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Conversions of Waste Tube-Tyres (WTT) and Waste Polypropylene (WPP) into Diesel Fuel through Catalytic Pyrolysis Using Base $SrCO_3$

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Abstract

Diesel fuels obtained from waste tube-tyre (WTT) and waste polypropylene (WPP) were found using the base strontium carbonate ($SrCO_3$) as a catalyst through a catalytic-pyrolysis cracking. Liquid hydrocarbons fuels were analyzed through GC-MS-MS, FT-IR, ^1H and ^{13}C NMR, ICP. Physicochemical properties of diesel fuel were analyzed through ASTM methods. Their results were found such as saturates, naphthenes, aromatics, monohydric alcohols, aldehydes, esters, amides, halides. Conversions of 95 gm, 90 gm, and 100 gm WPP plastics with 5 gm, 10 gm and 0 gm $SrCO_3$ into diesel fuel were collected 92 %, 89%, and 80%, light gases were 7.52%, 10.52%, and 19.45%, residues were 0.48%, 0.48%, and 0.55%. Research octane numbers (RON) of diesel fuel from WPP and WTT are 87.32 and 89.65. Conversions of 95 gm, 90 gm, and 100 gm WTT with 5 gm, 10 gm, and 0 gm $SrCO_3$ into diesel fuel were collected 55%, 64%, and 48%, light gases were 15.55%, 11.64% and 15.56%, residues were 29.45%, 24.36 %, and 36.44%. Bromine numbers of diesel fuel from WPP and WTT are 59.87% and 45.83%.

Keywords: Polypropylene; Tube-tyre; Diesel fuel; Catalytic pyrolysis; $SrCO_3$.
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1. Introduction

Today the plastic-wastes are increasing day by day because people all over the world have been using some often-familiar plastics used such as LD-PE, HD-PE (Low- and high-density ethylene), PP (Polypropylene), PS (Polystyrene), and PVS (Polyvinyl chloride) which come to be 74% of the total plastics wastes.[1-2] They have 87% quantities of 1 to 6 identification codes of categories of waste plastics, their codes of plastics are given by SPI (Society of plastic industry).[3] 51 % of plastics are produced in Asia while 30% of it is alone produced in China.[4] Presently, plastic production is greater than before all over the globe for over last fifty years.[5] Globally, plastic consumption yearly has inflated sharply from around five million tons from 1950s to almost 280 million tons by 2012; nowadays, manufacturing of plastic has grown 56 times more in the last 62 years [6] and it will reach over 530 million tons in 2020 [5] Consumptions of virgin plastics are increasing because plastics have become an indispensable part of everyone is life.[3,20] The plastic requirement such as PP is 19.2%, PE-LD/PE-LLD is 17.2%, HD-PE/PE-MD is 12.1%, PVC is 10.3%, PUR is 7.5%, PS/PS-E are 7%, PET is 7%, and 19.7% others in Europe[7] All industries are providing premium quality of plastic products because of customers' demands. Therefore, waste plastics slowly degrade because 300 to 500 years are needed for their complete degradation process.[12] Their results are loss of natural-resources, the contribution of global warming due to the contaminated gases (CO, CO_2, SO_2, NOx) release in the environment, and waste plastics are no longer suitable for the environment.[5,7,27-28] The fractions collected from plastics by pyrolysis are very closely similar to fossil fuels because plastics are chemically made from carbon and hydrogen. Some additives are added during the manufacturing of virgin plastics.[8-9] Great efforts are made to find alternative hydrocarbon chemical sources to be used as fuels. Various researchers have primarily focused on waste plastics and tyres into hydrocarbons through the pyrolysis method.[10] Approximately, one ton of the plastics recycled saves ~130 million KJ (123 million BTU) which is equivalent to the energy released on combusting ~22 barrels of fuel.[3] Useful recoveries from plastic wastes are 39.5% energy and 29.7% fractions while go to 30.8% landfill.[12,7] HD-PE (high density polyrthylene) is a very good feedstock for

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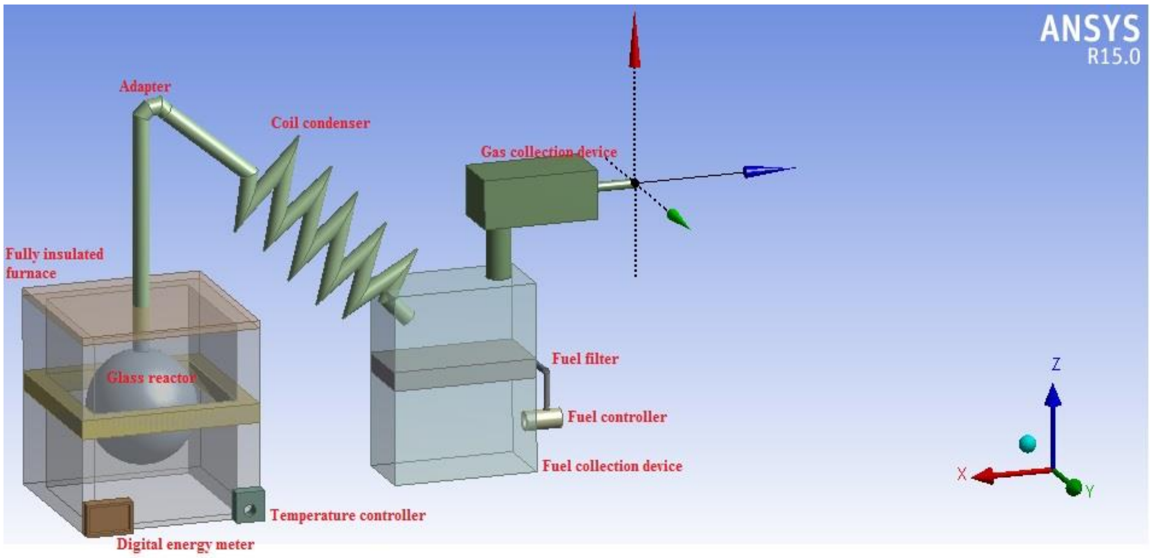

Fig. 1 Catalytic pyrolysis process diagram for WPP and WTT into diesel fuel [12]. Copyright@Royal Society of Chemistry.

pyrolysis process and it's recovery rate is 10%.[3-11] The technology helps to solve lots of environmental problems when it utilizes plastics waste into valuable energy. The appropriate catalyst can have the good ability to control the quality of fractions with yields, catalytic pyrolysis which is a plastic recycling.[5,11] These catalysts include as Singh has used CoCO3 catalyst for conversation of waste and virgin HD-PE into fuel[5], Singh *et al* used $CuCO_3$ for waste HD-PE [12], Kunwar *et al* used $MgCO_3$ for HD-PE.[13] Demribas *et al* used Na_2CO_3 with waste-tyre.[14] Shah *et al* used $CaCO_3$ for waste tyre rubber.[15] FCC, silica-alumina, and zeolites are used in the petroleum refineries for cracking of crude-oil into petroleum fractions. FCC (Fluid catalytic cracking) catalyst came from refineries industry and it's successfully used in pyrolysis cracking process. Presently, FCC catalyst is used for plastics waste such as LD-PE, HD-PE, PP, and PS into liquid hydrocarbons.[11] Devy *et al* used zeolite ZSM-5 for waste HD-PE.[16] Lin *et al* used spent FCC commercial catalyst for waste polymers and FCC gave higher yield (82.7 wt%) than silicate (14.2 wt%).[17] The economic development rate is indefensible without the saving of hydrocarbons fuel energy.[18-19] Waste plastics have the excellent potential because they are converted 70 to 90% in liquid fuel during pyrolysis process. Recently, the author used four metal carbonate catalysts to convert plastics into liquid hydrocarbons. The results of the catalyst were very good, so the new $SrCO_3$ catalyst was chosen for further WPP and WTT conversion. $SrCO_3$ catalyst also had good results as well 92 % maximum diesel yield was obtained from 95 gm WPP plastics with 5 gm while the maximum 64% was obtained from 90 gm WTT with 10 gm $SrCO_3$. The thermal stability of WTT and WPP was decreased due to the presence of a $SrCO_3$ catalyst while without catalyst it was higher. Research is focused on WPP and WTT into fuels using with $SrCO_3$ that could be used by diesel engines and diesel furnaces without any modification. The higher rate of conversion was obtained at mild temperature via pyrolysis catalytic process.

2. Experiment

2.1 Material

WPP and WTT were collected from near the university mess of the laboratory. WPP was isolated through the help of the SPI code 5, while WTT which is the chemical name of SBR. Collected WPP and WTT were washed with caustic free liquid soap making them totally free from any foreign particles. The wastes were ringed with distilled water and then dried in the presence of sunshine for 10 hours. Dried WPP and WTT were grounded into < 3-4 mm^2 size with the help of a grinder machine. 95 gm, 90 gm, and 100 gm WPP plastics were simply blended with 5 gm, 10 gm, and 0 gm base $SrCO_3$ powder (made by CDH Company). Then pyrolysis feedstocks were separately loaded in the glass reactor for the first, second, third experiments process. 95 gm, 90 gm, and 100 gm WTT were simply blended with 5 gm, 10 gm, and 0 gm $SrCO_3$ then it was loaded for the fourth, fifth, six experiments prior to the experiment process. Base $SrCO_3$ powder was analyzed for pore size, volume, and surface area.

2.2 Experimental Procedure

All samples of wastes were blended with $SrCO_3$ as a catalyst. Then each sample was separately placed inside a glass reactor for the experiment before starting the process. The diameter of the pyrolysis round-shape glass reactor was 160 mm, 158 mm height, length of the rector-neck was 300 mm, and the wall thickness of the reactor was 3 mm. Later the glass reactor was positioned inside an insulated-furnace. The coil condenser unit was set up with the glass reactor at one end and another finish was added with the fuel collection device. The furnace consists of a digital electricity meter for temperature measurement. The heating temperature of the furnace was controlled from the beginning to the end by a regulator. A furnace started at 23 °C room temperature; the maximum temperature of pyrolysis was

390 °C and reached 24 °C/min. It had to yield recoveries of diesel fuel from WTT and WPP by the distillation process. The long chain of WTT (Styrene butadiene) and WPP [-(C_3H_6)n-] cracked in short-chains (chemical composition of diesel fuels as shown in the Table 4 such as C_nH_{2n+2}, C_nH_{2n-6}/C_nH_{2n}, $C_nH_{2n+1}OH$, $C_nH_{2n+1}CHO$, RCOOR' esters) during the pyrolysis process and mechanism of plastic degradation has been deeply described by Singh.[21] And their cracked carbon chains came into the vapors phase inside the glass reactor because it had lower molecular weight. After that, it was passed from the beginning to the end of a reactor neck to a condenser. Gases were condensed in the condenser at 23 °C room temperature then it was collected in fuel collection device, and gases were collected in a gas collection device. Residues were collected in a glass reactor after finishing the experiment process.

2.3 Analytical Techniques.

TGA 4000 thermo-gravimetric analyzer (Perkin Elmer) was used to determine for the thermal stability of WPP and WTT. The functional groups of diesel fuels from WPP and WTT were determined with FT-IR spectrometry (Alpha-T Bruker). To further investigate the diesel fuel collected from the degradation of WPP and WTT using a SrCO3 catalyst was analyzed through thermo scientific TSQ 8000 triple quadruple GC-MS-MS system with MS/MS simplicity and even higher performance SRM. Analytical methods of GC-MS-MS are deeply described by man vir singh.[21] Nitrogen adsorption-desorption determines was performed at liquid N_2 analysis gas with a Quantachrome Asiqwin^{TM}. Diesel fuels from WPP and WTT were analyzed by ASTM (American Society for Testing and Materials) method for physicochemical properties such as TAN through an ASTM D 664, TBN through an ASTM D 2896 method, ash content through an IS 1448 (P4) 2008 method, RBCR (On 10% Residue) through an IS 1448 (P8) 2008, copper strip corrosion for 3 h at 100 ºC through IS 1448 (P15) 2004 and ISO, 2160 :1998 methods, flash point through an IS 1448 (P20) 2007 method, kinematic viscosity at 40 ºC and 100 ºC through an ASTM D 445 methods, density at 15 ºC through IS 1448 (P32) 2008 method, sulfur content through a ASTM D 5185 method, H_2O Content through an ASTM D 1744 method, particles counter through a ISO 4406 method, particles counter through a NAS 1638 method, initial boiling point and final boiling point through an ASTM D 86 method. The bromine number is the amount of the grams of bromine absorbed by 100 grams' sample and is a useful tool to measure aliphatic unsaturation in the gasoline sample. Diesel fuels were analyzed by ICP (Inductively coupled plasma) for 23 types of metal. Diesel fuels were characterized for ^{1}H and ^{13}C NMR (300 MHz).

3 Results and Discussions

3.1 Thermal properties of WTT and WPP for pyrolysis feedstock

For thermal property as shown in Fig. 2. Temperature-ranges of more degradation of WTT and WPP plastics were found between 340 °C to 500 °C and 480 °C to 510 °C inside the TGA furnace, nitrogen gas was supplied for inert atmosphere at 20 °C/min. The heat started from 30 °C to 700 °C at 20 °C/min. This could be useful for investigation of the thermal stability of WTT and WPP plastics. WPP consists of C 88 %, H 10.2 %, N 0.01 %, S 0.1 %, O 1 %. It was required for the pyrolysis temperature of the furnace. WTT consists of C 86.4 %, H 8 %, N 0.5 %, S 1.7 %, O 3.4 %.[22]

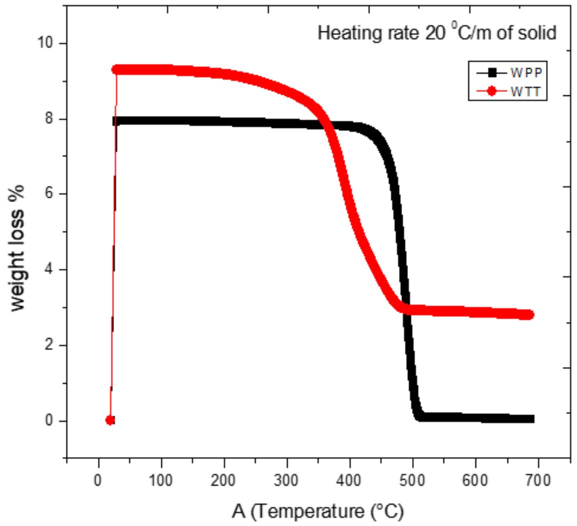

Fig. 2 TGA showing thermal stability of WPP and WTT.

3.2 Physicochemical properties of diesel fuel from WTT and WPP

Table 1 shows the physicochemical properties of liquid fuels from WTT and WPP. Physicochemical properties of diesel fuel limit as per IS1460-2005 have been deeply described by man vir *et al.*[12] All physicochemical properties of the diesel fuel are found to be close to regular diesel; thus, it is appropriate for diesel-engines and diesel furnace. Total acid number and total basic number properties of fuel were measured through a volumetric titration. Ash content, RBCR and copper strip corrosion put for three hours at 100 ºC in fuel samples were evaluated and found to be close to ordinary diesel oil. Flash and fire point were slightly higher than their standard values. Kinematic Viscosity was measured at 40 and 100 ºC through a Kinematic Viscometer Bath and their results were 1.75 cSt and 1.01 cSt. Density calculated through a hydrometer and their result was found to be close to ordinary diesel. Sulfur content is also found lower than the ordinary diesel. Chlorine contents were absent. Therefore, diesel-engine of an Autorickshaw (Bajaj compact 4S) was run with diesel fuel from WPP and WTT. Yield recoveries of diesel fuels from WTT and WPP by distillation process have been shown in Fig. 3. Diesel recoveries are increasing with rising temperature. Diesel fuel from WPP is more volatile than diesel from WTT. The auto rickshaw engine ran for 3 km from 150 ml standard diesel while from 150 ml plastic diesel fuel, it ran for 3.1 km. The most promising substitute for petroleum can

Table 1 Diesel fuel from WTT and WPP were analyzed for physicochemical properties of diesel.

Physicochemical properties	Results of diesel fuel from WPP	Results of diesel fuel from WTT	Limitations of standard values [12]	Commercials values
TAN	2.00 mg KOH/g	1.17	NO	
TBN	0.30 mg KOH/g	0.21	NO	
Ash content	0.003 % by wt	0.003	0.01	
RBCR (On 10% Residue)	0.024 % by wt	0.014	0.30 maximum	
Copper Strip Corrosion for 3 h at 100 ºC	1a	1a	Not worse than number 1	
Flash point	37 ºC	41 ºC	35 ºC	>55
Fire Point	53 ºC	53 ºC	50 ºC	
Kinematic Viscosity at 40 ºC	1.75 centistokes	2.01	NO	
Kinematic Viscosity at 100 ºC	1.01 centistokes	104	NO	2-4.50
Density at 15 ºC	0.81 g/ml	0.872	820 to 845 Kg/m^3	82-86
Sulfur Content	171.32 ppm	1.394	50 maximum	1.2 Wight %
H_2O Content	354 ppm	597	200 maximum	
Particle Counter	18/17/15	18/17/15	NO	
Particle Counter	9	8	NO	
Initial Boiling Point	142 ºC	159	NO	
Final Boiling Point	318 ºC	348	NO	
Chlorine content	nil	nil	NO	

be diesel fuels from WTT. Physicochemical properties are found to be closely similar of diesel such as a density is 0.77-0.84 g/cm^3, a viscosity is 1.74-2.5 mm^2/s, a kinematic viscosity is 1.1-2.27 cSt, HHV is 38-45.86 MJ/kg, a pour point is -9 to -67 ºC, a boiling point is 68-352 ºC, and a flash point is 26.1-48 ºC (5,21,11).

NO: Not specified, KOH: potassium hydroxide, PPM: part per million.

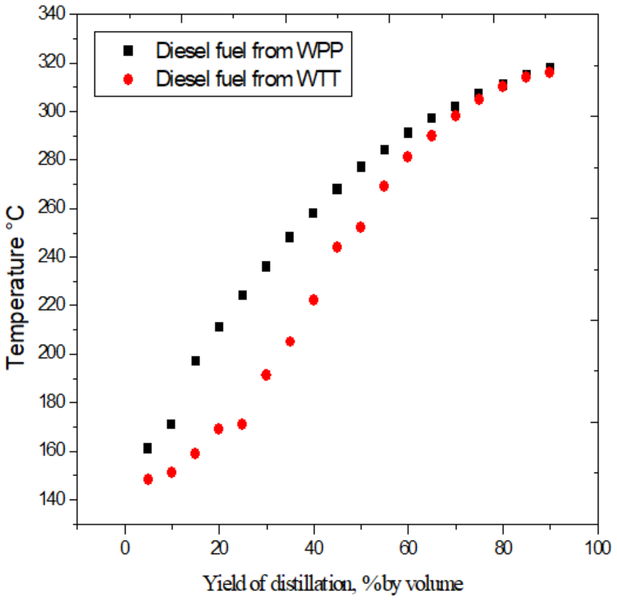

Fig. 3 Distillations properties of diesel fuels obtained from WPP and WTT.

Diesel fuel from WPP and WTT were analyzed by ICP (Inductively coupled plasma) for metal contents. Percentages of metal contents were found less than standard limits and are shown in Table 2.

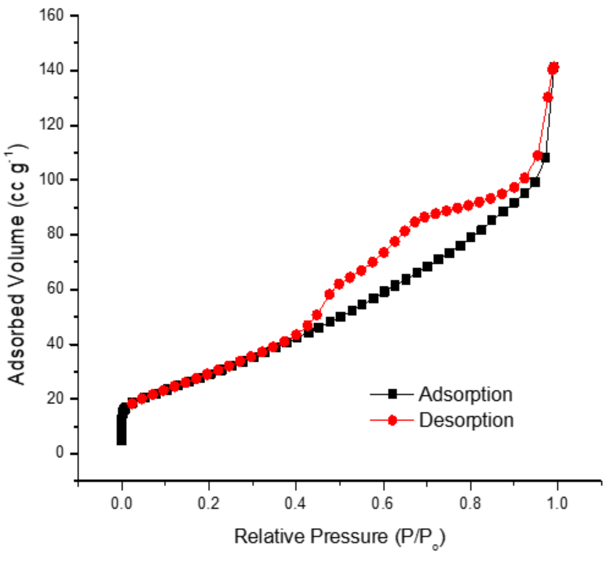

Fig. 4 Showing multi point of BET curves.

3.3 Characteristics of strontium carbonate ($SrCO_3$) catalyst

As shown in Fig. 4 and 5, the surface area of $SrCO_3$ from BET adsorption data is found to be 114 m^2 g^{-1}. The BET isotherm is obtained when $P/P_0 < 1$ and $c > 1$ in the BET equation, where c is BET constant and P/P_0 partial pressure. The pore

Table 2 Diesel fuel analyzed by ICP for metal contents.

S	Cu	Ca	K	Na	Zn	Cd	Cr	Mg	Fe	Si	Al	B	Ti	V	Ni	Mn	Mo	Sn	P	Pb	Ba	Ag
Limits of metal contents in diesel (PPM) ASTM D 5185																						
--	15	--	0	50	--	--	5	--	45	20	10	--	--	--	10	--	--	10	--	20	-	--
Percentage of metal contents in diesel from WPP																						
171.3	0.013	0.01	0.847	1.08	0.102	0.003	0.008	00	0.01	0.053	0.222	2.26	0.004	0.17	0.014	0.001	0.03	0.073	3.8	0.15	0	0.01
Percentage of metal contents in diesel from WTT																						
1.394	0.012	0.012	0.836	1.05	0.041	0.003	0.007	00	0.01	0.052	0.149	2.52	0.004	0.17	0.014	0.001	0.03	0.072	4.65	0.15	0	0.016

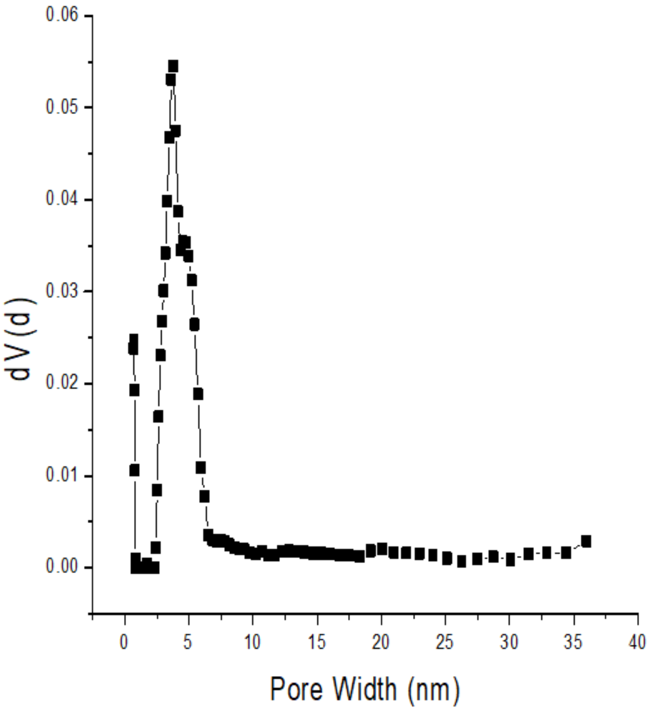

Fig. 5 Showing DFT pore size distribution curve.

size of $SrCO_3$ is found to be 3.79 nm when nitrogen adsorption isotherm is measured at 77 K. the volume for the $SrCO_3$ catalyst is 0.22 cc g^{-1} as has been shown in the figure of e-component. If higher the surface area of the catalyst is higher, more WTT and WPP plastics could be cracked.[21] During pyrolysis, the thermal stability of WTT and WPP decreases due to the presence of $SrCO_3$ catalyst.

3.4 Mass recoveries of gases, diesel fuel, and residues from WTT and WPP

The mass quantity of diesel fuel, gases and residues were collected from 95 gm, 90 gm 100 gm waste polypropylene plastic (WPP) with 5 gm, 10 gm, and 0 gm $SrCO_3$ and Obtained liquid yields from WPP and WTT with $SrCO_3$ and has been compared with another metal carbonates catalysts and, are shown in Fig. 6 and Table 3. WPP plastics whose rate of conversion in diesel fuel were 92%, 89%, 80% light gases 7.52 %, 10.52%, 19.45% and residues 0.48 %, 0.48%, 0.55% at 382 °C, 380 °C, 389 °C temperatures. Again, the mass quantity of diesel fuel, gases, and residues were collected from 95 gm, 90 gm, 100 gm of WTT plastic with 5 gm, 10 gm, 0 gm $SrCO_3$. WTT whose rates of conversion in diesel fuel were 55 %, 64%, 48% light gases 15.55%, 11.64 %, 15.56 and residues 29.45%, 24.36 %, 36.44% at 370 °C, 370 °C, 375 °C temperatures. All recoveries obtained from WPP and WTT have been compared with others as shown in Table 3.

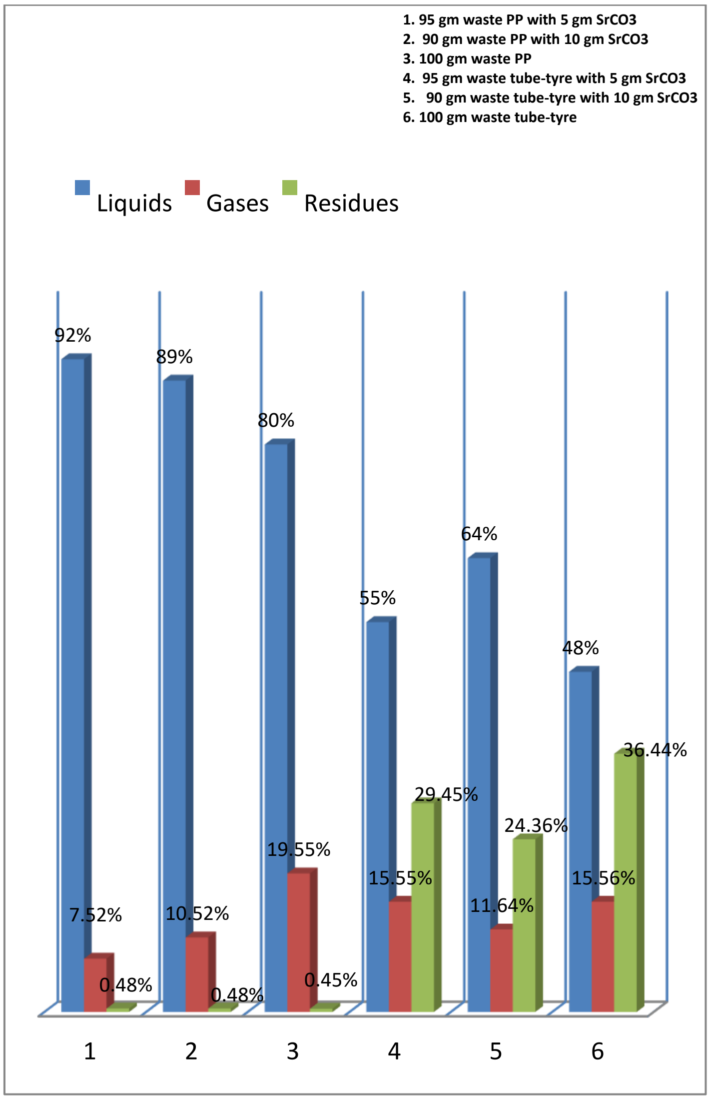

Fig. 6 Fractions of WPP and WTT.

Table 3 Comparison of collected gases, liquids, and residues from different plastics used with different catalysts.

Types of plastic	Types of catalyst	Temperature range (°C)	Liquids (%)	Gases (%)	Residues (%)	References
Virgin HD-PE	$CoCO_3$ 2%	21-395	84.40	15.35	0.25	[21]
Virgin HD-PE	$CoCO_3$ 5%	21-395	88.22	11.35	0.43	[21]
Virgin HD-PE	$CoCO_3$ 10%	21-395	92	7.77	0.23	[21]
Waste HD-PE	$CoCO_3$ 2%	21-395	82	17.55	0.49	[21]
Waste HD-PE	$CoCO_3$ 5%	21-395	84	15.65	0.35	[21]
Waste HD-PE	$CoCO_3$ 10%	21-395	91	8.59	0.41	[21]
Waste HD-PE	$CuCO_3$ 8%	23-390	92	7.45	0.55	[12]
Virgin Polypropylene	$NiCO_3$ 5 %	23-370	90	9.50	0.49	[5]
Virgin Polypropylene	$NiCO_3$ 10 %	23-370	89	10.45	55	[5]
Waste tyres	$CaCO_3$	350	32.2	32.5	35.2	[15]
PP, PE, PS, PVC= weight ratio 3:3:3:1	$CaCO_3$	430	65	25	10	[29]
Waste tube tyres	$FeCO_3$	23-370	56	13.55	3.45	[30]
WPP	Without catalyst	23-389	80	19.45	0.55	Present Study
WPP	$SrCO_3$ 5 %	23-382	92	7.52	0.48	Present Study
WPP	$SrCO_3$ 10 %	23-380	89	10.52	0.48	Present Study
WTT	$SrCO_3$ 5 %	23-270	55	15.55	24.36	Present Study
WTT	$SrCO_3$ 10 %	23-370	64	11.64	29.45	Present Study
WTT	Without catalyst	23-375	48	15.56	36.44	Present Study

3.5 Analyses of diesel fuel from WTT and WPP with $SrCO_3$ by GC-MS-MS

To further examine the diesel fuel obtained from the WPP plastic and WTT using with a base $SrCO_3$ catalyst was analyzed using with GC-MS-MS, it has been shown in Table 4. The chemical composition of diesel fuel from WTT was 35.21 % of aliphatic (C_7-C_{20}), 47.07% of aromatics and cyclic hydrocarbons, 0.83% of amide, 4.59% of aliphatic hailides, and 8.33% of monohydric alcohols. The chemical composition of diesel fuel from WPP was 66.19% of aliphatic (C_7-C_{20}), 25.52% of alkyl hailides, 0.43% of esters, 0.03% of aldehydes, 7.42% of monohydric alcohols, while aromatic compounds were absent. Oxygenates compounds help during the combustion process. Obtained chemical composition is perfectly suitable for diesel fuel. Without a catalyst, 39.6% oil from waste tires were collected at 458 °C while 49.2% oil were collected using a 10% Na_2CO_3 catalyst at 452 °C. [14] 34.40 % oil from waste tires were collected while and 75.93% oil from natural rubber was collected at 600 °C. 80 % aliphatic and 12 % aromatic hydrocarbons were found in oil from natural rubber while 42 % aliphatic and 34 % aromatics in oil from waste rubber.[23] 73.6 % oil from LD-PE with a mixture of catalysts (kaoline, bentonite, activated charcoal, silica gel) had been collected and their chemical compositions were 67.79 % saturates 7.47 % isoparaffins, 2.92 % naphthalene, 9.63 aromatics, and 12.16 olefins.[24] Total 8.01% oxygenate compounds were collected in diesel fuel from WPP such as 1-Trifluoroacetoxy-10-undecene is 0.13%, monohydric alcohols are 7.42%, aldehyde is 0.03%, and esters are 0.43%. Total 13.1 % oxygenate compounds were collected in diesel fuel from WTT such as esters is 3.94%, monohydric alcohols are 8.33%, and amide is 0.83%.

3.6 Analyses of diesel fuel from WTT and WPP with $SrCO_3$ through FT-IR

The functional groups of diesel fuel obtained from WPP and WTT with $SrCO_3$ catalyst were analyzed through FT-IR and it is shown in Table 5. The FT-IR spectrum has provided all functional groups of diesel.

3.7 Analyses of diesel from WPP and WTT with SrCO3 by ^{1}H and ^{13}C NMR

Fig. 7 and 8 show the 300 MHz ^{1}H and ^{13}C NMR spectrum of representative diesel fuel from WPP. The NMR for diesel fuel indicates the presence of aliphatic and olefinic protons. Comparison of the ^{1}H NMR and ^{13}C NMR spectrum of diesel fuel with that of the above graph indicates the presence of a large quantity of aliphatic components.

Table 4 chemical composition of diesel fuel.

Chemical composition of diesel fuel obtained from WTT with SrCO3 catalyst		**Chemical composition of diesel fuel obtained from WPP with $SrCO_3$ catalyst**	
Compounds Name	**Area (%)**	**Compounds Name**	**Area (%)**
Aromatics/Cyclic Hydrocarbons or napthene	**47.07**	**Aliphatics**	**66.19**
Cyclobutane, 1,2-bis(1-methylethenyl)-, trans-	2.51	4-Dodecene, (E)-	2.62
Benzene, 1-ethyl-3-methyl-	1.37	Undecane	2.15
1,3-Cyclohexadiene, 1,3,5,5-tetramethyl-	2.31	1-Dodecene	9.02
Cyclohexene, 1-methyl-5-(1-methylethenyl)-, (R)-	23.63	4-Nonene, 3-methyl-, (Z)-	0.02
Oxazole, 2,5-dihydro-5-(4-methylphenyl)-4-phenyl-	1.14	1-Tridecene	9.55
Bicyclo[4.2.1]nona-2,4,7-triene, 9-(phenylseleno)-, (anti-)	1.08	Dodecane	8.93
1,3-Cyclopentadiene, 1,2,3,4-tetramethyl-5-methylene-	0.97	6-Tridecene	0.03
1,3,5,7-Cyclooctatetraene, 1-(methoxymethyl)-	1.21	9-Octadecene, (E)-	9.63
Benzene, (1,2-dicyclopropyl-2-phenylethyl)-	0.65	Tetradecane	5.35
4a,8a-(Methaniminomethano)naphthalene-9,11-dione, 10-phenyl-	0.6	4-Tetradecene, (E)-	0.03
5,8-Etheno-5H-benzocycloheptene-6,6,7,7-tetracarbonitrile, 6,7,8,9-tetrahydro-	2.47	1-Nonylcycloheptane	0.06
		10-Heneicosene (c,t)	11.35
1,5-Hexadiene, 3,4-diethyl-1,6-diphenyl-, (E,E)-	0.68	5-Eicosene, (E)-	7.37
1,4-Methanonaphthalene-2,2,3,3-tetracarbonitrile, 1,4-dihydro-9-(1-methylethylidene)-	2.44	5-Tridecene, (E)-	0.08
1,5-Cyclodecadiene, 1,5-dimethyl-8-(1-methylethylidene)-, (E,E)-	0.78	**Alkyl Hailides**	**25.52**
		1-Iodo-2-methylundecane	25.39
Spiro[4.5]dec-7-ene, 1,8-dimethyl-4-(1-methylethenyl)-, [1S-(1à,4á,5à)]-	0.89	1-Trifluoroacetoxy-10-undecene	0.13
Hydrazine, tetraphenyl-	2.97	**Monohydric alcohols**	**7.42**
N-Benzyl-4-styrylpyridinium chloride	1.37	E-11,13-Tetradecadien-1-ol	7.39
Esters	**3.94**	Z-10-Pentadecen-1-ol	0.03
Sulfurous acid, 2-ethylhexyl hexyl ester	2.86	**Aldehyde**	**0.03**
Sulfurous acid, butyl heptadecyl ester	1.08	cis-7-Decen-1-al	0.03
Aliphatics	**35.21**	**Esters**	**0.43**
Cyclopropane, 1-(1-methylethyl)-2-nonyl-	4.15	Oxalic acid, cyclobutyl octadecyl ester	0.02
2-Undecyne	0.69	Oxalic acid, allyl tridecyl ester	0.41
Decane, 2,4,6-trimethyl-	1.34		
7-Hexadecene, (Z)-	6.13	**Total**	**99.59**
Undecane, 4,7-dimethyl-	1.26		
1,6-Heptadiene, 3,3-dimethyl-	1.12		
Decane, 2,4,6-trimethyl-	1.29		

10-Heneicosene (c,t)	6.58
Undecane, 4,7-dimethyl-	1.26
Z-6-Phenyldec-4-en-2-yne	1.43
Heptadecane	1.37
Eicosane	5.35
2-methylhexacosane	0.87
Tetracontane, 3,5,24-trimethyl-	0.91
2-methylhexacosane	1.46
Monohydric Alcohols	**8.33**
1-Dodecanol, 3,7,11-trimethyl-	2.96
1,4-Methanonaphthalen-9-ol, 1,4-dihydro-	0.55
1-Hexadecanol	4.82
Aliphatic halide	**4.59**
1-Iodo-2-methylundecane	4.59
Amide	**0.83**
Furazan-3-carboxamide, 4-(chloroacetylamino)-	0.83
Total	**99.97**

Table 5 functional groups of diesel fuel from WPP and tube-tyre.

Wavenumber^{-1}	**Functional groups of diesel fuel from WPP**	**Wavenumber^{-1}**	**Functional groups of diesel fuel from WTT**
3077	terminal (vinyl) C-H stretch	2921	methylene CH_2 asym./sym. stretch
2955	methyl C-H asym./sym. stretch	2859	CH_2 asym./sym. stretch
2922	methylene CH_2 asym./sym. stretch	1641	alkenyl C=C stretch
2853	methylene CH asym./sym. stretch	1601	conjugated C=C
1641, 1459	alkenyl C=C stretch	1451	methylene C-C bends
1377	gem dimethyl CH_3	1374	gem dimethyl CH_3
991	vinyl C-H out of plane bend	1310	methyne C-H bend
964	trans C-H out of plane bend	1159	secondary amine, CN stretch
908	vinyl C-H out of plan bends	993	C-H bend
887	C-H out of plan bends	884	vinylidene C-H out of plan bends
721	methylene -(-CH_2)n- rocking	810	aromatic C-H out of plan bends
636	thioether CH_3-S(C-S stretch)	753	aromatic C-H bend
		697	aryl thioethers, -S(C-S stretch)

The PONA components of aromatics are present albeit in very low concentration as indicated by the NMR spectrum. The signals at δ 5.4 and δ 5.8 further suggest the presence of FCC. The absence of signals around δ 3.5-4.2 indicates that the diesel fuel does not contain oxygenates like iso-propanol, ethanol. From the ^{13}C NMR, it is clear that naphthalene fraction is not present.

3.7.1 Calculation of bromine number for diesel from WPP

From the above NMR the spectra the bromine number is calculated as indicated below.[25-26]

Bromine No = K x$^{H}I_{o}$ %

Where $^{H}I_{o}$ %= $^{H}I_{0}$/ $^{H}I_{T}$ x 100

$^{H}I_{T}$ = Integral of the region 0.5-8.0 ppm

$^{H}I_{O}$ = integral of 4.6-6.6 ppm

The value of *K* is dependent upon the nature of olefins (16.2 for FCC and 9.3 for Coker)

From NMR data of diesel fuel from WPP:

$^{H}I_{0} = 1$; $^{H}I_{T} = 27.06$ and K = 16.2

Therefore, Bromine No. for diesel fuel from WPP = 59.87%

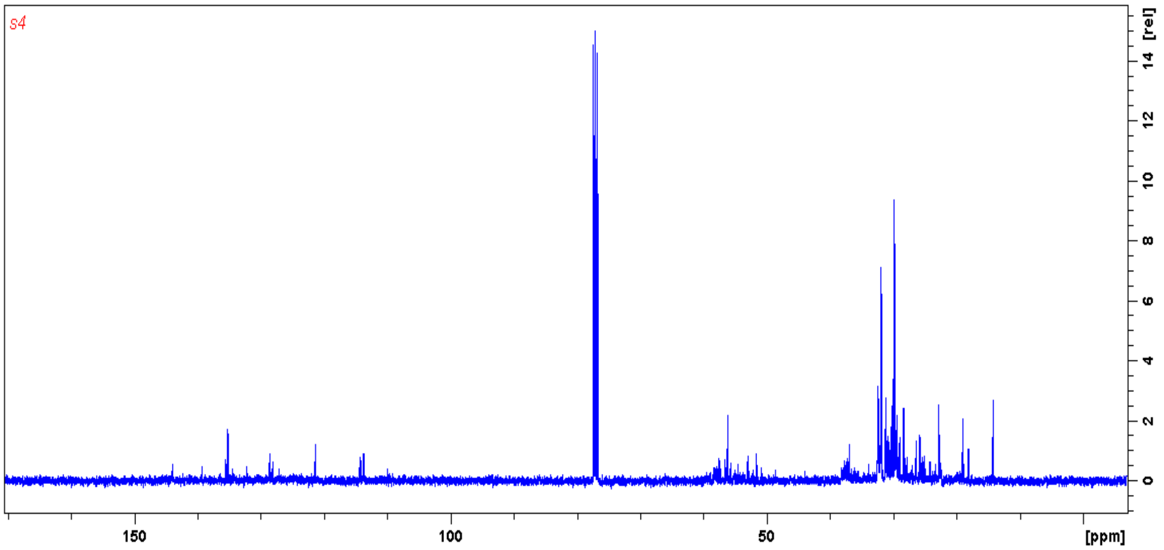

Fig. 7 300 MHz ^{13}C NMR spectrum of diesel fuel from WPP.

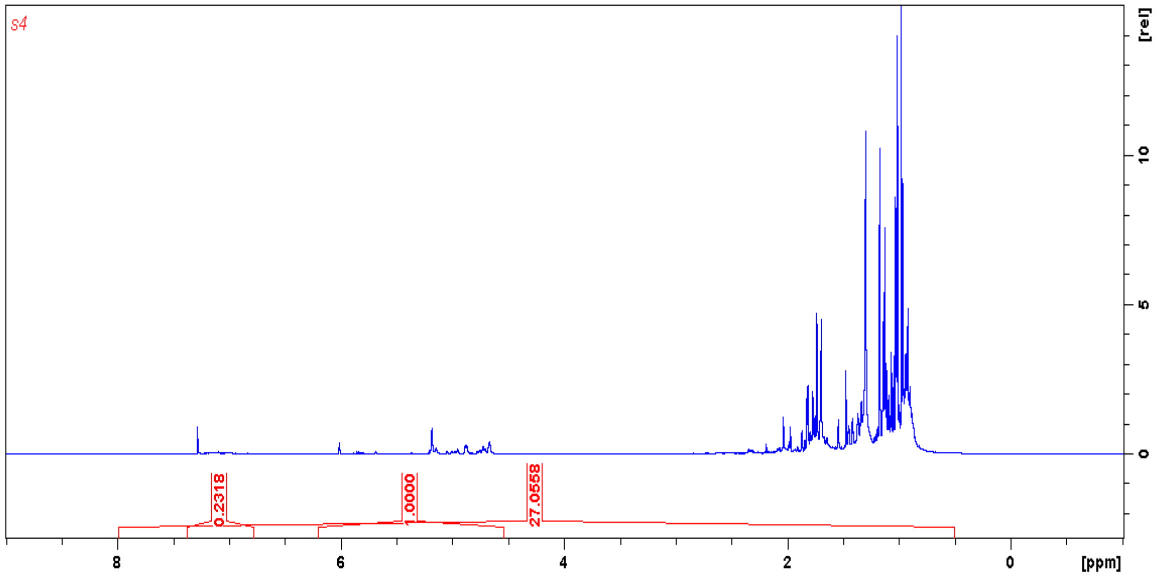

Fig. 8 300 MHz ^{1}H spectrum of diesel fuel from WPP.

3.7. 2 Calculation of research octane number of diesel from WPP

Octane number determined by research test is termed as (Research octane number). It is a measure of knock characteristics of the diesel fuel from WPP sample under mild operation condition. It can be calculated by the following NMR method:

$$\text{RON (NMR)} = 83.14 + 0.48\,(H_{ar}) + 1.02\,(H_{olf})$$

H_{ar} = % Aromatic Hydrogen (6.5 -8.0 ppm)

H_{olf} = % Olefinic Hydrogen (4.5 -6.0 ppm)

From the above proton NMR it is clear that the % Aromatic Hydrogen (H_{ar}) is 0.85 and % Olefinic Hydrogen (H_{olf}) is found to be 3.70. Therefore, RON for diesel fuel from WPP = 83.14 + 0.48 (0.85) + 1.02 (3.70) = 87.32.

Fig. 9 and 10 show the 300 MHz ^{1}H and ^{13}C NMR spectrum of representative diesel fuel from WTT. The NMR for diesel fuel from WTT indicates the presence of aliphatic, aromatic and olefinic protons. Compare the ^{1}H NMR and ^{13}C NMR spectrum of diesel fuel from WTT with that of literature indicates the presence of a large quantity of aliphatic components. The signals at δ 4.5 and δ 5.8 further suggest the presence of FCC. The absence of signals around δ 3.5-4.2 indicates that the diesel fuel does not contain oxygenates like iso-propanol, ethanol. From the ^{13}C NMR it is clear that naphthalene fraction is not present. The NMR for diesel fuel from WTT indicates predominately aliphatic components. The low-intensity signal at δ 7.5 suggests the presence of aromatics. The NMR spectrum indicates the absence of any Coker component in diesel fuel from WTT.[26]

3.7.3 Calculation of bromine number for diesel from WTT

From the above NMR spectra, the bromine number is calculated as indicated below.[25-26]

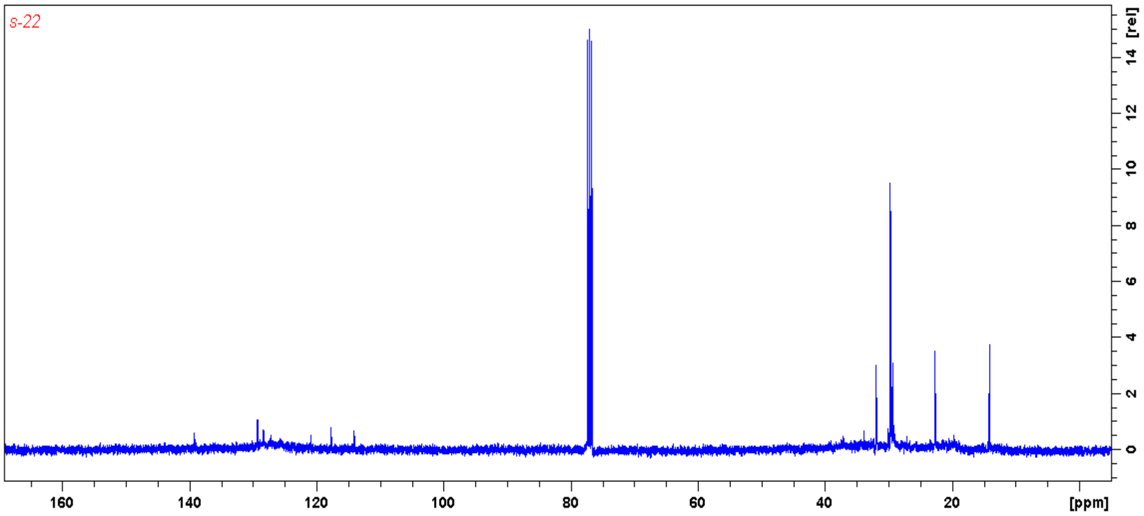

Fig. 9 300 MHz ^{13}C NMR spectrum of diesel fuel obtained from WTT.

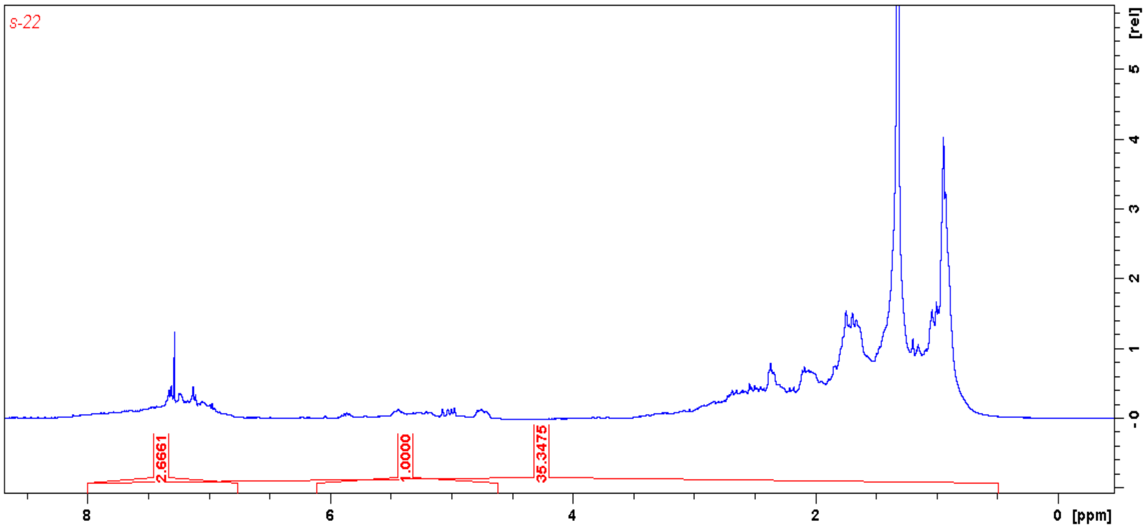

Fig. 10 300 MHz ^{1}H NMR spectrum of diesel fuel obtained from WTT.

Bromine No = K x$^{H}I_o$%

Where $^{H}I_o$%= $^{H}I_0$/ $^{H}I_T$ x 100

$^{H}I_T$ = *Integral of* the region 0.5-8.0 ppm

$^{H}I_O$ = *integral* of 4.6-6.6 ppm

The value of *K* has been found to be dependent upon the nature of olefins (16.2 for FCC and 9.3 for Coker)

From NMR data of diesel fuel obtained from WTT:

$^{H}I_0$ = 1; $^{H}I_T$ = 35.35 and K = 16.2

Therefore, Bromine no. for diesel fuel obtained from WTT is 45.83%

3.7.4 Calculation of research octane number of diesel from WTT

Research octane number is a measure of knock characteristics of a diesel fuel obtained from WTT under mild operation conditions. It can be calculated by the following NMR method.

RON (NMR) = 83.14 + 0.48 (H_{ar}) + 1.02 (H_{olf})

H_{ar} = % Aromatic Hydrogen (6.5 -8.0 ppm)

H_{olf} = % Olefinic Hydrogen (4.5 -6.0 ppm)

From the above proton NMR, it is clear that the % Aromatic Hydrogen (H_{ar}) is 7.55 and % Olefinic Hydrogen (H_{olf}) is found to be 2.83. Therefore, RON for diesel fuel obtained from WTT = 83.14 + 0.48 (7.55) + 1.02 (2.83) = 89.65

4. Conclusion

The research paper aims at solving the problems of environmental pollution due to plastics waste. The need for an alternative fuel source had the catalytic-conversion of WTT and WPP into diesel fuel with a $SrCO_3$. Liquid oil was analyzed through sophisticated instruments such as GC-MS-MS, FT-IR, and TGA. The results obtained through a GC-MS-MS have been put into five categories as paraffin, napthenes, alcohols, esters, amides, and acetates. Branched-chain and cyclic hydrocarbons were presented in more liquid hydrocarbon fuels from waste; therefore, spontaneously the calorific value of the diesel fuel will be increased. The auto rickshaw (Bajaj compact 4S) ran with diesel fuel which causes less smoke. Diesel fuel is analyzed through all analytical instruments and physicochemical properties of diesel, after that it was found to have liquid hydrocarbons equal to diesel fuel; therefore, the diesel engine was run. Diesel fuel was very combustible and flammable. ^1H and ^{13}C NMR results have been shown to be saturates, olefins, cyclic/aromatics hydrocarbons. RON and bromine numbers were found to be appropriate in diesel. Diesel was found with very low sulfur contents than the regular fuel.

Supporting Information

Not applicable

Conflict of interest

There are no conflicts to declare.

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