical Feedstock for the Production of Diesel Range Liquid Fuel*

E. A. Arthur¹, G. Mensah-Sackey², S. N., Baisi Ebo¹, I. J. Cobbinah¹, J. Dankwah^{1,3}, E. Abotar¹ and J. R. Dankwah¹

¹University of Mines and Technology (UMaT), Tarkwa, Ghana

²Egypt Japan University of Science and Technology (EJUST), Alexandria, Egypt

³Goldfields Ghana Limited (Damang Mine), Tarkwa, Ghana

Arthur, E. A., Mensah-Sackey, G., Baisi Ebo, S. N., Cobbinah, I. J., Dankwah, J., Abotar, E. and Dankwah, J. R., (2023), Conversion of End-of-Life Latex Gloves as Chemical Feedstock for the Production of Diesel Range Liquid Fuel", *Ghana Journal of Technology*, Vol. 7, No. 1, pp. 53 – 61.

Abstract

Globally, over 780 billion plastics are used and discarded annually, with no proven avenues for value recovery from this category of the waste stream. This research work investigated the potential for generating diesel range liquid fuel from end-of-life laboratory examination latex gloves (LGs) using a charred palm kernel shell fired reactor-blower assembly in the temperature range 350 °C – 550 °C. Samples of LGs were collected from the Minerals Engineering Laboratory of the University of Mines and Technology (UMaT), Tarkwa and were dried in the open without shredding. Samples of the non-shredded LGs weighing approximately 4.0 kg were fed from the top of a stainless steel reactor and pyrolysed for 1hr 40 min at a heating rate of 40 °C/min. The gas leaving the reactor was then condensed in a plastic container, weighed and characterised by FT-IR and GC-MS. The results indicate that samples of diesel range liquid fuel (density 0.858 g/cm³) can be produced from LGs with a yield in the range of 0.40-0.78 litres/kg of pyrolysed material. Results from FT-IR and GC-MS analysis showed that the liquid fuel consists primarily of aromatic hydrocarbons (alkyl benzenes), aliphatic hydrocarbons and minor amounts of naphthenes. Analysis of the solid by-product revealed partly carbonaceous material (~36.58 wt.% C) that could burn to yield an ash rich in CaO, ZnO and TiO₂. It was concluded that liquid fuel production by pyrolysis could offer a benign route for the sustainable disposal of hazardous end-of-life laboratory examination gloves.

Keywords: Latex Gloves, Pyrolysis, Liquid Fuel, Char, GC-MS Analysis, FT-IR Analysis, SEM-EDS Analysis

1 Introduction

Waste polymers disposal is a weighty environmental matter since polymeric materials do not decompose easily. Large amounts of natural rubber are used as latex gloves. Almost the whole amount of rubber from the used latex glove is discarded which will require a very long time for natural decomposition due to crosslinked structure of rubbers and presence of stabilizers and other additives (Ahmad *et al.*, 2016).

In the mining industry, latex gloves are used at the metallurgical laboratory, assay laboratory, CIL laboratory and at the milling section when handling the solid samples or slurry. However, after use the end-of-life latex gloves are chiefly disposed by burning.

Addressing threats posed by plastics wastes, hopefully some measures are in place while others have been proposed, which include mechanical recycling, landfilling, incineration and lately the call for the acceptance of biodegradable plastics. Major challenges related to each of these measures have been outlined by some researchers (Uddin *et al.*, 1997; Panda *et al.*, 2010; Stoler *et al.*, 2012; Cleetus *et al.*, 2013).

However, a thermal approach for recycling waste polymers which is presently gaining the attention of researchers is pyrolysis.

The pyrolysis method disintegrates long chain polymers into smaller but useful molecular weight compounds that can be harnessed as fuels or chemicals in a variety of ways. The process of pyrolysis can be catalytic or solely thermal. A number of researchers have investigated the conversion of different forms of waste plastics into liquid fuels (Songip *et al.*, 1993; Uddin *et al.*, 1997; Manos *et al.*, 2000; Akpanudoh *et al.*, 2005; Gulab *et al.*, 2010; Jan *et al.*, 2010; Panda *et al.*, 2010; Cleetus *et al.*, 2013).

One of the procedures employed thermally to recover energy and some fundamental materials including oil and carbon black from waste rubber is pyrolysis. Pyrolysis technically involves all manners of heat disintegration (Abraham *et al.*, 2011).

Pyrolysis is a conversion process, which means thermal decomposition at different high temperatures in an environment free of oxygen or non-reactive environment. This yields liquid products, char, volatiles and gases from waste rubbers or polymeric articles (Abraham *et al.*, 2011; O'Hara, 1981).

End-of-life plastics pyrolysis is a gateway to the processing of end-of-life laboratory examination latex gloves (LGs) as feedstock for the production of liquid fuel (Rowhani *et al.*, 2016; Ishola *et al.*, 2018).

Accordingly, in this investigation, we report preliminary results on the production of liquid fuels from LG using a self-designed pyrolysis reactor.

2 Resources and Methods Used

2.1 Materials

Feedstock (Fig. 1) used for the investigation was LGs collected from the Minerals Engineering Laboratory of the University of Mines and Technology (UMaT), Tarkwa. Samples of the non-shredded LGs were dried and about 4 kg was used for four sets of pyrolysis runs and the average outcome determined.



Fig. 1 Samples of LGs utilised for the Investigation

2.2 Methods

The experimental setup consisted of a heating assembly (charred palm kernel shell fired furnace), self-designed pyrolysis reactor (Fig. 2), condensers A and B kept at 42 °C and 30 °C respectively, and a collecting plastic container. Condenser A was a coiled copper tube and condenser B was water in the plastic container. Samples of end-of-life latex gloves were fed from the top of the reactor for pyrolysis.



Fig. 2 Experimental Reactor used for the Investigation

2.2.1 Thermal Degradation (Non-Catalytic Pyrolysis)

The experiment was performed without catalyst. Non-shredded end-of-life latex gloves (4 kg) were fed into the reactor and the experiment was carried out at a maximum temperature of about 550 °C, measured by a BENETECH GM900 Infrared Thermometer (Fig. 3).



Fig. 3 BENETECH GM900 Infrared Thermometer used for Temperature Measurements in this Investigation

The steps involved in the non-catalytic pyrolysis of LGs are shown in Fig. 4.

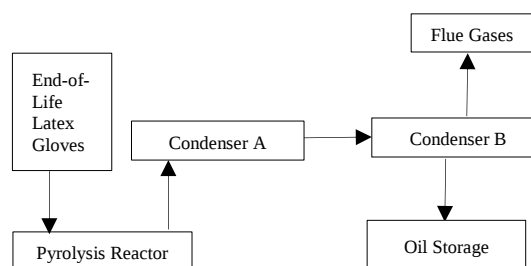


Fig. 4 Reaction Scheme for the Non-Catalytic Pyrolysis of End-of-Life Latex Gloves

During the non-catalytic process, the non-shredded LGs first melted and then turned into liquid slurry whiles creating a hot gaseous mixture of hydrocarbons. The hot gaseous mixture from the reactor then evolved through a primary condenser (copper coil); a high pressure gas hose linked an HDPE plastic container with water, which served as secondary condenser to the hot hydrocarbon gas mixture. The liquid fuel obtained from the condensed hydrocarbon gas mixture settled on top of the water and was separated using a separating funnel.

2.3 Yield of the Fuel Production Process

The yield of the process (L/kg) was calculated from the volume of clean filtered fuel per weight of latex gloves pyrolysed as shown in equation (1):

$$\text{Yield} = \frac{\text{Volume of fuel (L)}}{\text{Weight of latex gloves pyrolysed (kg)}} \quad (1)$$

2.4 Characterisation of Liquid Fuel, Tar and Char Residue Produced

The liquid fuel produced, tar and char residue from the pyrolysis of the end-of-life laboratory latex gloves were characterised by FT-IR to help identify various functional groups present to determine whether the liquid fuel produced mimics a diesel fuel. The liquid fuel was also characterised by GC-MS analysis to detect the various polymers present. The char was further analysed using SEM/EDS to detect the various elements present.

3 Results and Discussion

3.1 Results of Thermal Degradation (Non-Catalytic Pyrolysis)

Gas emission commenced after about 30 seconds of heating. This gas upon testing with naked fire was flammable, indicating shorter range hydrocarbon gases ($C_1 - C_5$) which could not be condensed at the temperatures of the condensers. Gas coming out after the melting of the end-of-life latex gloves was condensed primarily in condenser A. Oil started flowing from condenser A to B after about 1 minute of heating. This continued until about 1 hour 40 minutes where bubbling in condenser B ceased and no oil flowed from condenser A. The oil was later collected and stored in plastic containers (Fig. 5).



Fig. 5 Samples of Liquid Fuel obtained from the Pyrolysis of End-of-Life Laboratory Gloves

A dark-brown fluid-like residue (Fig. 6) remained, which solidified (Fig. 7) after the temperature in the reactor dropped to room temperature.



Fig. 6 Tar Residue after Non-Catalytic Pyrolysis



Fig. 7 Char obtained from solidified tar after Non-Catalytic Pyrolysis

3.2 Characterisation of Pyrolytic Products Produced from End-of-life Laboratory Gloves

3.2.1 GC-MS Analysis of Liquid Fuel Produced from End-of-life Laboratory Gloves

The oil produced from the pyrolysis of the end-of-life laboratory gloves was subjected to GC-MS to determine the chemical composition and the spectrum is shown in Fig. 8 while the compounds list is shown in Table 1.

According to the analysis, the pyrolytic oil from the latex gloves consisted of about 61 compounds detected by the GC-MS. The 61 selected compounds had peak areas about or higher than 0.1% as shown by the GC-MS spectrum in Fig. 8.

The result revealed the oil as a mixture of $C_8 - C_{59}$ with the highest from C_8 to C_{15} , identified as aliphatics and aromatic compounds. The constituent with the most elevated peak area was an olefin, limonene ($C_{10}H_{16}$). After limonene, aromatic compounds such as benzene, naphthalene, indene, xylene and beta-Chamigrene were the other commonly seen components. The result suggests a higher proportion of aliphatics in the pyrolytic fuel to a relatively lower level of aromatic hydrocarbons.

3.2.2 FT-IR Analysis of Liquid Fuel Produced from End-of-life Laboratory Latex Gloves

Fourier Transform Infrared spectroscopy (FT-IR) was carried out to determine the various characteristic functional groups present in the oil. The results of analysis of the liquid fuel produced from the end-of-life laboratory gloves are shown in Fig. 9 and Table 2

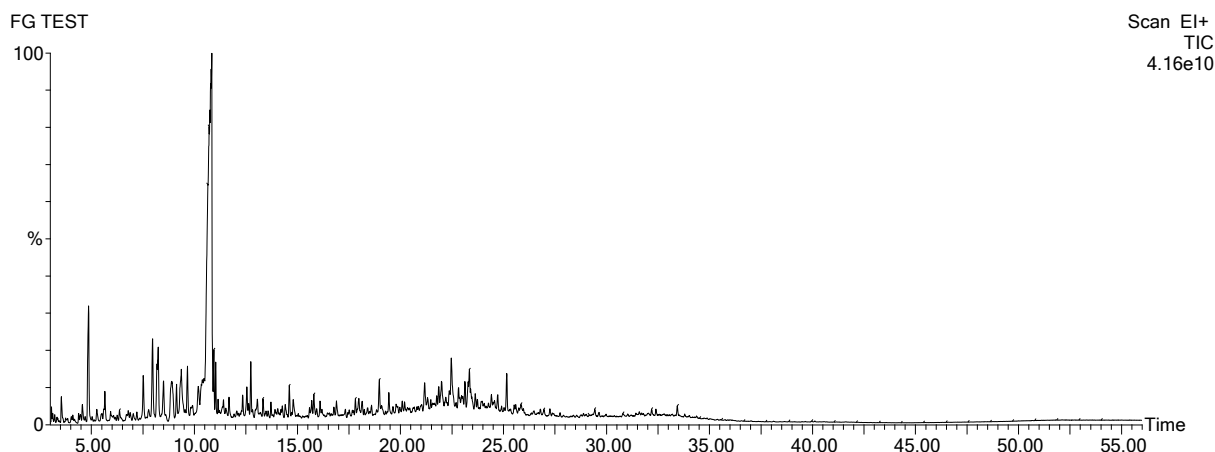


Fig. 8 GC-MS Analysis of Liquid Fuel obtained from Pyrolysis of End-of life Laboratory Gloves

Table 1 GC-MS Compound List of Liquid Fuel obtained from Pyrolysis of End-of life Laboratory Gloves

Retention Time (min)	Compound Name	Molecular Formula	Retention Time (min)	Compound Name	Molecular Formula
3.539	Cyclohexene, 3,5-dimethyl	C ₈ H ₁₄	21.552	Benzo[b]thiophene, 2,7-dimethyl-	C ₁₀ H ₁₀ S
4.559	Ethylbenzene	C ₈ H ₁₀	21.752	Oct-3-ene-1,5-diyne,3-t-butyl-7,7-dimethyl-	C ₁₄ H ₂₀
4.859	p-Xylene	C ₈ H ₁₀	21.862	6,8-Nonadien-2-one, 6-methyl-5-(1-methylethylidene)-	C ₁₃ H ₂₀ O
5.259	Cyclohexene, 3-(2-propenyl)-	C ₉ H ₁₄	21.982	Naphthalene, 1,7-dimethyl-	C ₁₂ H ₈ O ₂
5.649	Benzene, 1,3-dimethyl	C ₈ H ₁₀	22.192	2,6,10,10-tetramethylbicyclo[7.2.0]undeca-2,6-diene	C ₁₅ H ₂₄
7.509	1,3,6-heptatriene, 2,5,6-trimethyl-	C ₁₀ H ₁₆	22.362	Naphthalene, 1,7-dimethyl-	C ₁₂ H ₈ O ₂
7.969	Limonene	C ₁₀ H ₁₆	22.462	Naphthalene, 1,7-dimethyl-	C ₁₂ H ₈ O ₂
8.239	Benzene, 1,2,3-trimethyl	C ₉ H ₁₂	22.702	c-HIMACHALENE	C ₁₅ H ₂₄
8.499	1,3,6-heptatriene, 2,5,6-trimethyl-	C ₁₀ H ₁₆	22.822	1,5,9-Decatriene, 2,3,5,8-tetramethyl-	C ₁₄ H ₂₄
8.900	1,5,5-Trimethyl-6-methylene-cyclohexene	C ₁₀ H ₁₆	22.962	Naphthalene, 1,2,3,4-tetrahydro-2,5,8-trimethyl-	C ₁₃ H ₁₈
9.130	2,6-Octadiene, 2,6-dimethyl	C ₁₀ H ₁₈	23.122	Caryophyllene	C ₁₅ H ₂₄
9.360	Benzene, 1,2,3-trimethyl	C ₉ H ₁₂	23.342	Spiro[5.5]undec-2-ene, 3,7,7-trimethyl-11-methylene-,(-)-	C ₁₅ H ₂₄
9.660	2,6-Octadiene, 2,6-dimethyl	C ₁₀ H ₁₈	23.622	c-HIMACHALENE	C ₁₅ H ₂₄
9.900	1,6-Dimethylhepta-1,3,5-triene	C ₉ H ₁₄	23.722	6-(3-isopropenylcycloprop-1-enyl)-6-methylhept-3-en-2-one	C ₁₄ H ₂₀ O
10.180	Camphene	C ₁₀ H ₁₆	23.972	Naphthalene, 2-ethenyl-	C ₁₂ H ₁₀
10.840	Limonene	C ₁₀ H ₁₆	24.063	Succinic acid,dec-2-yl dodec-9-yn-1-yl ester	C ₂₆ H ₄₆ O ₄
10.940	Camphene	C ₁₀ H ₁₆	24.263	Naphthalene, 1,4-dihydro-2,5,8-trimethyl-	C ₁₃ H ₁₆
11.030	Camphene	C ₁₀ H ₁₆	24.413	Tetradecahydro-1-methylphenanthrene	C ₁₅ H ₁₂
11.410	Benzene, 1-methyl-3-propyl-	C ₁₀ H ₁₄	24.563	Guaia-1(10),11-diene	C ₁₅ H ₂₄
11.670	Benzene, 1-ethyl-3,5-dimethyl-	C ₁₀ H ₁₄	24.723	Caparratriene	C ₁₅ H ₂₆
12.340	Benzene, 1-ethyl-2, 4-dimethyl	C ₁₀ H ₁₄	25.153	Naphthalene 1,6,7-trimethyl-	C ₁₃ H ₁₄
12.540	1,3,8-p-menthatriene	C ₁₀ H ₁₄	25.843	Columbin	C ₂₀ H ₂₂ O ₆
12.730	Benzene,1-methyl-4-(1-methylethenyl)-	C ₁₀ H ₁₂	29.424	1,4,5,8-Tetramethylnaphthalene	C ₁₄ H ₁₆
13.050	Benzene,1-methyl-4(2-methylpropyl)-	C ₁₁ H ₁₆	30.794	phenanthrene	C ₁₄ H ₁₀
13.320	Benezene, (1,1-dimethylpropyl)-	C ₁₁ H ₁₆	31.594	Caryophyllene	C ₁₅ H ₂₄
14.401	1,3-cyclohexadiene, 1,3,5,5-tetramethyl-	C ₁₀ H ₁₆	32.024	2,3-Dimethoxy-5-methyl-6-dekaioprenyl-chinon	C ₅₉ H ₉₀ O ₄
14.601	Benzene, 1-methyl-4-(1-propynyl)-	C ₁₀ H ₁₀	32.184	trans-Geranylgeraniol	C ₂₀ H ₃₄ O
19.432	Naphthalene, 2-methyl-	C ₁₁ H ₁₀	32.394	trans-Geranylgeraniol	C ₂₀ H ₃₄ O
19.782	Caryophyllene	C ₁₅ H ₂₄	32.784	trans-Geranylgeraniol	C ₂₀ H ₃₄ O
21.172	1,1,3-trimethyl-1H-Indene	C ₁₂ H ₁₄	33.434	c-Elementene	C ₁₅ H ₂₄
21.312	1,1,3-trimethyl-1H-Indene	C ₁₂ H ₁₄			

Fig. 9 is the FT-IR spectrum of the liquid fuel obtained from the experiment revealing peaks which are in correlation with functional groups shown in Table 2.

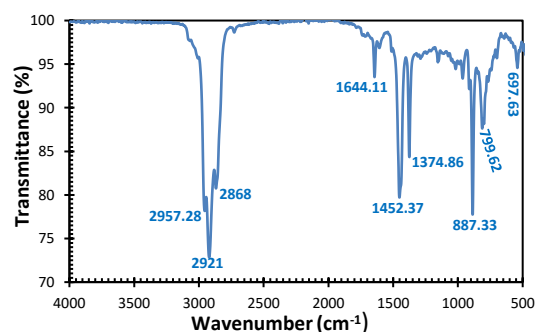


Fig. 9 FT-IR Spectra of Liquid Fuel Produced from Latex Gloves

Table 2 shows the frequencies with the related bonds and functional groups in the liquid fuel derived from the end-of-life latex gloves pyrolysis.

Table 2 Major Absorption Peaks and Assigned Configurations in the FT-IR Spectra of the Liquid Fraction Derived from Latex Gloves

Frequency (cm ⁻¹)	Bonds	Functional Group
2957.28	C-H stretch	Alkanes
2921	C-H stretch	Alkanes
2868	C-H stretch	Alkanes
1644.11	-C=C- stretch	Alkenes
1452.37	C-H bend	Alkanes
1374.86	C-H rock	Alkanes
887.33	C-H "oop"	Aromatics
799.62	C-H "oop"	Aromatics
697.63	C-H "oop"	Aromatics

According to Fig. 9, a weak peak at 2957.28 cm⁻¹ and 2868 cm⁻¹ combine with very prominent peaks at wavenumber 2921 cm⁻¹ corresponding characteristically to C-H stretch in alkanes of diesel fuel in Table 2. The next four peaks at wavenumbers 1644.11, 1452.37, 1374.86, 887.33 cm⁻¹ (in Fig. 9) correspond to -C=C- stretch of alkenes, C-H bend in alkanes, C-H rock in alkanes and C-H "oop" in aromatics respectively in Table 2. Peaks with wavenumbers 799.62 cm⁻¹ and 697.63 cm⁻¹ also correspond to C-H "oop" in aromatics. The high presence of alkanes proves the predominance of aliphatics in the liquid fuel.

3.2.3 FT-IR Analysis of Tar Produced from End-of-life Laboratory Gloves

Fig. 10 is the FT-IR spectrum of the tar residue obtained from the experiment revealing peaks which are in correlation with functional groups shown in Table 3.

The peaks from the graph shown in Fig. 10 correlate with alkanes and aromatics in the infrared absorption spectrum.

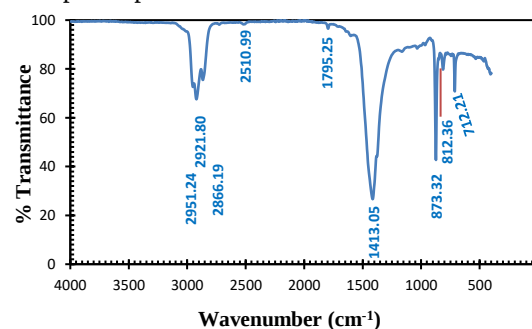


Fig. 10 FT-IR Spectrum of Tar Residue after Non-Catalytic Pyrolysis

Table 3 shows the frequencies with the related bonds and functional groups in the tar derived from the end-of-life latex gloves pyrolysis.

Table 3 Major Absorption Peaks and Assigned Configurations in the FT-IR Spectra of the Tar Derived from Latex Gloves

Frequency (cm ⁻¹)	Bonds	Functional group
2951.24	C-H stretch	alkanes
2921.80	C-H stretch	alkanes
2866.19	C-H stretch	alkanes
1413.05	C-C stretch (in-ring)	aromatics
873.32	C-H "oop"	aromatics
812.36	C-H "oop"	aromatics
712.21	C-H "oop"	aromatics

In Fig. 10, weak peaks at 2951.24 cm⁻¹ and 2866.19 cm⁻¹ combine with a moderate peak at wavenumber 2921.80 cm⁻¹ corresponding characteristically to C-H stretch in alkanes in Table 3.

The next peak at wavenumber 1413.05 cm⁻¹ in Fig. 10 is very strong and conforms to C-C stretch (in-ring) in aromatics. The next three peaks at 873.32, 812.36 and 712.21 cm⁻¹ also correspond to C-C stretch (in-ring) in aromatics as shown in Table 3. The result suggests that the tar is predominantly composed of aromatic hydrocarbons.

3.2.4 FT-IR Analysis of Char Produced from End-of-life Laboratory Gloves

Fig. 11 is the FT-IR spectrum of the char obtained from the experiment revealing peaks which are in correlation with functional groups shown in Table 4.

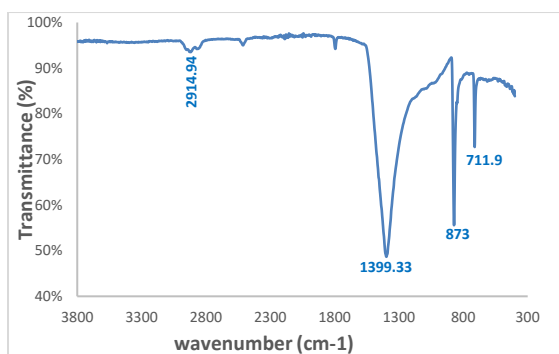


Fig. 11 FT-IR Spectrum of Char after Non-Catalytic Pyrolysis

Table 4 shows the frequencies with the related bonds and functional groups in the char derived from the end-of-life latex gloves pyrolysis.

Table 4 Major Absorption Peaks and Assigned Configurations in the FT-IR Spectra of the Char Derived from Latex Gloves

Frequency (cm ⁻¹)	Bonds	Functional group
2914.94	C-H stretch	alkanes
1399.33	C-C stretch (in-ring)	aromatics
873	C-H "oop"	aromatics
711.9	C-H "oop"	aromatics

According to Fig. 11 and Table 4, FT-IR analysis carried out on the char produced from the experiment revealed that it is predominantly made of aromatics. There is a weak peak at 2914.94 cm⁻¹ which correlate with alkanes and strong peaks at 1399.33 cm⁻¹, 873 cm⁻¹ and 711.9 cm⁻¹ as shown in Fig. 11 which correlate with aromatics in the infrared absorption spectrum. The result suggests a far stronger concentration of aromatics in the char.

3.2.5 SEM-EDS Analysis of Char

SEM-EDS analysis conducted on the latex glove char showed that there is uneven intrinsic particle size distribution. There are areas of coarse sizes as well as areas of smaller sizes. Particles shapes also differ across portions of the char as shown in Fig. 12.

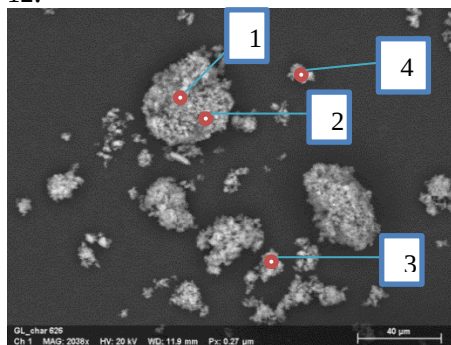


Fig. 12 SEM of Char (2038X)

The EDS analysis at point 1 of the SEM scan of the latex gloves char detected strong peaks of elements such as calcium, carbon, oxygen and weak peaks of sulphur, zinc, sodium, magnesium and titanium in the spectrum shown in Fig. 13.

The most abundant element present at point 1 of the latex gloves char by the SEM-EDS was oxygen with a percentage abundance of 48.11%. This was followed by carbon, calcium, titanium, zinc and sodium with 27.86%, 14.66%, 4%, 2.96%, and 1.2% respectively.

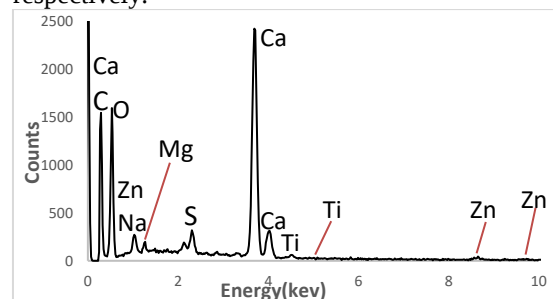


Fig. 13 SEM-EDS Spectrum of Point 1

The SEM-EDS analysis at point 2 detected elements such as calcium with the strongest peak, followed by carbon, oxygen, sulphur, zinc, sodium and titanium in the spectrum shown in Fig. 14.

The most abundant element at point 2 in the latex glove char was carbon with a percentage abundance of 42.33. This was followed by oxygen recording 31.97%, calcium, zinc, sodium, sulphur and titanium with 14.45%, 6.68%, 1.76%, 1.45% and 1.34% respectively.

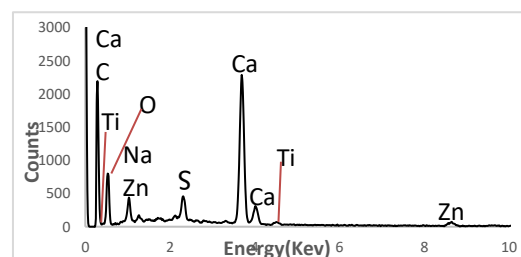


Fig. 14 SEM-EDS Spectrum of Point 2

The SEM-EDS analysis at point 3 detected strong peaks of elements such as calcium, carbon, oxygen and weak peaks of zinc, sodium and magnesium in the spectrum shown in Fig. 15.

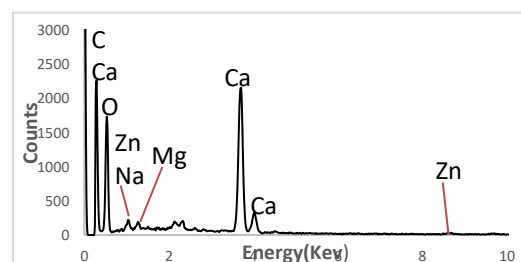


Fig. 15 SEM-EDS Spectrum of Point 3

The most abundant element at point 3 in the end-of-life latex glove char was oxygen with a percentage abundance of 48.41. This was followed by carbon recording 34.10%, calcium, zinc, sodium and magnesium with 13.77%, 1.98%, 1.08% and 0.67% respectively.

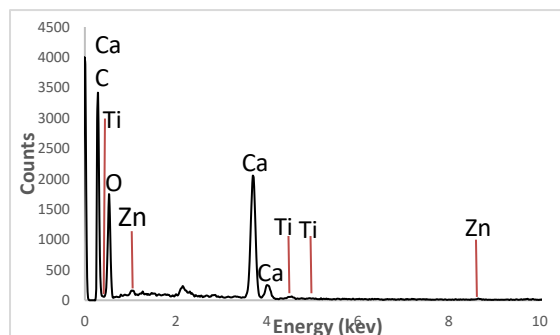


Fig. 16 SEM-EDS Spectrum of Point 4

The SEM-EDS analysis at point 4 detected strong peaks of elements such as calcium, carbon, oxygen and weak peaks of zinc and titanium according to the spectrum shown in Fig. 16.

The most abundant element present in the latex glove char at point 4 was oxygen with a percentage abundance of 43.93%. This was followed by carbon recording 42.03%, calcium, zinc and titanium with 12.02%, 1.09% and 0.92% respectively.

3.2.6 Physicochemical Properties of Liquid Fuel Produced from End-of-life Latex Gloves

Table 5 shows comparison between the properties of the fuel produced from end-of-life latex gloves and those of SANS 342:2016 standard diesel.

Table 5 Physicochemical Properties of Liquid Fuels Compared

Properties	Test Method	Unit	LG Fuel	Conventional Diesel* fuel
Density @ 20°C	ASTM D7042	g/cm ³	0.858	0.800 min
Viscosity @ 40°C	ASTM D7042	cSt	1.1	2.0-5.3
Flashpoint	ASTM D93	°C	26	55 min
Water Content	ASTM D6304	mg/kg	0.042	0.035 max
Total Contamination	IP440/SA NS 52662	mg/kg	35.2	24 max
Sulphur	ASTM D4294	mg/kg	4900	500 max

*SANS 342:2016 standard diesel

At 20°C, the density of the pyrolysis fuel from end-of-life latex gloves (0.858 g/cm³) was close to the minimum standard density of conventional diesel fuel (0.800 g/cm³).

The viscosity value of the pyrolysis fuel from end-of-life latex gloves (1.1 cSt) was below the

minimum permissible limits of conventional standard diesel (2.0 – 5.3 cSt).

The flashpoint of latex glove derived fuel (26 °C) was lower than the 55 °C minimum requirement of conventional fuel. The lower flash point could be that the composition of the pyrolytic oils is a blend of compounds with a broad distillation temperature range (Osayi *et al.*, 2018).

The water content of the latex gloves fuel was appreciably close (0.042 mg/kg) to that of conventional fuel (0.035 mg/kg). Total contamination in the end-of-life latex glove derived fuel was (35.2 mg/kg) above the permissible limit of 24 mg/kg of conventional diesel.

The high sulphur level in the liquid fuel (4900 mg/kg) as shown (in Table 5) could be due to the high levels of sulphur in the chemistry of the latex gloves (0.8 wt.%) (Zakaria *et al.*, 2011).

4 Conclusions and Recommendations

4.1 Conclusions

From the experimental works carried out, it can be concluded that it is possible to recycle end-of-life latex gloves into useful fuel products through pyrolysis in a self-designed stainless steel laboratory reactor. The density of the liquid fuel obtained overlap that of conventional hydrocarbon diesel fuel.

The lower viscosity and flash point values of the liquid fuel which are below the minimum permissible limits of conventional diesel suggest the presence of lower molecular weight hydrocarbon fuels such as petrol, kerosene and jet fuel.

Analysis of the solid by-product (char) revealed partly carbonaceous material (~36.58 wt% C) that could burn to yield an ash rich in CaO and ZnO.

The feasibility of end-of-life latex gloves pyrolysis can provide solution to waste plastic issues in the country.

4.2 Recommendation

The fuel obtained from the experiment should further be refined to produce commercial hydrocarbon fuels.

Acknowledgements

Authors acknowledge the Ghana Chamber of Mines for its financial support in the form of the Ghana Chamber of Mines Tertiary Education Fund (GCM-TEF) which provided the financial support for the project.

References

- Abraham, E., Cherian, B.M., Elbi, P. A., Pothan, L.A. and Thomas, S. (2011), "Recent Advances In The Recycling Of Rubber Waste", *Recent Developments in Polymer Recycling*, vol. 47, pp. 100.
- Ahmad, N., Abnisa F., and Daud, W.M.A.W., (2016), "Potential Use Of Natural Rubber To Produce Liquid Fuels Using Hydrous Pyrolysis - A Review", *RSC Advances*, Vol. 6, pp. 68906-21.
- Akpanudoh, N. S., Gobin, K. and Manos, G. (2005), "Catalytic Degradation of Plastic Waste to Liquid Fuel over Commercial Cracking Catalysts: Effect of Polymer to Catalyst Ratio/Acidity Content", *Journal of Molecular Catalysis A*, Vol. 235, No. 1-2, pp. 67-73.
- Cleetus, C., Thomas, S. and Varghese, S. (2013), "Synthesis of Petroleum-Based Fuel from Waste Plastics and Performance Analysis in a CI Engine", *Journal of Energy*, Vol. 608979, pp. 1-10.
- Gulab, H., Jan, M. R., Shah, J. and Manos, G. (2010), "Plastic Catalytic Pyrolysis to Fuels as Tertiary Polymer Recycling Method: Effect of Process Conditions," *Journal of Environmental Science and Health*, vol. 45, no. 7, pp. 908-915.
- Ishola, F. A., Ajayi, O. O., Oyawale, F. and Akinlabi, S. A. (2018), "Sustainable End-of-Life Tyre (EOLT) Management for Developing Countries - A Review", In: *Proceedings of the International Conference on Industrial Engineering and Operations Management*, Vol. 29, pp. 1054 - 1058.
- Jan, M. R., Shah, J. and Gulab, H. (2010), "Catalytic Degradation of Waste High Density Polyethylene into Fuel Products using BaCO_3 as a Catalyst," *Fuel Processing Technology*, Vol. 91, No. 11, pp. 1428-1437.
- Manos, G., Garforth, A. and Dwyer, J. (2000), "Catalytic Degradation of High Density Polyethylene on an Ultrastable-Y Zeolite. Nature of Initial Polymer Reactions, Pattern of Formation of Gas and Liquid Products, and Temperature Effects", *Industrial and Engineering Chemistry Research*, Vol. 39, No. 5, pp. 1203-1208.
- O'Hara J. B. (1981), "Liquid Fuels from Coal", *Coal Handbook*, pp. 715-816.
- Osayi J. I, Iyuke S., Daramola M. O., Osifo P., Van Der Walt I. J. and Ogbeide S. E. (2018), "Pyrolytic Conversion Of Used Tyres To Liquid Fuel: Characterization And Effect Of Operating Conditions", *Journal Of Material Cycles and Waste Management*, Vol 20, pp. 1273-1285.
- Panda, A. K., Singh, R. K. and Mishra, D. K. (2010), "Thermolysis of Waste Plastics to Liquid Fuel: a Suitable Method for Plastic Waste Management and Manufacture of Value Added Products: a World Prospective," *Renewable and Sustainable Energy Reviews*, vol. 14, No. 1, pp. 233-248.
- Rowhani, A. and Rainey, T. J. (2016), "Scrap tyre management pathways and their use as a fuel-a review", *Energies*, Vol. 9, No. 11, 888 pp.
- Songip, A. R., Masuda, Kuwahara, T. H. and Hashimoto, K. (1993), "Test to Screen Catalysts for Reforming Heavy Oil from Waste Plastics," *Applied Catalysis B*, Vol. 2, No. 2-3, pp. 153-164.
- Stoler, J., Weeks, J.R., and Fink, G. (2012), "Sachet Drinking Water in Ghana's Accra-Tema Metropolitan Area: Past, Present, and Future", *J Water Sanit Hyg Dev.*, Vol. 2(4), pp. 223 -240.
- Uddin, M. A., Koizumi, K., Murata, K. and Sakata, Y. (1997), "Thermal and Catalytic Degradation of Structurally Different Types of Polyethylene into Fuel Oil," *Polymer Degradation and Stability*, Vol. 56, No. 1, pp. 37- 44.
- Zakaria N., Ani F. N., Yunus, M. N. M. and Husain M. A. S. (2011), "Oxidative Pyrolysis of Examination Rubber Gloves in the Integral Pyrolysis Test Plant", *International Journal of Mechanical and Materials Engineering (IJMME)*, vol. 6, pp.1-9.

Authors

E. A. Arthur holds a distinction in MPhil Minerals Engineering from the University of Mines and Technology (UMaT), Tarkwa and a BSc degree in Materials Engineering from the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana. His research interests include material processing, high-temperature metallurgical processes, iron and steel making, corrosion control, utilisation of waste polymers in metal extraction processes and conversion of waste polymers into liquid fuel and chars.



G. Mensah-Sackey obtained a BSc degree in Minerals Engineering from the University of Mines and Technology (UMaT). He is currently enrolled in MSc programme in Environmental Engineering at Egypt - Japan University of Science and Technology (EJUST). His research interest is in environmental remediation, water treatment, solid waste management and liquid fuel production.



S. N. Baisi Ebo holds a BSc in Minerals Engineering at the University of Mines and Technology, Ghana (2021). He is a member of the West Africa Institute of Mining, Metallurgy and Petroleum. His current research interest includes pyrolysis of waste plastics to produce valuable products, including liquid fuels and carbon black (char), water quality assessment and purification of water using natural coagulants.





I. J. Cobbinah holds a BSc in Minerals Engineering at the University of Mines and Technology, Ghana (2020). He is a senior laboratory manager at Minerals Engineering Department (UMaT). His research interests are extractive metallurgy, small scale mining tailings re-processing and hydrometallurgy. He is a

graduate member of the Ghana institute of Engineers (GhiE).



J. Dankwah is a metallurgist at Goldfields Ghana Limited, Damang Mines. She holds an MPhil Degree in Minerals Engineering from the University of Mines and Technology, Tarkwa and BSc degree in Chemical Engineering at the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. She is part of

the research group at the University of Mines and Technology currently involved in the recycling of post-consumer plastics in the reduction of metal oxides and the production of liquid fuels (diesel, kerosene and aviation fuel).



E. Abotar is a lecturer and a PhD candidate at the Minerals Engineering Department of the University of Mines and Technology, (UMaT), Tarkwa. He obtained his MPhil and BSc Degrees in Minerals Engineering at the University of Mines and Technology. His current research areas include Mineral processing, iron and steelmaking, high-

temperature metallurgical processes and utilisation of waste polymers in metal extraction processes.



J. R. Dankwah is an Associate Professor of Metallurgical and Materials Engineering at the University of Mines and Technology, Tarkwa, Ghana. He obtained his PhD from the School of Materials Science and Engineering, UNSW-Australia, MSc (Process Metallurgy) from the Norwegian University of Science and Technology and

BSc (Metallurgical Engineering) from the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. He is a fellow of the West Africa Institute of Mining, Metallurgy and Petroleum. His research and consultancy works cover iron and steelmaking, high-temperature metallurgical processes, utilisation of waste polymers in metal extraction processes, utilisation of waste polymers in liquid fuel production.