

Conversion of End-of-Life Face Mask as Chemical Feedstock for the Production of Diesel Range Liquid Fuel

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Dankwah, J. R., Forson, R., Mensah-Sackey, G. and Cobbinah, I. J. (2022), "Conversion of End-of-Life Face Masks as Chemical Feedstock for the Production of Diesel Range Liquid Fuel", *Proceedings of the 7th UMaT Biennial International Mining and Mineral Conference*, pp 1 – 8.

Abstract

Globally, as at the end of December 2021, COVID-19 had accounted for over 285 million cases and 5.42 million deaths. In addition to this scary statistics, the pandemic has left in its wake a new category of hazardous waste stream, face masks (FM). This research work investigated the potential for generating Diesel range liquid fuel from discarded FMs using a charred palm kernel shell fired reactor-blower assembly in the temperature range 400 – 450 °C. Samples of discarded FMs (collected from a household in Tarkwa) weighing approximately 2.0 kg were fed from the top of a stainless steel reactor and pyrolysed continuously until gas flow into the condenser ceased. Gases leaving the reactor were condensed in a primary reactor and the condensed fuel was trapped in a plastic container, weighed and characterised by FTIR and GC-MS analyses. The solid by-product (tar) was characterised by FTIR analysis to assess its reuse or safety disposal into the environment. The results indicate that samples of liquid fuel can be produced from discarded FMs with a yield of up to 0.80 litres/kg of pyrolysed material. Results from the characterisation by FTIR and GC-MS analyses showed that the liquid fuel consists primarily of a mixture of aromatic and aliphatic hydrocarbons in the C₉-C₁₈ range, along with significant amounts of cycloalkanes. Physical examination and FTIR analyses of the solid by-product revealed a benign product suitable for use as a high temperature gas sealant. It was concluded that liquid fuel production by pyrolysis could offer a sustainable route for the disposal of hazardous end-of-life face masks.

Keywords: Liquid Fuel; Face Mask; Pyrolysis; GC-MS Analysis; FTIR Analysis.

1 Introduction

Globally, as at the end of December 2021, COVID-19 had accounted for over 285 million cases and 5.42 million deaths. In addition to this scary statistics, the pandemic has left in its wake a new category of hazardous waste stream, face masks.

Work done by Aragaw and Mekonnen (2021) using FTIR analysis revealed that face masks consist of polypropylene (PP), a thermoplastic polymer that can be easily transformed to fuel energy via pyrolysis. However, this thermoplastic material is usually combined with textile and rubber bands produced from natural rubber. Globally, at the peak of the COVID-19 pandemic, an estimated 4.3 billion pieces of face masks were released into the environment daily (Aragaw and Mekonen, 2021).

FMs belong to single-use disposable plastics and, accordingly, have been recognised as a major cause of micro-plastic litter in the environment (Schnurr, *et al.* 2018).

In an attempt to address the plastics waste menace, several measures are currently in place or have been proposed, among which are mechanical recycling, landfilling, incineration and lately the call for the adoption of biodegradable plastics. Major problems associated with each of these measures have been enumerated by some researchers (Panda *et al.*, 2010; Cleetus *et al.*, 2013; Uddin *et al.*, 1997; Stoler *et al.*, 2012).

Various researchers have investigated the conversion of various forms of waste plastics into liquid fuels (Cleetus *et al.*, 2013; Kumar and Singh, 2014; Panda *et al.*, 2010; Songip *et al.*, 1993; Manos *et al.*, 2000; Uddin *et al.*, 1997; Akpanudoh *et al.*, 2005; Jan *et al.*, 2010; Gulab *et al.*, 2010). Although surgical FMs are manufactured from PP, HDPE and their blends with textile materials like nylon (Jung *et al.* 2021), its utilisation in the production of liquid fuels has not been widely documented as a potential route to waste plastics recycling. Besides, the effect of the presence of

textile material and natural rubber on the properties of liquid fuel is worth investigating.

Accordingly, in this investigation, we report preliminary results on the production of liquid fuels from FM using a stainless steel reactor.

2 Resources and Method

2.1 Materials

The feedstock (Fig 1) used for the investigation was end-of-life FM that were cautiously placed in a plastic trash can over a period of one month, in a household within the Tarkwa municipality. About 2.0 kg of the masks were used for each process.



Fig 1 Samples of FM utilised for the Investigation

2.2 Methods

The experimental setup (Fig. 2) consisted of a heating assembly (charred palm kernel shell fired), self-designed pyrolysis reactor equipped with a copper coil condenser (A) and a plastic bowl condenser (B) kept at 42 °C and 30 °C respectively, and a collecting plastic container. Samples of end-of-life FM were fed from the top of the reactor for pyrolysis.



Fig 2 Experimental Setup

2.2.1 Thermal Degradation (Non-Catalytic Pyrolysis)

The investigation was done without a catalyst. Samples of end-of-life FM (~2.0 kg) were fed into the reactor and the experiment was carried out at a maximum temperature of about 640 °C, measured by a BENETECH GM900 Infrared Thermometer (Fig. 3), (Dankwah, *et. al.*, 2021).



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

The series of steps involved in the non-catalytic pyrolysis of FM is shown in Fig 4.

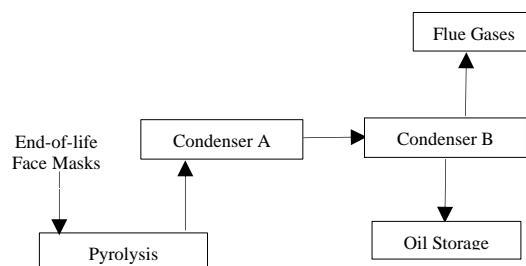


Fig 4 Reaction Scheme for the Non-Catalytic Pyrolysis of End-of-Life FM

As illustrated in Fig. 4, the samples of FM went through a melting process after being exposed to a high temperature environment in the reactor. Further heating resulted in the conversion of the molten mass into a hot gaseous mixture of hydrocarbons. The hot gaseous hydrocarbon mixture from the reactor then evolved through a primary condenser (coil) and a connecting tube linked to an HDPE plastic container with water, which serves 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 pressure tube.

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 FM pyrolysed as shown in equation (1):

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

2.4 Characterisation of Samples of Shredded FM, Liquid Fuel Produced and Solid By-Product

Dry samples of FM used for the pyrolysis process, the liquid fuel produced and the solid byproduct were characterised by FTIR analysis to identify various functional groups present, which can help in determining the types of polymers present in the sample. The liquid fuel was also characterised by GC-MS analysis to detect the various polymers present.

3 Results and Discussion

3.1 Characterisation of Raw Material by FTIR Spectroscopic Analysis

FT-IR spectroscopy is a useful tool used to examine the hydrocarbon types or functional groups in the pyrolytic oil derived from waste polymers (Arabiourrutia *et al.* 2012; Kumar and Singh 2011; Dogan and Kayacan 2011; Islam *et al.* 2010).

The FTIR analyses of the various parts of the face mask used for the investigation are illustrated in Figs 5-7.

From Fig. 5, the FTIR spectrum of the main portion of FM showed peaks in the two broad ranges from 2837.22 to 2948.96 and from 807.20 to 1452.30 cm^{-1} , which are characteristic FT-IR peaks of polypropylene (PP) (Jung *et al.*, 2018; Jung *et al.*, 2021).

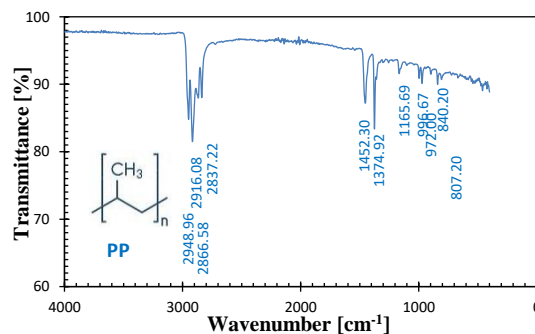


Fig 5 FTIR Spectrum of Main Portion of Face Mask

The FTIR spectrum in Fig. 6 shows peaks that are consistent with polyamide (nylon-6) and therefore suggests that ear straps were produced from the textile polymer nylon-6.

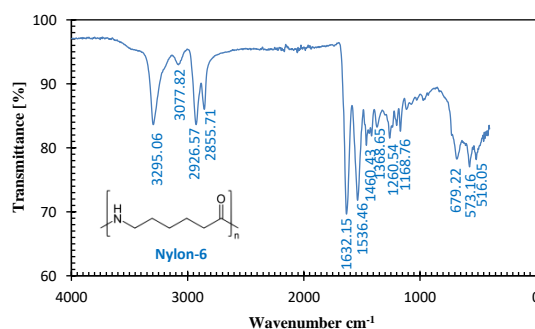


Fig 6 FTIR Spectrum of Ear Strap of Face Mask

The FTIR spectrum of the hard plastic portion of FM, which is typically placed on the nose, is shown in Fig. 7. The peaks from 2837.24 to 2924.95 cm^{-1} and from 808.32 to 1454.32 cm^{-1} are characteristic of PP, similar to what was observed for the main portion. The FM samples utilised for this investigation therefore consist of a mixture of the thermoplastic polymer PP and the textile material nylon-6.

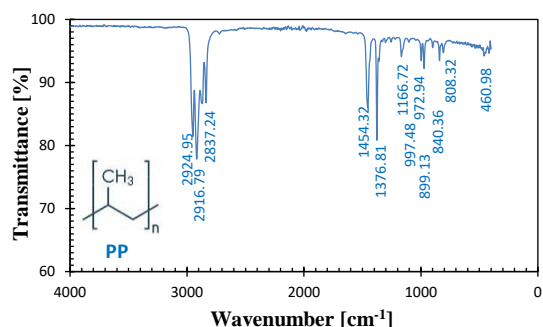


Fig 7 FTIR Spectrum of the Hard Plastic Portion of Face Mask

3.2 Results of Thermal Degradation (Non-Catalytic Pyrolysis)

Gas emission commenced after about 10 minutes of heating. This hydrocarbon gas mixture exiting the reactor after the melting of the waste FM was condensed primarily in condenser A. The product from condenser A was comprised of a mixture of liquid fuel and some uncondensed hydrocarbon gases; these were channeled into condenser B within a period of 2 hours 03 minutes, after which bubbling of gases in condenser B ceased and no liquid flowed from condenser A. The liquid was allowed to settle above the water in condenser B and later collected and stored in a glass container, as shown in Fig. 8.



Fig 8 Sample of Liquid Fuel obtained from the Pyrolysis of FM

Not all the FM was converted into hydrocarbon gases. A dark fluid-like by-product was left in the reactor after the pyrolytic process, which solidified partially into a semi-solid grease after the temperature in the reactor dropped to room temperature as shown in Fig 9. Physical examination of the grease shows a product suitable for use as a high temperature sealant. This greasy by-product was also characterised by FTIR and the accompanying peaks are illustrated in Fig. 10.



Fig 9 Tar Residue after Non-Catalytic Pyrolysis of FM

The FTIR spectrum of the tar residue shows a small peak around 3000 cm^{-1} along with two major peaks from $2853\text{ to }2922\text{ cm}^{-1}$, which illustrate C-H stretch of alkanes. This set of peaks is followed by prominent peaks at 1642 , 1466 and 1378 cm^{-1} , which illustrate -C=C- stretch of alkenes, C-C stretch (in-ring) aromatics and C-H stretch of alkanes, respectively.

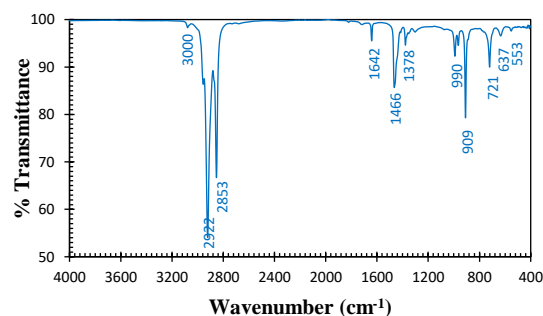


Fig 10 FTIR Spectrum of Tar Residue after Non-Catalytic Pyrolysis of FM

3.4 Characterisation of Liquid Fuel Produced from FM by FTIR and GC-MS Analyses

3.4.1 FTIR Analysis of Liquid Fuel Produced from Face Mask

The results of FTIR analysis of the liquid fuel produced from FM are shown in Fig. 11 and Table 1.

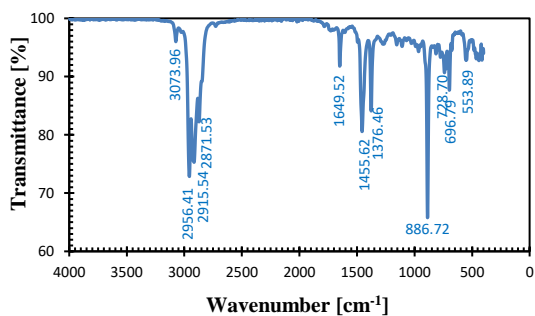


Fig. 11 FTIR Spectra of Liquid Fuel Produced from Face Mask

Table 1 Major Absorption Peaks and Assigned Configurations in the FTIR Spectra of the Liquid Fraction Derived from Face Mask Pyrolysis

Wavenumber	Vibration	Functional Group
3073.96	=C-H	Stretch of alkenes
2956.41	C-H	Stretch of alkanes
2915.54	C-H	Stretch of alkanes
2871.53	C-H	Stretch of alkanes
1649.52	-C=C-	Stretch of alkenes
1455.62	C-C	Stretch (in-ring) aromatics
1376.46	C-H	Stretch of alkanes
886.72	=C-H	Bend of alkenes
728.70	C-H	'Oop' of aromatics
696.79	C-H	'Oop' of aromatics
553.89	C-Br	Stretch of alkyl halides

From the FTIR of Fig. 11, a weak peak occurs at 3073.96, that corresponds to a =C-H stretch of alkenes. This is followed by very prominent peaks with wavenumbers 2956.41, 2915.54 and 2871.53 cm^{-1} , corresponding characteristically to C-H stretch in alkanes of polypropylene. The next two peaks at wavenumbers 1649.52 and 1455.62 cm^{-1} correspond to -C=C- stretch of alkenes and C-C stretch (in-ring) aromatics respectively. The strong peak at 1376.46 corresponds to C-H stretch of

alkanes. The FTIR spectrum of regular diesel, as observed by Wembabazi *et al.* (2015) is shown in Fig. 12 for comparison. Several functional groups are common to both diesel and the fuel sample obtained from FM. Accordingly, it is possible to blend FM fuel and regular diesel without any major upgrading.

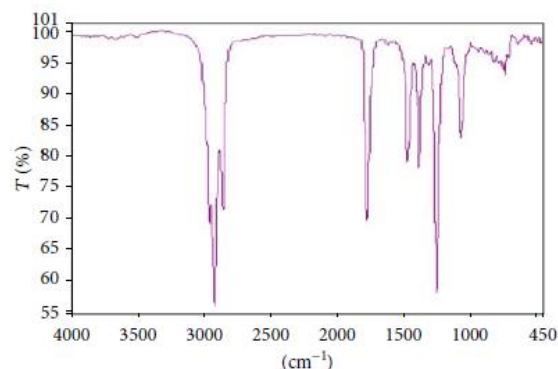


Fig. 12 Raw FTIR Spectrum of Regular Diesel Wembabazi *et al.* (2015)

3.4.2 GC-MS Analysis of Liquid Fuel Produced from FM

The liquid fuel produced from the pyrolysis of FM was characterised using GC-MS analysis to determine the chemical composition; the spectrum is shown in Fig. 13 and the compound list is shown in Table 2. It is seen from Table 2 that the fuel produced from FM consists of aromatic hydrocarbons with some paraffins (alkanes: $\text{C}_n\text{H}_{2n+2}$), olefins (alkenes: C_nH_{2n}), and naphthenes (cycloalkanes) with carbon number ranging from C₈-C₂₀. As would be expected, the FM derived fuel contains fewer alkanes than regular diesel and the dominant functional groups in both FM derived fuel and regular diesel samples are alkanes, alkenes, aromatics, carboxylic acids, alcohols, esters and ethers.

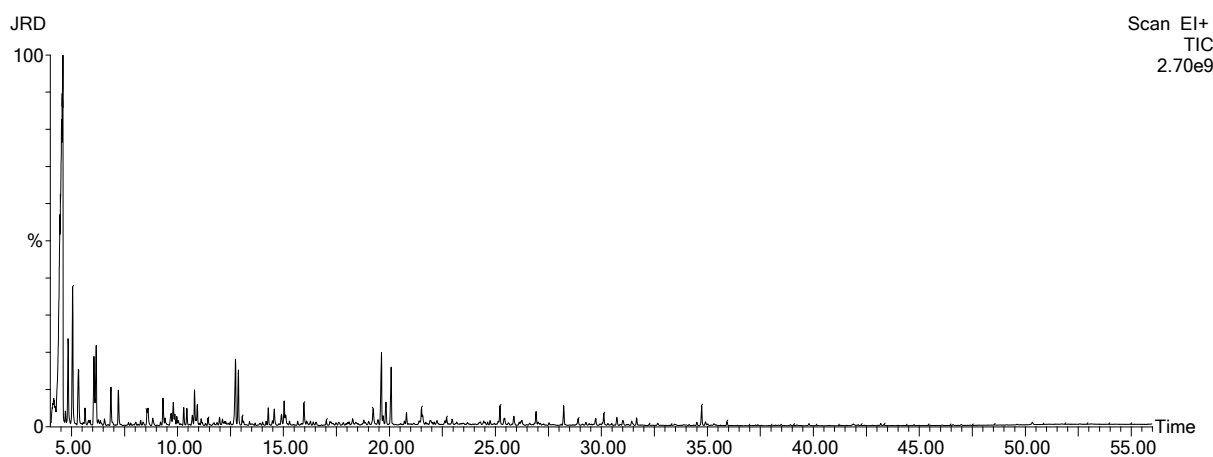


Fig. 11 GC-MS Analysis of Liquid Fuel obtained from Pyrolysis of FM

Table 1 GC-MS Compound List of Liquid Fuel obtained from Pyrolysis of Face Mask

SN	R Time (min)	Name	Molecular Formula	Area %
1	4.153	Cyclohexane, 1,3,5-trimethyl-	C ₉ H ₁₆	2.919
2	4.594	2,4-Dimethyl-1-heptene	C ₉ H ₁₈	44.835
3	4.709	1,3-hexadiene-3-ethyl-2-methyl-	C ₉ H ₁₆	0.332
4	4.834	Cyclohexane, 1,3,5-trimethyl	C ₉ H ₁₆	3.096
5	5.049	Ethylbenzene	C ₈ H ₁₀	5.379
6	5.324	p-Xylene	C ₈ H ₁₀	2.939
7	5.634	Cyclohexene, 3,3,5-trimethyl-	C ₉ H ₁₆	0.601
8	6.054	Styrene	C ₈ H ₈	2.996
9	6.164	3-Octene, 2,2-dimethyl-	C ₁₀ H ₂₀	3.440
10	6.860	1,7-Octadiene, 2,7-dimethyl-	C ₁₀ H ₁₈	1.587
11	7.210	Benzene, (1-methylethyl)-	C ₉ H ₁₂	1.419
12	8.555	Benzene, 1-ethyl-3-methyl-	C ₉ H ₁₂	0.417
13	8.6	Benzene, 1-ethyl-2-methyl-	C ₉ H ₁₂	0.722
14	8.83	Benzene, 1,2,4-trimethyl-	C ₉ H ₁₂	0.415
15	9.311	α -Methylstyrene	C ₉ H ₁₀	1.048
16	9.701	Benzene, 1,2,4-trimethyl-	C ₉ H ₁₂	0.562
17	9.796	2-Decene, 4-methyl-, (Z)-	C ₁₁ H ₂₂	0.914
18	9.871	1-Hexyn-3-ol, 3,5-dimethyl-	C ₈ H ₁₄ O	0.352
19	10.296	Decane, 4-methyl-	C ₁₁ H ₂₄	0.654
20	10.436	Decane, 4-methyl-	C ₁₁ H ₂₄	0.572
21	10.696	Benzene, 1,2,4-trimethyl-	C ₉ H ₁₂	0.390
22	10.801	Benzene, 1-ethyl-2,4-dimethyl-	C ₁₀ H ₁₄	1.039
23	10.936	D-Limonene	C ₁₀ H ₁₆	0.564
24	12.732	3-Octadecene, (E)-	C ₁₈ H ₃₆	2.937
25	12.872	3-Dodecene, (Z)-	C ₁₂ H ₂₄	1.969
26	14.277	1-Undecene, 8-methyl-	C ₁₂ H ₂₄	0.576
27	14.563	Cyclobutyl phenyl ketone	C ₁₁ H ₁₂ O	0.647
28	14.903	1,4-Dihydronaphthalene	C ₁₀ H ₁₀	0.427
29	15.033	(2,4,6-Trimethylcyclohexyl) methanol	C ₁₀ H ₂₀ O	0.815
30	15.103	1H-Indene, 3-methyl-	C ₁₀ H ₁₀	0.411
31	15.958	Naphthalene	C ₁₀ H ₈	0.809
32	18.259	Naphthalene, 1,2-dihydro-3-methyl-	C ₁₁ H ₁₂	0.342
33	19.229	Naphthalene, 1-methyl-	C ₁₁ H ₁₀	0.854
34	19.62	11-Methyldodecanol	C ₁₃ H ₂₈ O	2.759
35	19.83	1-Octanol, 2-butyl-	C ₁₂ H ₂₆ O	0.940
36	20.08	3-Eicosene, (E)-	C ₂₀ H ₄₀	2.341
37	20.805	Trichloroacetic acid, tetradecyl ester	C ₁₆ H ₂₉ Cl ₃ O ₂	0.388
38	21.51	Cyclodecanemethanol	C ₁₁ H ₂₂ O	0.666
39	21.56	Biphenyl	C ₁₂ H ₁₀	0.366

40	25.212	1-Decanol, 2-hexyl-	C ₁₆ H ₃₄ O	0.691
41	25.422	Naphthalene, 2,3,6-trimethyl-	C ₁₃ H ₁₄	0.396
42	25.862	1-Decanol, 2-hexyl-	C ₁₆ H ₃₄ O	0.435
43	26.242	Trichloroacetic acid, hexadecyl ester	C ₁₆ H ₂₉ Cl ₃ O ₂	0.366
44	26.912	(2,4,6- Trimethylcyclohexyl) methanol	C ₁₀ H ₂₀ O	0.538
45	28.218	Benzene, 1,1'-(1,3-propanediyl)bis-	C ₁₅ H ₁₆	0.744
46	28.898	Benzene, 1,1'-(1-methyl-1,3-propanediyl)bis-	C ₁₆ H ₁₈	0.330
47	29.723	Naphthalene, 1,2,3,4-tetrahydro-2-phenyl-	C ₁₆ H ₁₆	0.363
48	30.114	1-Decanol, 2-hexyl-	C ₁₆ H ₃₄ O	0.560
49	30.729	1-Dodecanol, 2-hexyl-	C ₁₆ H ₃₄ O	0.373
50	34.725	Dibutyl phthalate	C ₁₆ H ₂₂ O ₄	0.766

4 Conclusions

This work investigated the generation of liquid fuel from FM using a charred palm kernel shell fired reactor and a blower assembly in the temperature range of 350 – 450 °C. The various portions of FM and the liquid fuel produced were analysed by FTIR and GC-MS. From the results it was concluded that:

- i) Face mask (FM) is comprised of mixtures of thermoplastic polymers like PP and textile materials like polyamide (nylon-6) that are promising feedstocks for liquid fuel production by pyrolysis;
- ii) The liquid fuel produced from FM consists of blends of aliphatic and aromatic hydrocarbons along with minor amounts of naphthenes in the range C₈ to C₂₀;
- iii) The solid by-product has the potential to function as a high temperature sealant.

Acknowledgements

Part of the analyses for the investigation was conducted at the Central Laboratory, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. The authors are grateful to the various authorising bodies for the assistance received.

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