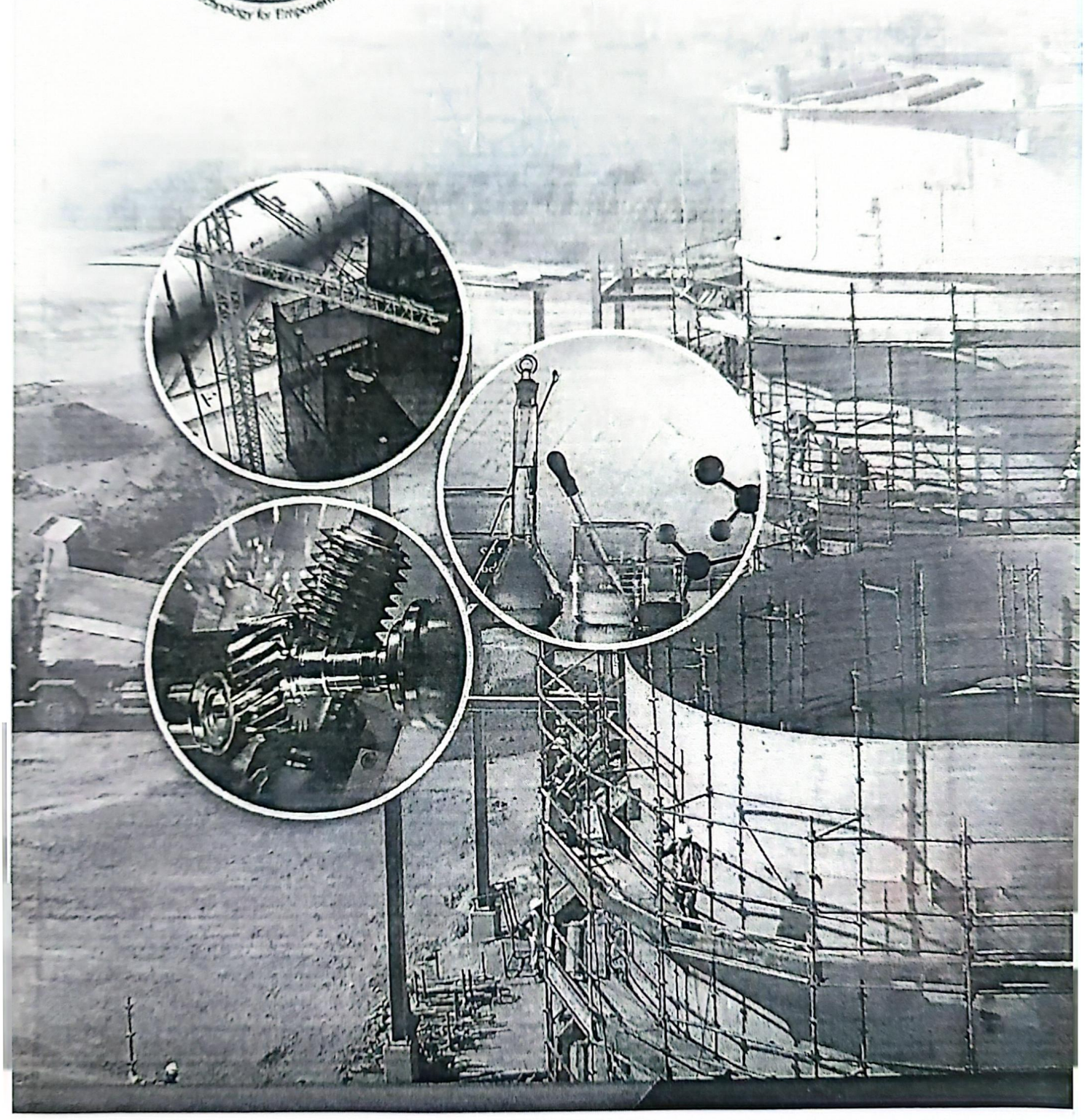
VOLUMES 7-9, 2022 ISSN 2465-7425

NIGERIA JOURNAL OF ENGINEERING AND APPLIED SCIENCES (NJEAS)



NIGERIA JOURNAL OF ENGINEERING AND APPLIED SCIENCES (NJEAS)

Nigeria Journal of Engineering and Applied Sciences – NJEAS (ISSN: 2465-7425) is a publication of the two schools of Engineering: School of Infrastructure, Process Engineering and Technology (SIPET) and School of Electrical Engineering and Technology (SEET) of Federal University of Technology, Minna, Nigeria.

The journal is committed to promoting and publishing original high quality research papers and stresses on academic excellence, knowledge distribution as well as joint scholarly efforts in order to support theoretical, experimental and practical research. Papers for publication are selected through peer review to ensure originality, relevance, and readability.

The subject areas related to this journal include but are not limited to:

1. Chemical, Petroleum and Gas Engineering 2. Civil Engineering 3. Computer Science and Information Technology. 4. Electrical Engineering 5. Electronics & Telecommunication Engineering 6. Mechanical & Mechatronics Engineering and 7. Allied Applied Sciences.

EDITORIAL BOARD MEMBERS

Engr. Prof. A. A. Amadi	Editor-in-Chief
Engr. Prof. O. M. Olaniyi	Managing Editor
Engr. Prof. (Mrs) Z. D. Osunde	Member
Engr. Prof. A. S. Kovo	Member
Engr. Prof. J. O. Okafor	Member
Engr. Prof. A. M. Aibinu	Member
Engr. Prof. M. Abdullahi	Member
Engr. Prof. A. S. Abdulrahman	Member
Engr. Prof. S. A. Lawal	Member
Engr. Dr. P. Adeoye	Member
Engr. Prof. M. Nwohu	Member
Engr. Prof. J. Tsado	Member

Published by:

School of Infrastructure, Process Engineering and Technology, School of Electrical Engineering and Technology and Academic Publishing Centre, Federal University of Technology, Minna, Nigeria.

All Correspondences to:

Editor-In-Chief,
Nigeria Journal of Engineering and Applied Science (NJEAS),
Federal University of Technology, P. M. B. 65, Minna, Nigeria.
E-Mail: njeas@futminna.edu.ng, Website: njeas.futminna.edu.ng

TABLE OF CONTENTS

INTELLIGENT CRIMINAL IDENTIFICATION SYSTEM FOR SEMI-REGULATED ENVIRONMENTS
**Ganiyu, S. O., Akpagher, T. D., Olaniyi, O.M., &Adebayo, S. O.* 1

EXTRACTION OF ADHESIVE FROM GUILL AND PERR (*CISSUS POPULNEA*) FOR PARTICLEBOARD PRODUCTION USING RICE HUSK
**Aboje, A. A., Akor, I. H., Uthman, H., & Bala, A.* 18

INVESTIGATING THE PERFORMANCE OF FULL DEPTH RECLAIMED SURFACE-DRESSED PAVEMENT TREATED WITH CEMENT AND CALCIUM CARBIDE RESIDUE AS ROAD BASE
**Alhassan, M., Alhaji, M. M., & Saidu, A. E.* 35

PACKET DELIVERY RATIO (PDR) OF AN ENHANCED WEIGHT BASED CLUSTER HEAD SELECTION ALGORITHM FOR ROUTING IN VEHICULAR ADHOC NETWORKS (VANETS)
**Jiya, A. G, Usman, A. U and David, M.* 46

MODELLING WATER LOSS IN HYDRAULIC DISTRIBUTION NETWORKS OF SHIRORO WATER DISTRIBUTION SYSTEM MINNA, NIGER STATE.
Tanimu, Y.; Jimoh, O.D. and Adesiji A. R.* 58

HYBRID AUTOREGRESSIVE NEURAL NETWORK (ARNN) MODEL FOR SPECTRUM OCCUPANCY PREDICTION
**Ajiboye, J.A, Adegboye, B.A, Aibinu, A.M, Kolo, J.G, Ajiboye, M.A, Usman, A.U* 68

STRUCTURAL ASSESSMENT OF A LATTICE TOWER IN FEDERAL CAPITAL TERRITORY, ABUJA
Auta S.M., Okunyomi O.O., & Kolo, D.N. 77

COMPARATIVE STUDY ON CO_2 CAPTURE USING ACTIVATED CARBON FROM SUGARCANE BAGASSE AND ZEOLITE (ZSM-5)
*Abdullahi, A., *Alhassan M., Alhassan. B., Audu, O. A., Ayobamiji C. I., Isah, A. G., & Kovo, A, S.* 85

HYDRAULIC CONDUCTIVITY CHARACTERISTICS OF LEACHATE - CONTAMINATED LATERITIC SOIL
Asogwa, E: O., Adie, D. B., Ibrahim, F.B., Amadi, A.A. and Agbonselobho, M.O 95

INTEGRATED MODE SELECTION AND BANDWIDTH ALLOCATION SCHEME FOR INTERFERENCE MITIGATION IN D2D NETWORKS
**Ameh, A. I., Usman, A. U., Mohammed, A. S. & Salihu, B. A.* 101

PHYSICO-CHEMICAL ANALYSIS OF BIO-OIL PRODUCE FROM CO-PYROLYSIS OF *SIDA RHOMBIFOLIA* WITH LOW AND HIGH DENSITY POLYETHYLENE
**Abdullahi, A. M., Garba, M. U., Eterigho E. J., Alhassan, M., Adeniyi, O. D.* 115

A COMPARATIVE ANALYSIS OF GRILLAGE METHOD AND BEAM LINE ANALYSIS OF A REINFORCED CONCRETE WAFFLE BRIDGE DECK
Adamu, H. N.; Abbas B.A.; Abubakar, M.; Yusuf, A.; Kolo, D.N. & Shehu, M. 127

EFFECT OF BINDERS ON THE PROPERTIES OF CONCRETE – A REVIEW
*Oritola, S. F., Olojede, R. O, Kolo, J. L, Ukog, A. S. and Ekpenyong, D. E 135

APPLICATION AREAS OF OPTICAL WIRELESS COMMUNICATION TECHNOLOGIES IN 5G, 6G AND INTERNET OF THINGS: EXPECTATIONS, DIRECTIONS, AND THREATS
Abdullahi, B B., Michael, D., Suleiman, Z. and Abraham,. U. U. 146

COMPARATIVE STUDY OF TAMARINDUS INDICA AND ADANSONIA DIGITATA AS COAGULANTS AND DISINFECTANTS FOR WATER TREATMENT
*Uthman, H. 169

PHYSICO-CHEMICAL ANALYSIS OF BIO-OIL PRODUCE FROM CO-PYROLYSIS OF *SIDA RHOMBIFOLIA* WITH LOW AND HIGH DENSITY POLYETHYLENE

*Abdullahi, A. M., Garba, M. U., Eterigho E. J., Alhassan, M., Adeniyi, O. D.
Chemical Engineering Department, Federal University of Technology, Minna. Nigeria.
Corresponding author email: abdulmusavespa@gmail.com

Abstract

Bio-oil was successfully produced from three samples Sida Rhombifolia (SR), Low Density Polyethylene (LDPE) and High Density Polyethylene (HDPE). Two step techniques was employed and this include pyrolysis of SR and co-pyrolysis of the samples. The preliminary analysis of the samples shows that the SR has volatile matters of 76.42 wt. %, LDPE 97.89 wt. % and HDPE 92.86 wt. %. These volatiles indicated that higher yield of bio-oil could be produced from the samples. The maximum yield of bio-oil obtained from pyrolysis of SR was 48.10 wt. % at pyrolysis parameters of temperature 500 ^{0}C, reaction time 60 minutes and particle size 2-4 mm. However co-pyrolysis increase the yield of the bio-oil from 48. 10 wt. % to 76.20 wt. %. The physio-chemical properties of the bio-oil: calorific value, viscosity, density, pH, moisture content, flash and pour point was carried out to determine the quality of the bio-oil while GC-MS and FTIR analyses were carried out to determine hydrocarbon composition present in the bio-oil. In order to ascertain the quality of the bio-oil produced, the properties were compared with the standard properties of diesel and gasoline. The GC-MS analysis shows that the bio-oil obtained from pyrolysis of SR contains 77.77 % oxygenated organics and 22.23 % aliphatic hydrocarbon. Co-pyrolysis reduces the organics from 77.77 % to 5.32 % and increases the aliphatic from 22.23 % to 88.48 % with the appearance of aromatic hydrocarbon. Therefore the co-pyrolysis shows an effective synergy between SR with LDPE and HDPE as well as the increase of the yield and quality of the bio-oil.

Keywords: SR, LDPE, HDPE, Bio-oil, Pyrolysis, Co-pyrolysis

Introduction

Renewable resources are the natural sources that can be replenished after its consumption. It can be classified into sustainable (those that can be naturally renewable) and renewable with careful planning as lingo-cellulosic biomass. Ligno-cellulosic biomass is a complex bio-polymer which primarily consisting of cellulose, hemicellulose and lignin. It is divided into three feedstock; woody biomass (forestry and wood waste), non-woody biomass (weeds such as *sida rhombifolia*, agriculture residues such as straws, bagasse strover and so on) and organic waste (animal waste and sewage sludge). Therefore, lignocellulosic is a promising renewable resource for sustainable production of various bio-oil (Tumuluru *et al.*, 2011 and Tian *et al.*, 2022). This study utilized the weed *Sida rhombifolia* (known as arrow leaf) which is a non-woody biomass species found in most parts of the north central, southwest and south-south of Nigeria. The morphology features of the species; is a glabrous, ramous, erect, perennial that grows from 90 to 120 cm high, with a short erect stem, leaf and root. It grows in uncompleted buildings, along roads and river banks. With these characteristics, the SR is yet to have attention for bio-oil production as transport fuel in Nigeria. Furthermore, the proximate and ultimate analysis of non-woody biomass indicated highest energy values, volatile content, higher fixed carbon contents and low ashes (Kumar *et al.*, 2011).

Asadullah *et al.* (2007) was among one of the several researchers who produced bio oil from pyrolysis of biomass. It was confirmed in their research that the bio oil cannot be

used directly as transportation fuel because of adverse characteristics. These characteristics, particularly the instability of bio oil is associated with the high oxygen and water content that is hydrogen deficiency. In-order to increase the amount of hydrogen in the bio oil, plastic material such as Low and High Density Polyethylene (LDPE and HDPE) that are Hydrogen-rich are used to supplement the deficiency (Esso *et al.*, 2022).

In recent times, there has been a rise in environmental concern over plastic waste generation and disposal worldwide, resulting from the rise in population and industrialization. Plastics are materials that are made of wide range of synthetic and natural compounds, and are malleable and can be molded into different shapes and sizes. Plastics have become an indispensable materials used in several countries of the world, due to their durability, lightweight as well as flexibility and are utilized in a range of industrial and domestic areas (Khan *et al.*, 2016).

MATERIALS AND METHOD

Materials

Sida Rhombifolia was collected from road side in shabu along Jos road Lafia. Nasarawa State, Nigeria. LDPE and HDPE were collected from waste plastic dump site in Lafia. Nasarawa State, Nigeria.

METHODS

Preliminary Investigation of SR

Prior to pyrolysis, SR was physically treated by removing any adhering dirt on the surface then sun dried for 48 hour and subsequently dried in oven at 105 ^{0}C for one hour to remove moisture content.

The SR was milled to smaller particles sizes range between 1.0 - 8.0 mm. Proximate analysis of SR, LDPE and HDPE were conducted so as to ascertain the moisture content, volatile content, the fixed carbon and the ash content. On the other hand, the ultimate analysis that provides the composition (wt. %) of carbon, hydrogen, nitrogen, oxygen and sulphur (CHNOS) for the SR, LDPE and HDPE were also conducted.

The thermal behaviour of the three samples (SR, LDPE and HDP) were performed by using a thermogravimetric analyser (Perkin Elmer, TGA 4000 Made in Netherlands model,). The samples were first analysed in a nitrogen atmosphere, pressure of 2.0 bar and heating rate of 20 °C/min. Derivative Thermo- gravimetry (DTG) was also used to evaluate the degree of loss of material's weight when temperature is elevated.

Pyrolysis of Set-Up

A pyrolyser as shown in the schematic diagram in figure 1 was used for experiment. The set-up comprises N_2 gas cylinder, valve, tubes and shells, pressure gauge, reactor, electric cell heater, condenser, ice bath and gas collector couple. The setup was used to investigate the pyrolysis parameters; temperature, reaction time, particle size at the desired heating rate. The condenser attached to the pyrolysis reactor was used to condense the volatile products from the reactor by exchanging with water at temperature below 25^{0}C while the volatile passing through the tube side of the condenser. The temperature was varied from 350 ^{0}C to 650 ^{0}C, reaction time from 30 to 120 minutes and particle sizes between 1 mm to 8 mm.

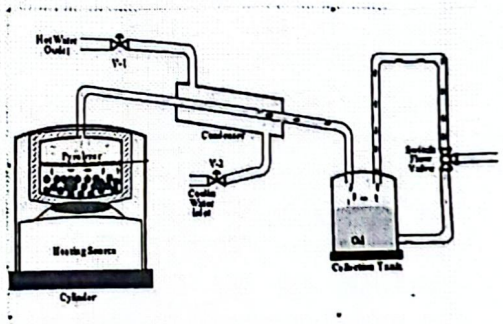


Fig. 1: Pyrolysis process setup

The equation for the calculation of bio-oil yield are given as follows:

$$\% \text{ Yield of Bio-oil} = \frac{Volume\ of\ bio\ oil\ (ml)}{Starting\ weight\ of\ SR} \quad (1)$$

% Yield of Bio-Char = $\frac{\text{weight of solid char (g)}}{\text{starting weight of SR}}$ (2)

% Yield of gas = 100 % − (%oil + % char) (3)

Characterization of Bio-Oil

The characterization of bio-oil produced from pyrolysis and co-pyrolysis was conducted to ascertain the viscosity, calorific value, density, moisture content, flash point, pour point, cetane, octane number, FTIR and GC-MS

Results And Discussion

Preliminary investigation of SR

Lignocellulose analysis of *Sida Rhombifolia*

The lignocellulose analysis of *Sida rhombifolia* (SR) are presented in Table 1. The Table 1 shows that the SR has cellulose 52.14 wt. %, hemicellulose 28.35 wt. % and lignin 17.67 wt. % respectively (Tian *et al.*, 2022).

Table 1: Lignocellulose analysis of *Sida rhombifolia*

Parameter	Wt.%
Cellulose	52.14
Hemicellulose	28.35
Lignin	17.67

Proximate and Ultimate analysis of SR

The proximate and ultimate analyses of SR, LDPE and HDPE are presented in Table 2. The Table 2 shows that the proximate analysis of SR has higher volatile matter 76.42 wt. % with low ash content 1.54 wt. % compared with the volatile matter of rice husk (68.20 wt. %) and sweet grass (69.14 wt. %) (Tumuluru *et al.*, 2011). The ultimate analysis of SR shows low hydrogen 5.00 wt. %. These results of SR corroborated with the result of other researchers (Ringer, *et al.*, 2006; Oyebanji *et al.*, 2022). The proximate and ultimate analyses of LDPE as presented in the Table 2 shows volatile content 97.39 wt. % with low ash content 0.53 wt. %, hydrogen 15.37 wt. % and no sulphur present. Similarly HDPE has volatile content 92.86 wt. % with ash content 3.68 wt. %, hydrogen 14.37 wt. % and no sulphur present. The ultimate analysis shows LDPE and HDPE have higher hydrogen as presented in the Table 2 which could serve as donor to SR during pyrolysis (Esso *et al.*, 2022).

Table 2: Proximate and ultimate analysis of SR

Composition	SR (wt. %)	LDPE (wt. %)	HDPE (wt. %)
		Proximate	
Moisture Content	4.30	1.24	1.32
Volatile Content	76.42	97.39	92.86
Fixed Carbon	17.44	0.84	2.14
Ash Content	1.84	0.53	3.68
		Ultimate	
Carbon	60.00	83.63	84.63
Hydrogen	5.00	15.37	14.37
Oxygen	37.00	0.34	0.44
Nitrogen	1.00	0.66	0.56
Sulphur	0.02	0.00	0.00

Thermo-Gravimetric and Differential Thermal Analysis

Thermo-Gravimetric Analysis of SR

The Thermo-Gravimetric Analysis (TGA) are presented in Fig. 2 (a). The curve pattern in the Fig. 2 (a) was divided into three phases; the first phase is evaporation at temperature 49^{0}C to 246.57 ^{0}C where the SR content was heated and the moisture elimination occurred. The second phase at temperature 240 ^{0}C to 370 ^{0}C is devolatilization where the volatile matters been removed. Temperature above 370 ^{0}C to 426 ^{0}C, an accelerated decomposition of internal constituent (cellulose and hemicellulose) with an approximate weight loss of about 72 wt. %. At this phase, the

most significant complex organic compounds including partial lignin were breaking down for more removal of volatile substance. The third phase shows continuous removal of volatile component at temperature 500 ^{0}C. This explanation corroborated with the research work reported by Dewangan, (2014) where degradation of biomass involves three main stages; moisture removal, decomposition of unstable polymers and continuous slight valorization (Dewangan, 2014).

Differential Thermal Analysis of SR

The Differential Thermal Analysis (DTA) are presented in Fig. 2 (b). The Fig. 2 (b) shows the decomposition of cellulose, hemicelluloses and lignin was assigned to corresponding temperature peaks and reaction time as presented in Fig. 2 (b). At temperature 256.0 ^{0}C endothermic reaction occurred where the heat absorbed by the SR caused the decomposition of hemicelluloses and CO_2 and CH_2 been released. At temperature 283.03 ^{0}C correspond to the maximum decomposition rates of celluloses while at temperature 380 ^{0}C correspond to the maximum decomposition rate of lignin. Above temperature 380 ^{0}C correspond to time when volatilisation begins. The volatilisation continue up to temperature 500 ^{0}C as presented in Fig. 2(b). The DTA analysis of SR was slightly difference from research work presented by Bu *et al.* (2014).

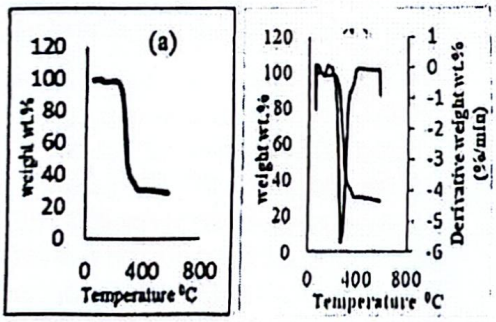


Fig. 2: (a) TGA of SR (b) DTA of SR

Thermo-gravimetric analysis of LDPE and HDPE

The thermal degradation of LDPE and HDPE are presented in Fig. 3 (a). The Fig. 3 (b) shows three stages for decomposition: the first stage at temperature 135 ^{0}C - 300 ^{0}C the LDPE and HDPE begins to decompose, at second stage, a significant thermal decomposition occurred at 300 ^{0}C – 500 ^{0}C where short and long chain of hydrocarbon decomposed and at third stage, a steady thermal decomposition continues till end of the decomposition at temperature above 500 ^{0}C.

Differential Thermal analysis (DTA) of LDPE and HDPE

The DTA curve of LDPE and HDPE are presented in Fig. 3 (b). The decomposition of short chain hydrocarbon of LDPE and long chain hydrocarbon of HDPE was assigned to corresponding temperature peaks and reaction time as presented in the Fig. 3(b). At temperature 285 ^{0}C endothermic reaction occurred that is, LDEP and HDPE begins to absorbed heat which could resulted to the decomposition of hydrocarbon though the decomposition of LDPE started before the HDPE. At temperature 400 ^{0}C appears to be the highest peaks in the thermograph which was assigned to the time when the decomposition rates of LDPE and HDPE occurred. The decomposition continuing up to the temperature 500 ^{0}C.

It was observed that the complete decomposition of LDPE and HDPE was achieved at final temperature of 500 ^{0}C as presented in the Fig. 3. This explanation of thermal decomposition of LDPE and HDPE corroborated with the research work of Garba *et al.*, (2018).

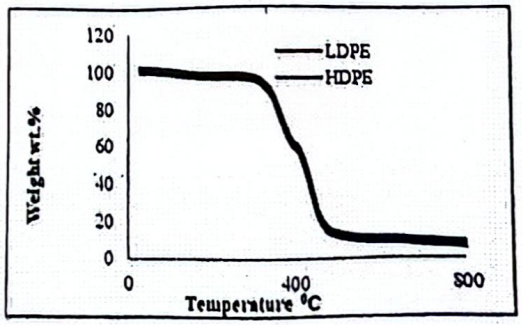


Fig. 3: TGA (a) LDPE

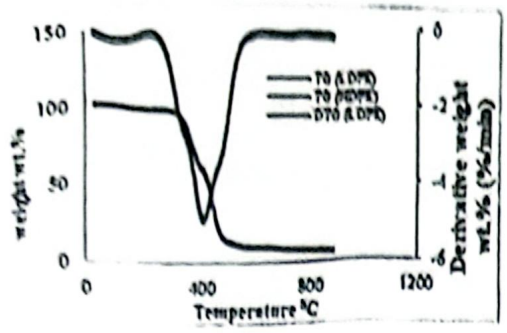


Fig. 3: DTA (b) HDPE

Pyrolysis of SR

The pyrolysis parameters namely; temperature, reaction time and particle size for production of the bio-oil were investigated using set-up in Fig. 1.

Effect of Temperature on pyrolysis of SR

The influence of temperature on pyrolysis of SR in the production of bio-oil was presented in Fig. 4 (a). Fig. 4(a) shows that the yield of bio-oil was 48.1 wt. % at temperature 500 ^{0}C with low bio-char 29.5wt. % (Dewangan *et al*, 2014). A sudden decrease in bio oil yield was observed from 48.1 to 46.9 wt. % as temperature increased from 500 ^{0}C to 550 ^{0}C and continued to decreases as temperature increases to 600 ^{0}C. Ali *et al.* (2016) and other researchers reported that at temperatures between 450 ^{0}C and 500 ^{0}C, higher yield could be achieved depending on the nature of biomass as either woody or non-woody Dewangan *et.al.* (2014).

Effect of reaction time on pyrolysis of SR

The influence of reaction time was investigated in the production of bio-oil Fig. 4 (b) presents the influence of reaction time on pyrolysis SR. The maximum yield of 48.30 wt. % was obtained at reaction time of 60 minutes which implies that at 60 minutes, there was total degradation of the SR particles. As reaction time increase from 60 to 70 minutes, the yield decreases and bio-char increased as presented in the Fig. 4 (b). The reaction time corroborated with the submission of Dewangan *et.al.* (2014).

Effect of particle size on pyrolysis of SR

Fig. 4 (a) presents the influence of particle size on pyrolysis of SR. The highest yield was 50.55 wt. % at particle sizes between 2.0 mm and 4.0 mm. At these particle sizes, there was higher penetration of heat inside SR which favours the breakdown of the cellulose, hemicellulose and lignin. This explanation corroborated with the research work of Zang *et al.* (2013). As particle size increases from 4.0 to 8.0 mm the char increases linearly as presented in Fig. 4 (c). This implies that, the SR demonstrated inverse relationship between bio oil and bio-char.

It can be inferred from the pyrolysis parameters that, the highest yield of bio-oil was achieved at temperature of 500 ^{0}C, reaction time of 60 minute and particle size range of2-4 mm. The parameters obtained in this study were compared with the research works; Dewangan *et al.* (2014) and Ali *et al.* (2016) for the influence of temperature and reaction time, Dewangan *et al.* (2016) for the influence of particle size.

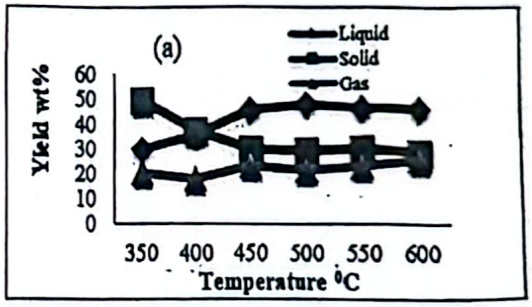


Fig. 4(a) Effect of temperature

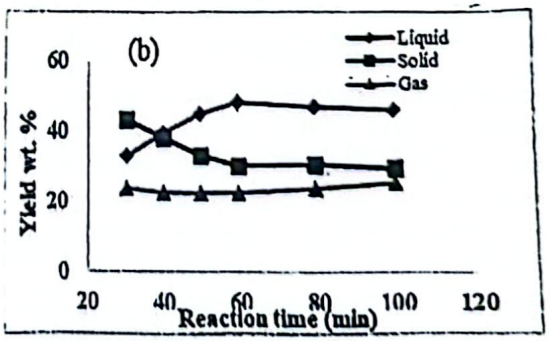


Fig. 4: (b) Effect reaction time

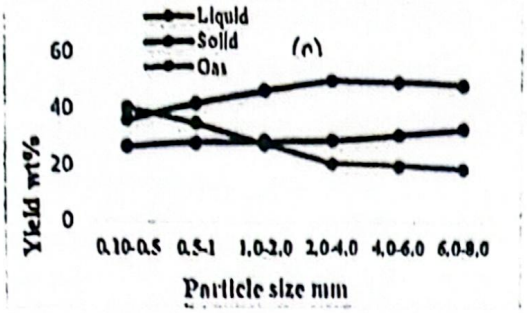


Fig. 4: (c) Effect particle sizes

Pyrolysis of LDPE and HDPE

The pyrolysis of LDPE is presented in Fig. 5 (a). Fig. 5 (a) shows that the yield of oil from pyrolysis of LDPE was 78.6 wt. %. Similarly, the pyrolysis of HDPE is presented in Fig. 5 (b). The Fig. 5 (b) also shows that the yield of oil from pyrolysis of HDPE was 75.20 wt. %. Though, it was observed that the yield of the oil from LDPE was slightly higher than the yield of oil from HDPE. These results of pyrolysis of LDPE and HDPE corroborated with explanation of Sogancioglu *et al.* (2017). However, the yield of the oil from both pyrolysis of LDPE and HDPE are higher than the yield of bio-oil from pyrolysis of SR.

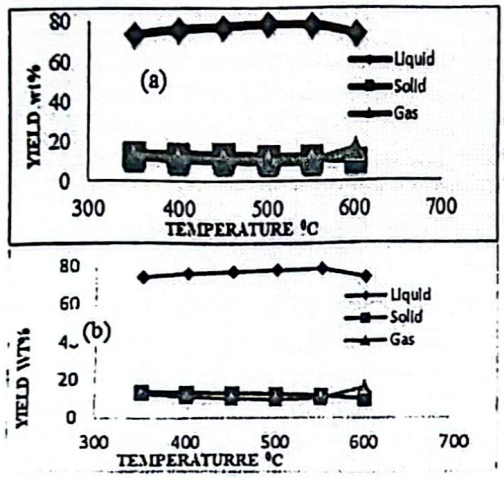


Fig. 5: Pyrolysis (a) LDPE (b) HDPE

Co-Pyrolysis of SR with LDPE

The co-pyrolysis of SR with LDPE are presented in Fig. 6 (a). It was observed from Fig. 6 (a) that co-pyrolysis produced higher bio-oil yield of 68.4 wt. % with low solid char than the bio-oil yield of 50.55 wt. % from pyrolysis of SR alone. The highest yield of bio-oil occurred as a result of the synergistic effect between SR and LDPE (Abnisa *et al.*, 2014; Hassan *et al.*, 2016). Also the co-pyrolysis of SR with HDPE was presented in Fig. 6 (b). It can be seen from the Fig. 6 (b) that the yield of bio-oil from co-pyrolysis was 64.5 wt. %. The yield of bio-oil from co-pyrolysis of SR with HDPE was little lower than the yield of bio-oil from co-pyrolysis of SR with LDPE. Though the co-pyrolysis of SR with LDPE and HDPE showed effective synergy. This synergy was due to free radicals generated from linear molecule of long and short branch chain of LDPE and HDPE (Sun *et al.*, 2013) and (Dewangan *et al.*, 2016).

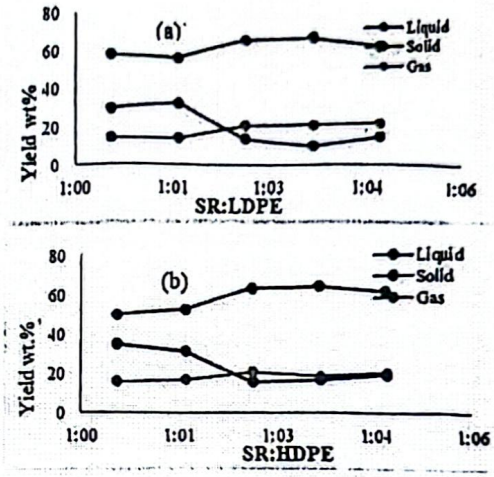


Fig. 6: Co-Pyrolysis (a) SR with LDPE (b) SR with HDPE

Physical Properties of Bio-Oil

The physical properties of the oil from pyrolysis of SR, LDPE, HDPE and co-pyrolysis of SR with LDPE and HDPE are presented in Table 3. The Table 3 shows that the calorific value of bio-oil from pyrolysis of SR was 17.01 MJ/kg which is lower than the acceptable standard limits of the calorific values of diesel and gasoline as 42.60 and 43.71 MJ/kg as presented in Table 3.

Table 3. Physical properties of the bio-oil

Sample description	pH Value	Viscosity (cst)	Density (kg/m^3)	Moisture Content (wt. %)	Caloric Value (MJ/Kg)	Flash Point (^{0}C)	Pour Point (^{0}C)
SR	5.97	13.23	1.0460	4.30	17.01	36	-32
LDPE	6.96	5.06	0.7801	2.01	35.04	54	-21
HDPE	6.89	5.73	0.7806	2.14	34.02	53	-21
SR LDPE	6.75	6.01	0.7887	2.70	27.90	51	-35
SR:HDPE	6.41	6.94	0.7893	2.75	26.17	50	-34
Diesel fuel	-	2- 4.5	0.8450	0	42.60	60	-40
Gasoline	-	0.006	0.7197	-	43.71	-43	-57

This low calorific value was due to the presence of oxygen in significant amount and thereby reducing the enthalpy of the bio-oil (Mohanty *et al.*, 2011) hence, this bio-oil cannot be used directly as transport fuel unless it undergoes further treatment by co-pyrolysis with LDPE and HDPE to remove oxygen in significant amount.

The calorific value of oil from pyrolysis of LDPE and HDPE are 35.04 MJ/kg and 34.02 MJ/kg respectively (Demetra *et al.*, 2016) and (Dongxue *et al.*, 2019). The calorific value from co-pyrolysis SR with LDPE and HDPE are 27.90 and 26.17 MJ/Kg. The increase could be attributed to effective interaction between free radicals of SR with LDPE and HDPE. Onal *et al.* (2014) and Martinez *et al.* (2014) explained that the oil from co-pyrolysis with plastic has higher calorific value than pyrolysis of individual biomass.

The viscosity of the oil from pyrolysis of SR was 13.23 cst while LDPE and HDPE are 5.06 and 5.73 cst respectively. This clearly reveal that the viscosity of LDPE and HDPE was much closer to the viscosity of diesel 2- 4.5 cst as presented in the Table 3. However, the bio-oil from co-pyrolysis of LDPE and HDPE are 6.01 and 6.94 cst. The decrease in the viscosity was due to the influence of hydrogen donor from LDPE and HDPE during co-pyrolysis as well as rapid condensation (Bardalai, 2015). The moisture content from the pyrolysis of SR was 4.20 % while LDPE and HDPE are 2.01 and 2.14 % respectively. The moisture content of the bio-oil from co-pyrolysis are 2.70 and 2.75 % respectively. The co-pyrolysis shows significant reduction in the moisture content. This reduction is corroborated by other researchers such as Abnisa *et al.* (2014) where co-pyrolysis biomass with plastic reduced the moisture content in the bio-oil.

The density of the oil from pyrolysis of SR was 1.0460 kg/m^3 while LDPE and HDPE are 0.7801and 0.7806 kg/m^3 respectively. It was observed that the density of the oil from LDPE and HDPE was very close to the density of gasoline but the density of the oil from SR alone was higher than the density of both diesel and gasoline as presented in the Table 3. The density of the bio-oil reduced from 1.0460 to 0.7887 and 0.7893 kg/m^3 respectively. This implies that there was effective synergy between SR with LDPE and HDPE. This assertion was similarly reported by other researchers (Bardalai 2015). The pH of the oil from pyrolysis was 5.97 while LDPE and HDPE are 6.96 and 6.89 respectively. Though the major contributory factor for high pH in the bio-oil from pyrolysis of SR was due to the presence of organic acids such as carboxylic acid (Bardalai, 2015). The pH of bio-oil from the co-pyrolysis was 6.01 and 6.95 respectively. The pH does not apply as measurable properties in gasoline.

The flash point of the oil from pyrolysis of SR was 36 ^{0}C while LDPE and HDPE are 54

^{0}C and 53 ^{0}C respectively. The flash point of the bio-oil from the co-pyrolysis was 48 and 51 ^{0}C respectively. It was observed that the flash point of the blend was close to flash point of diesel 60 ^{0}C but not close to flash point of gasoline as -43 ^{0}C (George *et al.*, 2015). The pour point of bio-oil from pyrolysis of SR was -32 ^{0}C while LDPE and HDPE are -23 and -21 ^{0}C respectively. The pour point of the oil from the co-pyrolysis are -35 and -34 ^{0}C respectively. It was observed that the co-pyrolysis does not improve the pour point of the bio-oil significantly as is to the pour point of gasoline.

Chemical Properties of Bio-Oil

This study focused on producing higher quality bio-oil that can be used as a transport fuel. The bio-oil produced from pyrolysis of SR and co-pyrolysis with LDPE and HDPE were analysed using Gas Chromatography and Mass Spectroscopy (GC-MS) and Fourier Transform Infra-Red (FTIR).

GC-MS analysis of the bio-oil pyrolysis

The GC-MS analysis of bio-oil from pyrolysis of SR are presented in Fig. 7 (a). The hydrocarbon compounds exist in the bio-oil obtained from pyrolysis of SR contains carbon number ranging C_9-C_{24} with high concentration of C_9-C_{18}. The analysis corroborated by the research work of Hassan *et al.* (2009) where the bio oil also contains higher molecular weight. The analysis as presented in the Fig. 7 (a) shows the highest peak was assigned to Phenol compound in peak nine. The first peak at retention time of 3.443 minutes was assigned to Propanoic acid ($C_8H_{14}O_3$), retention time of 4.842 compound is Oxirane (C_4H_8O), retention time of 5.37 minutes compound is Acetamide (CH_3CONH_2), retention time of 7.508 compound is Butane (C_4H_{10}), retention time of 8.551 minutes compound is 1,2-Ethanediol (C_5H_6O), retention time of 9.553 minutes compound is Phenol (C_6H_5OH), retention time of 9.767 minutes compound is 3-Penten-2-one (C_5H_8O), retention time of 9.917 minutes compound is Propanoic acid, retention time of 12.633 minutes compound is 2-Propanol (C_3H_8O), retention time of 14.473 minutes compound is Decane. It can be deduced that the GC-MS analysis of bio-oil obtained from SR contains 77.77 % oxygenated organics while 22.23 % are aliphatic hydrocarbon (Wang *et al.*, 2021).

The GC-MS analysis of oil from pyrolysis of LDPE is presented in Fig. 7 (b). The analysis shows that the majority of hydrocarbon compounds are light and heavy aliphatic compound with carbon number ranging from C_6-C_{24} though with high concentration from carbon number ranging C_6-C_{15}. The first compound identified from the analysis was 1-hexene, (C_6H_{12}) at retention time of 1.91 minutes and last compound identified was Tetracosane ($C_{24}H50$) at retention time of 2.26 minutes. It also shows that the hydrocarbon compounds are straight chain as well as branch chain hydrocarbon compounds, this is because long chains hydrocarbon were breakdown to form shorter ones thus generating a new substance during thermal degradation of LDPE. Therefore, the list of hydrocarbon compounds identified from GC-MS analysis of the oil from pyrolysis of LDPE are alkane and alkene compounds (Yang *et al.*, 2016).

The GC- MS analysis of oil from pyrolysis of HDPE are presented in Fig. 7 (c). The analysis shows that the majority of hydrocarbon compounds are also light and heavy aliphatic compounds with carbon number ranging from C_6-C_{28} though with majority C_9-C_{15}. The first compound identified from the analysis was Nonene (C_9H_{28}) at retention time of 3.062 minutes and last compound identified as Tetracosane ($C_{28}H_{58}$) at retention time 28.45 minutes. Similarly, the Fig. 7 (c) shows that the majority of hydrocarbon compounds are straight chain as well as some branch chain. This long chain hydrocarbon compounds were breakdown to form smaller ones during pyrolysis (Al-Salem 2019).

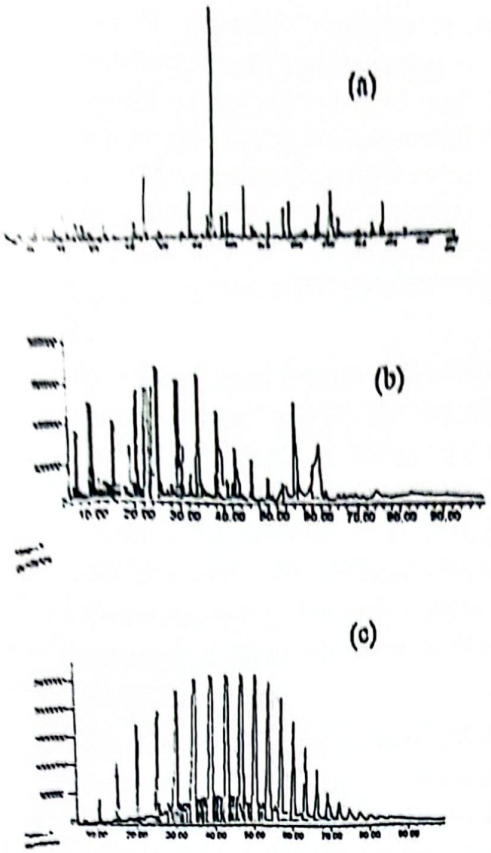


Fig 7: GC-MS analysis of the bio-oil obtained from (a) SR (b) LDPE (c) HDPE

GC-MS Analysis of the Bio-Oil obtained from Co-Pyrolysis

The GC-MS analysis of bio-oil from co-pyrolysis of SR with LDPE are presented in Fig. 8 (a). The co-pyrolysis lead to appearance of aromatic with more of aliphatic hydrocarbon and little oxygenated organic compounds. The oxygenated which emanated from SR begins to disappear as indicated by retention time of the peaks as presented in the Fig. 8 (a). This disappearing could be attributed to the effect of LDPE which donated hydrogen during co-pyrolysis consequently, oxygenated compounds such as esters, ethers, aldehyde and ketones began to reduce. It was observed that the influence of LDPE shows that the 77.77 % of oxygenated organic in the bio-oil from pyrolysis of SR reduces to 5.32 % while the 22.23 % of aliphatic in the bio-oil increases to 88.48 % with appearances of aromatic hydrocarbon of 6. 20 %.

The GC-MS analysis of bio-oil from co-pyrolysis of SR with HDPE was presented in Fig. 8 (b). It also shows that the co-pyrolysis reduced significantly the oxygenated organics that emanated from SR as indicated by retention time of the peaks as presented in Fig. 8 (b). It was observed that the influence of HDPE shows that the 77.77 % of oxygenated organic in the bio-oil from pyrolysis of SR reduces to 21.05 % while the 22.23 % of aliphatic in the bio-oil increases to 73.53 % with appearances of aromatic hydrocarbon of 5.42 %.

Therefore, it can be deduced that the co-pyrolysis shows an effective synergy between SR and LDPE and HDPE as well as the increase in the yield and quality of the bio-oil (Thuan *et al.*, 2022).

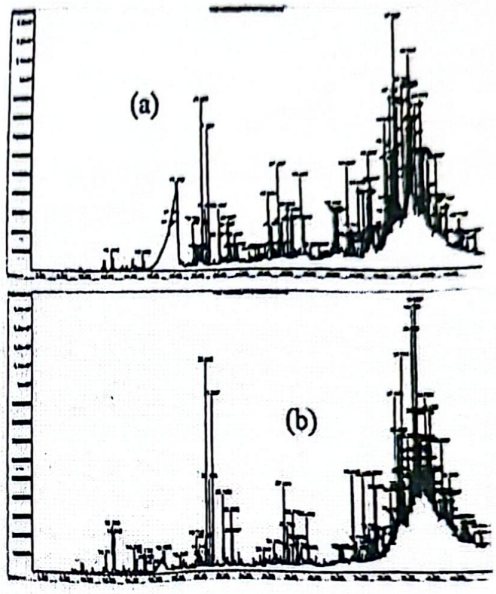


Fig. 8: GC-MS analysis of co-pyrolysis (a) SR with LDPE (b) SR with HDPE

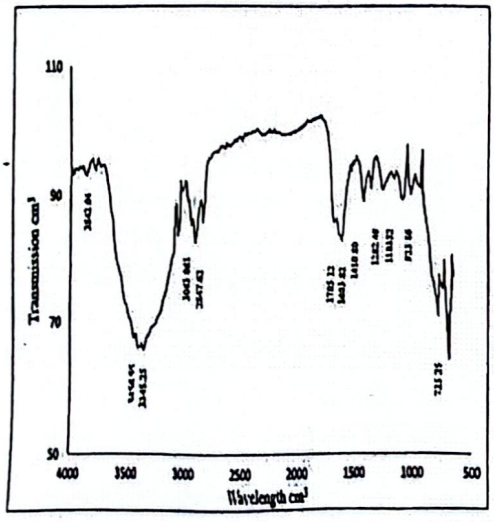
FTIR Analysis

The result of FTIR analysis of bio-oil from SR is presented in Fig. 9 (a). The absorption bands of 725.25, 923.86, 1103.32, 1282, 1410.80, 1603.82, 1705.12, 3063.061, 3456.55, and 3842.04 cm^{-1} correspond to functional groups; C-H, CH-CH_2, C=O, C-O-C, C=O, C=C, COO, CH-CH, OH, N-H, O-H and O-H respectively. The absorption

bands as presented correspond to light compounds; alkane, ketones, esters, ethers, aromatic, alcohol and carboxylic acid. This result of the FTIR analysis corroborated with the FTIR analysis of bio-oil described by Zhang *et al.* (2016). It was observed that the FTIR confirmed the presented of oxygenated organic compound as presented in the Fig. 9 (a).

The FTIR of the oil from pyrolysis of LDPE was presented in Fig. 9 (b). The absorption bands of 725.25, 964.44, 902.72, 1473.44, 1604.20, 2731.29, 2729.30 and 2939.61 cm^{-1} correspond to functional group CH=CH, -CH=CH (trans), $-CH_3$, $-C-CH_3$,$-C-CH_3$, and $-C-CH_3$ respectively. The bands as presented correspond to alkane and alkene (Sachin *et al.*, 2011).

The FTIR of the oil from pyrolysis of HDPE is presented in Fig. 9 (c). The absorption bands 887.28, 991.23, 1226.77, 1465.94, 1604.26, 2731.29, 2729.30 and 3616.58 cm^{-1} correspond to functional group CH=CH, -CH=CH (trans), $-CH_3$, $-C-CH_3$,$-C-CH_3$, and $-C-CH_3$ respectively. The bands as presented correspond to alkane and alkene (Sachin *et al.*, 2011).



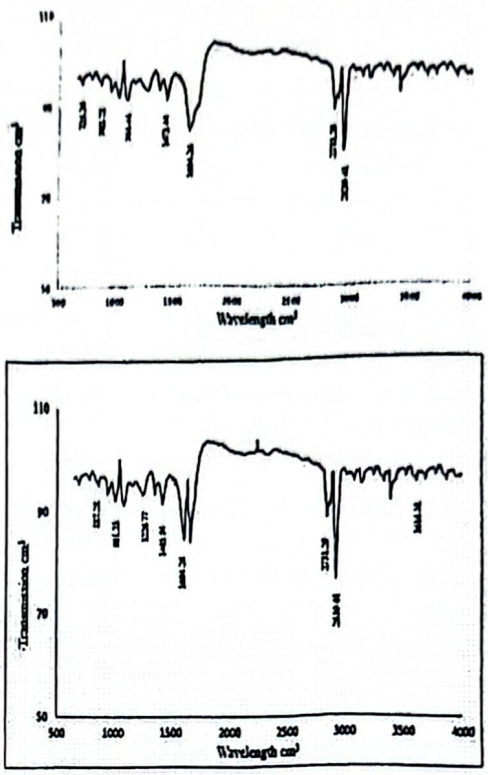


Fig. 9: FTIR of the oil from (a) SR (b) LDPE (c) HDPE

CONCLUSION

This study investigated the production of high quality bio-oil from co-pyrolysis of SR with LDPE and HDPE. From preliminary study, the proximate analysis shows that the SR has volatile matters of 76.42 wt. %, LDPE of 97.89 wt. % and HDPE of 92.86 wt. % which indicated the potentials for producing high yield of oil. The highest yield of bio-oil from pyrolysis of SR was 48.10 wt. % at temperature 500 ^{0}C, in reaction time of 60 minutes and particle size of 2-4 mm. However, the co-pyrolysis increased the yield of bio-oil from 48. 10 wt. % to 76.20 wt. %. The physio-chemical properties of the bio-oil shows that the calorific value, viscosity, density, flash point and pour point increases significantly. The GC-MS analysis of bio-oil shows that the influence of co-pyrolysis reduced the oxygenated organic contained in the bio-oil from 77.77 % to 5.32 % while aliphatic increased from 22.23 % to

88.48 % with appearances of aromatic hydrocarbon of 6. 20 %. Therefore, it can be deduced that the co-pyrolysis shows an effective synergy between SR with LDPE and HDPE as well as the increase of the yield and quality of the bio-oil.

REFERENCES

Abnisa, F., Daud, W. M. A.W., & Saliu, J.N. (2014). Pyrolysis of Mixtures of Palm Shell and Polystyrene: an Optional Method to Produce a High Grade Pyrolysis Oil. Environmental Progress and Sustainable Energy, 33, 1026 33.

Ali, N., Saleem, M., Shahzad, K., Hussain, S., Chughta, A. (2016). Effect of operating parameters on production of bio-oil from fast pyrolysis of maize stalk in bubbling fluidized bed reactor. Journal of Chemical Technology. 18, 3, 88—96, 10.1515

Al-Salem, S., M. (2019). Thermal pyrolysis of high density polyethylene (HDPE) in a novel fixed bed reactor system for the production of high value gasoline range hydrocarbons (HC). Process Safety and Environmental Protection, 127, P171-179.

Asadullah, M., Rahman, M., A., Ali, M., M., Rahman, M., S., Motin, M., A. (2007). Production of bio-oil from fixed bed pyrolysis of bagasse. Fuel. 86 (16): 2514-2520.

Bardalai, M. (2015). A review of physical properties of biomass pyrolysis oil. International Journal of Renewable Energy Research (IJRER), 5(1): 277-286.

Bu, Q., Lei, H., Wang, L., Wei, Y., Zhu, L., Zhang, X., Liu, Y., Yadavalli, G., Tang, J. (2014). Bio-based phenols and fuel production from catalytic microwave pyrolysis of lignin by activated carbons. Bioresour. Technol., 162, 142-147.

Dewangan, A., K. (2014). Co-pyrolysis of Lignocellulosic Biomass and Synthetic Polymer. Biomass and Synthetic Polymer. T-R 110CH0464

Dewangan, A., Pradhan, D., & Singh, R. K. (2016). Co-pyrolysis of Sugarcane Bagasse and Low-Density-Polyethylene: Influence of Plastic on Pyrolysis Product Yield. Fuel, 185, 508-516.

Dongxue, Y., Helong, H., Songgeng, L. (2019). Two-step catalytic co-pyrolysis of walnut shell and LDPE for aromatic-rich oil. Energy Conversion and Management. 198 111816

Esso, S., B., E., Xiong, Z., Chaiwat, W. Kamara, F., M. (2022). Review on synergistic effects during co-pyrolysis of biomass and plastic waste: Significance of operating conditions and interaction mechanism. Biomass and Bioenergy. 159, 106415.

Garba, M.U., Inalegwu A, Musa U., Aboje A.A., Kovo A.S. and Adeniyi O.D. (2018), Thermogravimetric characteristic and kinetic of catalytic co-pyrolysis of biomass with low- and high-density polyethylenes, *Biomass Conversion and Biorefinery*, Springer-Verlag Berlin, Germany, (1),143-150

Hassan, E., M., Yu, F., Ingram, L., Steele, P. (2009). The Potential Use of Whole-tree Biomass for Bio-oil Fuels. Energy Source. 31:20, 1829-1839, DOI: 10.1080/15567030802463364.

Khan, M., H., M. Sultana, M. R. Al-Mamun, and M. R. Hasan, (2016). Pyrolytic Waste Plastic Oil and Its Diesel Blend: Fuel Characterization. Journal of Environmental and Public Health Volume, Article ID 61-67

Kumar, M., Patel, S., K., Hamid, P., F. (2011). Characteristics of some forestry nonwoody biomass species and estimation of their power generation potentials. Energy sources, part a: recovery, utilization, and environmental effects. 132.1650-1654

Martinez, J. D., Vesses, A., Mastral, A. M.,

Murillo, R., Navarro, M. V., & Puy, N. (2014). Co-pyrolysis of Biomass with Waste Tyres: Upgrading of Liquid Biofuel. Fuel Process Technology, 119, 263-71.

Mohanty, P., Pant, K., K., Naik, S., N., Das, L., M., Vasudevan P. (2011). Fuel production from biomass. Indian perspective for pyrolysis oil, 6 11-34.

Onal, E., Uzun, B. B., & Putin, A., E. (2014). Bio-oil Production via Co-pyrolysis of Almond Shell as Biomass and High-Density Polyethylene. Energy Conversion and Management, 78, 704-710

Oyebanji, J., A., Fayomi, O., I., S., Oyeniyi, P., G., Akor, & Ajayi, S., T. (2022). Physico-Chemical analysis of pyrolyzed bio-oil from *Lophira alata* (Iron wood) wood. Volume 4. 4-9

Ringer, M., Putsche, V., Scahill, J. (2006). Large-scale pyrolysis oil production and economic analysis; technical report; National renewable energy laboratory: Cole Boulevard, Co, USA. NREL/TP -510–37779.

Sachin, K., Singh, R., K. (2011). Recovery of hydrocarbon liquid from waste high density polyethylene by thermal pyrolysis. Brazilian Journal of Chemical Engineering. Vol. 28,665-666.

Sogancioglu, M., Yel, E., Ahmetli, G. (2017). Pyrolysis of waste high density polyethylene (HDPE) and low density polyethylene (LDPE) plastics and production of epoxy composites with their pyrolysis chars. Journal of Cleaner Production. 165: 369e381.

Sun, X., Y., L., Xiang, J., Hu, S., Su, S. (2013). Pyrolysis and dehalogenation of plastics from Waste Electrical and Electronic Equipment (WEEE): A review. West Management. 33. 462-473

Tian, D., Shen, F., Hu, F., Huang, M., Zhao, L., He, J., Li, Q., Zhang, S., Shen, F. (2022). Complete conversion of lignocellulosic biomass into three high-value nanomaterials through a versatile integrated technical platform.

Thuan, A., V., Khanh, Q., VuLy, T., H., Kwon, B., Hyun Hwang, T., Kim, J., Kim, J. (2022). Co-pyrolysis of lignocellulosic biomass and plastics: A comprehensive study on pyrolysis kinetics and characteristics. Journal of Analytical and Applied Pyrolysis. Vol. 163, 105464

Tumuluru, J. S., Wright, C. T., Hess, J. R., & Kenney, K. L. (2011). A review of biomass densification systems to develop uniform feedstock commodities for bioenergy application. Biofuels, Bioproducts and Biorefining, 5(6), 683–707

Wang, X., Zhai, M., Guo, H., Panahi, A., Dong, P. (2021). High-temperature pyrolysis of biomass pellets: The effect of ash melting on the structure of the char residue. Fuel, 285, 1-2 119084

Yang, J., Rizkiana, J., Widayatno W., B., Karnjanakom, S., Kaewpanha M., Hao X., Abudula, A., Guan, G. (2016). Fast co-pyrolysis of low density polyethylene and biomass residue for oilProduction. Energy Conversion and Management 120 422–429

Zhang, X., Wang, T., Ma, L., Zhang, Q., Jiang, T. (2013). Hydrotreatment of bio-oil over Ni-based catalyst. Bioresource Technology. 127 306-311.

Zhang, H. L., Lei Z., Xiaolu Z. (2016). Thermal behavior and kinetic study for catalytic co-pyrolysis of biomass with Plastics.